SMART WATER MANAGEMENT

Case Study Report

K water

IWRA

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Foreword from K-water

It is my great honour to publish this Smart Water Management (SWM) Case Studies report, led by K-water and the International Water Resources Association (IWRA), which presents exemplary SWM projects from around the world to share the benefits of SWM implementation and lessons learned so far. The contributions of the IWRA and the participating case studies in leading the way to SWM, and the value of their efforts, will continue to be appreciated in the future.

Thanks to their dedication, SWM has already been achieved in many areas, offering solutions for improved water management and also assisting to achieving our global common goal of sustainable development. Many recent studies and demonstrations of SWM have been conducted worldwide to address issues and challenges made increasingly severe by climate change, such as flooding and drought, water access, water quality, groundwater management and efficient irrigation. To support the future successful implementation of SWM around the world, this report discusses the technological, social, economic, environmental and integrated governance considerations, in the contexts of Information and Communication Technology such as intelligent water supply networks, and real-time information exchange system through smart metering and networking.

This report shares the benefits of SWM and the lessons learned from these SWM projects from around the world, and in doing so encourages the sustainable use of water through using innovative water resource management. By accurately monitoring and optimizing forecasting systems, SWM can minimize economic, social and environmental risks from water-related disasters. It can also maximize the efficiency and effectiveness of water supply and sanitation by saving water and energy, by reducing costs, and most importantly by meeting consumers' needs and interests.

We can assist with achieving the SDGs around the world by adopting SWM where better water management strategies are needed, and by establishing guidelines and a roadmap for SWM to transition towards more sustainable use of water in the future. While there are still many water challenges being faced globally, this report shows the potential for SWM to assist not only in achieving SDG 6 directly, delivering water and sanitation for all, but also by affecting a positive impact on the mitigation of poverty, food security, quality education, gender equality and much more.

Lastly, this report presents the key findings and recommendations to provide key insights for decision-makers interested in supporting the future implementation of SWM in their own countries and regions. It is my ardent hope that SWM will advance our endeavours to achieve the SDGs. I am indeed grateful for this publication on SWM case studies and confidently expect that through our on-going joint efforts monumental achievements will be made in the not-so-distant future.

Dr. Haksoo Lee
CEO
Korea Water Resources Corporation (K-water)
15 October 2018

Foreword from IWRA

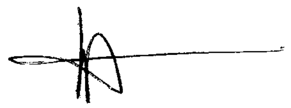
Water challenges are increasingly impacting every region around the world, with both developed and developing regions facing the effects of a changing climate, urbanisation, as well as aging and absent infrastructure. Thankfully, at the same time we are seeing a rapid increase in innovative, smart solutions continuing to provide a way forward. As we work together to resolve these water challenges, governments, water utilities and industry have the opportunity to advance how they manage water, and to resolve many of the issues we face today through the use of smart, integrated solutions.

The Government of the Republic of Korea and K-water have championed Smart Water Management over the past decades by supporting and developing innovative solutions for current water challenges faced domestically and around the world. During a special session at the IWRA XVI World Water Congress on Smart Water Management (SWM), IWRA and K-water decided to work together to better understand and promote the benefits of SWM solutions, as well as to understand the challenges faced by those looking to implement SWM. As water plays a pivotal role in achieving the Sustainable Development Goals, it was also of great interest to understand the role SWM can play in reaching these goals, not only SDG 6 for water and sanitation for all but most of the others as well.

On behalf of IWRA, our extended network of water professionals and the broader water community, I wish to extend my gratitude to the Republic of Korea and K-water for their dedication to SWM and for the remarkable collaboration that has been established to share these lessons with the world. This report reflects that excellent collaboration and I look forward to further collaborations and knowledge sharing with K-water in the future.

Finally, it is my hope that this report encourages water utilities, industries and water users around the world to move forward in implementing SWM solutions, in order to achieve great success in resolving the current water challenges we face. SWM provides us with a great potential to reach not only a better way forward for water management, but also a new set of solutions to help us achieve sustainable, integrated and smart water management and help to attain the global SDGs together.

Patrick Lavarde
President
International Water Resources Association (IWRA)
15 October 2018



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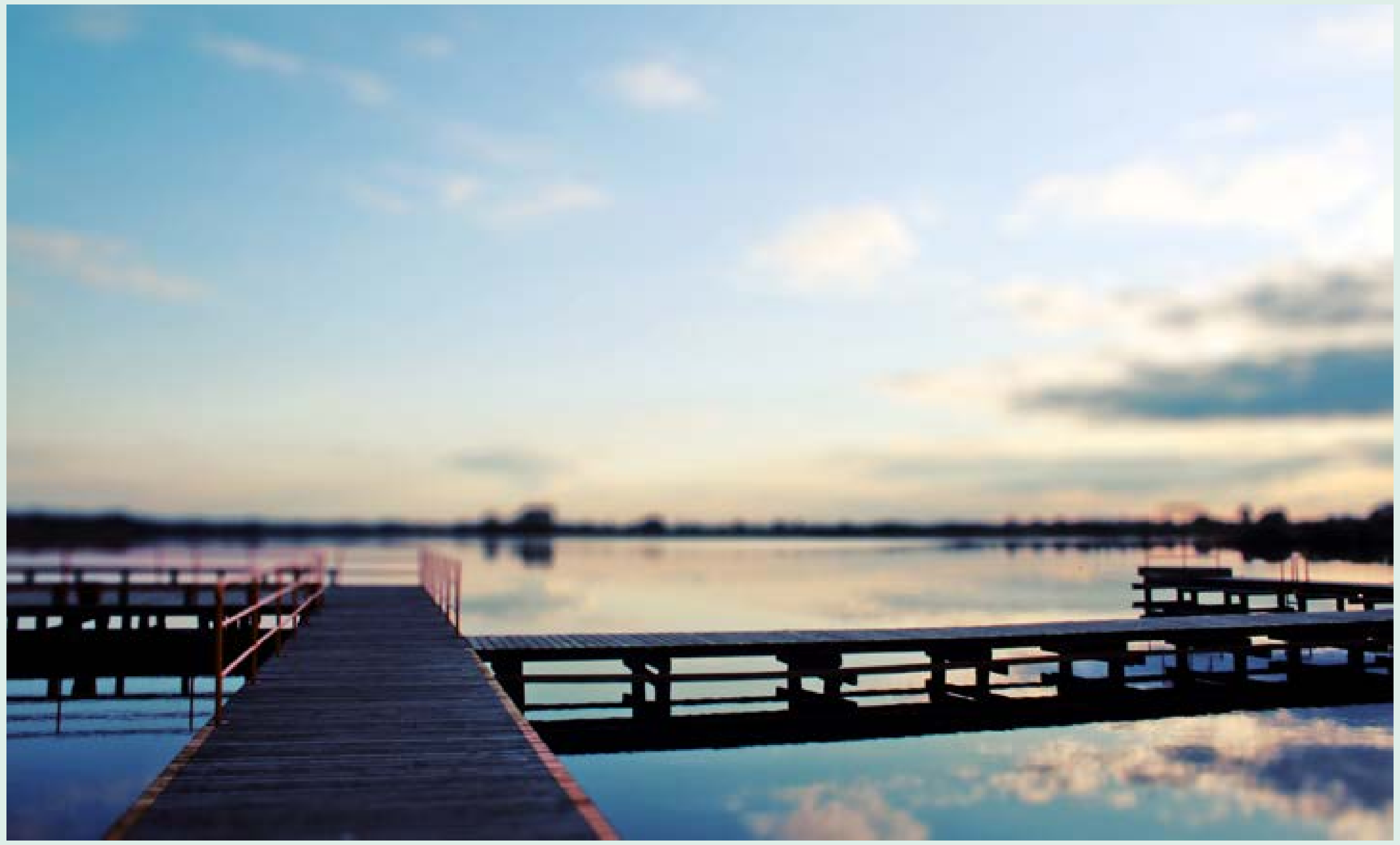


I. Introduction

This report is the major output of the Smart Water Management (SWM) project, a joint effort led by K-water (the Korea Water Resources Corporation) and the International Water Resources Association (IWRA), with contributions from over 40 organisations from around the world. The report showcases ten exemplary SWM projects based in both developed and emerging regions, along with 9 upcoming and potential SWM projects, which address the use of innovative smart technologies and solutions to address a wide range of water challenges across a number of scales (from household to transboundary). Table 1 below shows the SWM projects and their smart solutions in the order they appear in the report. The map below shows the global distribution of these projects and the text boxes included within the report.

Table 1. Case study location, project name and SWM solutions

Case study location	Project Name	SWM Solution
South Korea (national)	K-HIT	Flood and drought integrated network
Paju, South Korea	Paju Smart City	Water quality real-time monitoring for drinking water
Seosan, South Korea	Seosan Smart City	Smart sensors and real-time display increased leak detection and community satisfaction
Paris, France	SIAAP	Integrated network for improved real-time water quality in sanitation
Guantao County, China	Handan Pilot	Groundwater monitoring and modelling to reduce over abstraction
Mexico City, Mexico	PUMAGUA, UNAM	Smart sensors for drinking and wastewater quality and leak detection
Thailand, Tanzania, Kenya, Uganda, Rwanda, Burundi, Benin, Burkina Faso, Cote d'Ivoire, Ghana, Mali and Togo	Flood and Drought Monitoring Tools (FDMT)	Flood and drought monitoring and planning using satellite data
Zimbabwe, Mozambique, Tanzania	Small-scale agriculture productivity and efficient irrigation in Southern Africa	Efficient irrigation using real-time soil monitors and an Agricultural Innovation Platform (AIP)
Spain, The Netherlands, United Kingdom and France (SW4EU)	Smart Water for Europe (SW4EU)	Four demonstration sites addressing leak detection, water quality, community satisfaction and energy optimization using smart sensors and DMAs
Toronto, Canada	Stormwater SmartGrid	Real-time rainwater collection and monitoring for household stormwater management

The following section provides an overview of the ten SWM projects selected by K-water and IWRA for development into case studies as part of this report. From the case studies received, the ten identified for inclusion were selected to present a diverse range of scales, geographic locations in both developed and developing regions, water challenges faced, and technology solutions implemented. The report also includes 9 upcoming 'project highlights' looking to implement SWM or in the beginning of their implementation. These are presented as text boxes in the relevant sections of the report.

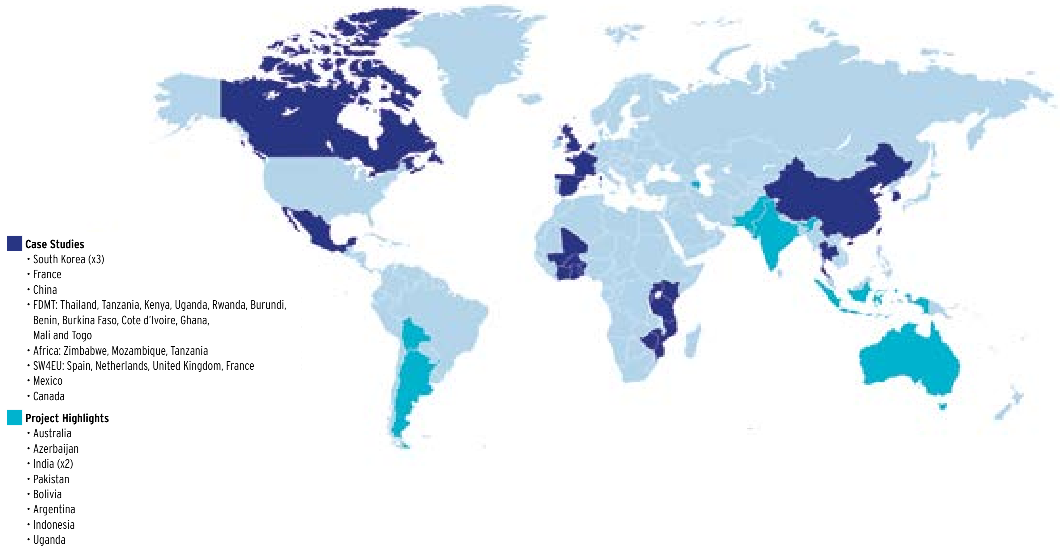


Figure 1: Map showing location of SWM Project case studies and text boxes

The purpose of the SWM report is to:

1. Demonstrate the potential for SWM implementation in a range of contexts, geographic locations, scales, and water challenges in both developing and developed countries.
2. Provide cross-case analysis of the case studies to illustrate the various enablers, barriers and lessons learned in each project during SWM implementation and operation.
3. Provide policy recommendations based on the findings of the analysis to support future SWM implementation.
4. Demonstrate the potential for SWM to assist in reaching the Sustainable Development Goals (SDGs).

SWM has become an area of increasing interest over the past decade as governments, industries and utilities move towards real-time data collection and use to optimise their operations and knowledge. K-water has championed the development of SWM during this time, developing various tools and technologies to address a range of water challenges. Within this report K-water will share their projects and the lessons learned of SWM over the past decade, to provide insight into the solutions available and to present the challenges that are still to be overcome. To present a broader view of the possibilities of SWM, case studies from around the world will also be presented to show how SWM technology has been implemented, at various scales and across various contexts, and the successes, and at times challenges, that these projects have faced.

The case studies within this report demonstrate the role smart technology can play in assisting to resolve numerous water challenges (e.g. water access and quality, efficient irrigation, reduced demand, flood and drought management and planning and inclusive governance and data management) across a diversity of scales. It also shows the potential for SWM projects to aid in the achievement of the Sustainable Development Goals (SDGs) (e.g. by improving livelihoods and economic and gender equity, reducing hunger, broadening access to knowledge and education, enhancing health and wellbeing, adapting to climate change and improving safety).

The full edition of this report on SWM includes policy recommendations aimed at stakeholders looking to adopt SWM policies at the local, national and regional level, as well as pointing to next steps to support the continued successful implementation of SWM across the world.

II. What is Smart Water Management?

Box 1. Definition of Smart Water Management

Smart Water Management (SWM) is the use of Information and Communication Technology (ICT) to provide real-time, automated data for use in resolving water challenges through IWRM.

SWM can be used for planning and operational purposes, from daily use to organisational and policy planning at a range of scales, across contexts and regions.

SWM enables governments, industries and utilities from around the world integrate smart principles (using ICT) into their urban, regional and national strategies. The potential application of smart systems in water management is wide, and includes solutions for water quality, water quantity, efficient irrigation, leak detection, pressure and flow, ecosystems, floods, droughts and much more.

By applying SWM infrastructure such as sensors, monitors, GIS, satellite mapping and other data sharing tools to water management, real-time solutions can be implemented and broader networks can work together to reduce current water management challenges.

SWM is a response to the need for shared information, collaborative practices and automated responses across the field of integrated water resource management (IWRM), in order to increase security and efficiency while decreasing risk and uncertainty. A key assertion of SWM is that by introducing real-time data and automation, services will become more efficient, water management will become more reliable, while decision-making will become more inclusive and knowledge-sharing and collaboration will improve.

The Republic of Korea has championed SWM since 2008 in an effort to achieve smarter technologies and more efficient and reliable water resource management. Since then Korea has developed world class projects in SWM which they will share within this report to demonstrate the potential of SWM and to support other countries interested in investing in SWM in the future.

III. International cooperation

Part of the Republic of Korea's policy on SWM is aimed at becoming a leader and role model for smart technologies in water management, in particular so as to impart its experience and expertise to developing countries through international cooperation.

As a country that has experienced rapid urbanization and economic growth in the past 50 years, transitioning from a developing to a developed economy, the Republic of Korea understands better than most both the challenges and needs faced by developing countries and the potential for improvements and lessons learned by developed countries. The Republic of Korea can therefore act as a messenger between the two, sharing the possibilities of smart technologies to both developed and developing countries interested in investing in SWM.

In order to meet the complex water challenges currently facing developing countries and to mitigate and adapt to an ever-changing climate, technological advances will need to be introduced. For some developing countries limited access to electricity or wireless internet connections, or limited basic water infrastructure, can result in challenging barriers to the successful implementation of SWM. Without basic infrastructure and resources, smart technology may seem limited in its potential. Nonetheless as shown within this report, not all smart tools required extensive physical infrastructure to succeed, and many challenges can be resolved. To support developing countries to participate in the emerging field of SWM, developed countries can provide access to smart tools and technologies, but to ensure the sustainability of these projects in the long-term, it is critical that capacity building and knowledge sharing be at the core of SWM development.

To demonstrate the types of projects not yet using smart technology that could greatly benefit from SWM implementation, this report also includes short textbox case studies on projects from around the world either in the initial stages of SWM implementation, or looking to introduce SWM once solutions are found to the barriers currently in place. It is intended that by sharing these stories and the challenges they face in adopting SWM, solutions can be found to enable their future implementation.

As water challenges vary greatly around the world, from water access concerns in dry climates to flooding in temperate and tropical climates, it was considered important to showcase SWM projects that cover a wide range of water challenges across both cities and regional areas. SWM projects located in cities face challenges such as improved water and sanitation quality, stormwater management, leak management, community engagement and decision-making. In regional and rural areas the projects focused more on water access, water quality and efficient irrigation.

It was also considered important to present a broad geographical range of projects as technologies are developed at varying speeds and in different ways in every country and region, based on knowledge, capacity, funding, and need. While some countries are already in the process of including smart technologies as a core element to their IWRM approaches, others are yet to begin this process. By sharing the lessons learned and solutions to challenges faced from the countries and regions where SWM has been successfully implemented, the aim is that countries interested in SWM will be able to better overcome or deal with the challenges faced by the early adopters of SWM presented within this report.

IV. Core elements of Smart Water Management

The analysis showed numerous benefits from the implementation of SWM as shown in Box 2. Across the 10 case studies, certain factors for success appeared consistently as critical for successful SWM implementation, across scales, geographic locations, levels of development and the water challenges being addressed. These factors for success are detailed in Box 3.

Box 2. Benefits of Smart Water Management Implementation

Social benefits

- **Access to clean water and sanitation** through water treatment and monitoring
- **Health improvements** through increased access to clean, safe water
- **Improved livelihoods** through job creation, greater opportunity for further education, higher productivity and other opportunities
- I**ncreased training and capacity building** for the local community and staff
- **Increased sharing of solutions** to support sustainable development
- **Increased decision-making opportunities** through increased engagement and knowledge-sharing
- **Greater collaboration with community** through engaging with local stakeholders at the beginning of the project
- **Greater security** by improving water security and increased resilience to climate change
- **Increased trust** in water suppliers and the safety of water sources
- **Improved access to data and information** through real-time data sharing with all water users
- **Increased gender equality** through increased opportunities for capacity building and further education
- **Reduced conflict over water access** leading to increased trust and willingness to engage in collective action

Economic benefits

- **Increased efficiency** in irrigation systems and wastewater treatment systems
- **Reduced waste** by the reduction of water loss through leakages
- **Job and opportunity growth** through job creation through SWM project research, design, development and implementation
- **Improved capacity** in water systems improving their capacity to manage flows and reduce damage during storms/floods
- **Reduction in future infrastructure costs** by integrating smart technology tools to improve capacity/efficiency, resulting in less need for additional infrastructure
- **Mobilisation of funds** from public and private sources, as well as international funding sources

Environmental benefits

- **Improved water quality** through reduced pollution and contamination in waterways
- **Improved ecosystem health and protection** through improved water quality and quantity

- **Reduction in groundwater depletion** through reduced over abstraction
- **Reduced land degradation** through flood and drought management and reduced nutrient loss in the soil
- **Reductions in CO^2 emissions** through energy optimisation and reduced energy consumption
- **Reduced water consumption** through leak detection and reduced demand and increased reuse

Governance benefits

- **Improved management and knowledge**, as measurement is critical for effective management
- **Improved accuracy of data**, as real-time data should also be SMART (specific, measurable, actionable, relevant and time-bound) data
- **Increased community-led decision-making opportunities** as water users can make decisions based on real-time water use and information
- **Improved transparency** as water users have access to water use and quality in real-time

Technology benefits

- **The opportunity to test and develop** new and innovative tools for water management
- **Innovative technologies created** with the potential for commercialization
- **Identification of the remaining gaps** in technology adoption (e.g. standardisation of software and tools to make it easier to adopt the 'right' mix of tools for each situation
- **Showing the potential for SWM tools** to deliver successful outcomes and in turn lead to significant social, environmental, governance and financial impacts

Box 3. Factors for success

Cross-cutting factors

- Political commitment from government at all levels
- Support from national government policy, legislation, and regulation
- Use of two-pronged approach (i.e. combining the use of SWM tools with engagement, governance and/or a strong business model) to support the implementation and increase the adoption for, and positive outcomes from, SWM technologies.
- Strong stakeholder engagement from the beginning of the project across and within sectors, (especially) including local agencies and communities, to ensure active community participation and decision-making.
- A multidisciplinary approach (both across sectors and within sectors) to ensure all factors can be taken into account (e.g. environmental, technical, scientific, policy, regulation, financial, maintenance, etc.).

Social factors

- Active stakeholder engagement from the beginning of the project
- Local stakeholders to be involved in decision-making and implementation
- Improved livelihoods from job creation and increased opportunities such as time for further education and skill development
- Increased trust in the community towards water suppliers and water resources
- Education, training and capacity building for local communities

Economic factors

- Long-term investment to enable on-going research, development, testing and implementation, to support taking SWM solutions to market
- External financial support to assist in the implementation of projects in the short-term/ financial support from both public and private investors
- Consideration of the non-financial benefits (e.g. environmental, social, governance), which are often apparent in the short-term, alongside the financial returns, which are medium- to long-term
- Strong business cases to support replication and scaling
- Demand management and improved efficiency as a means to water and energy savings

Environmental factors

- Regulations, economic instruments and information to encourage behavioural changes to improve water quality, efficient water use, natural resource protection
- National plans to improve/resolve water challenges
- Commitments from international funding bodies to meet and address the Sustainable Development Goals, including water
- Commitment from leading organisations and stakeholders to address these environmental challenges

Technical factors

- Allowing adequate time to design, develop, test and adjust technology for greater/more accurate results
- Undertaking a baseline assessment of the challenges and what needs to be addressed to ensure that the right mix of technology and non-technological solutions are implemented.
- Collaborating with all sectors to ensure adequate and accurate data (e.g. electricity data) are shared to support decision-making
- Integrating smart tools and systems across networks to enable collaborative decision making
- Integrating smart tools with traditional infrastructure
- Willingness of water utilities and governments to test the possibilities of smart technologies

V. Replication and scaling

Each of the projects report in these case studies has the potential to be scaled up and out, scaled down (for small-scale projects) and replicated in both developed and (under the right circumstances) developing regions to assist with resolving water challenges . As every project presented in these case studies is specific to the area and country where it was implemented, replication mandates an understanding of the different contexts faced by the initial project and the adopting region. An assessment on whether the conditions are similar enough to attempt the same approach, and what additional support is required prior to planning the replication is also recommended. However, with the right financial, policy and technology support, knowledge sharing and collaborative decision-making, each of these projects has the potential to be adopted in both developed and developing regions with long-term success.

To support other areas interested in adopting SWM, these case studies provide directions and identify factors of success; and equally important they identify the barriers faced during implementation. In is the hope that future projects can learn from these experiences so that they can easier and more quickly overcome these challenges.

The pilot projects (e.g. Paju, Seosan, Mexico, IWA, Africa, China, Canada), show how SWM can be adopted in stages, from minor adjustments to improve the efficiency of a system, to introducing a whole new suite of tools to change the way a challenge is addressed. While smaller in scale when compared with some of the larger citywide projects, these case studies show the significant benefits that can be achieved through adopting a SWM approach. The larger projects (e.g. K-HIT, SIAAP and SW4E), provide ambitious examples of fully integrated systems, showing what can be achieved when policy, financial and technology resources and strong collaboration are in place.

Based on these findings, the following section provides a series of policy recommendations in relation to social, economic, environmental, technological and governance strategies aimed at policy makers from all levels of government interested in supporting the future successful implementation of SWM in both developed and developing regions. It also provides a classification of the types of SWM implementation that occur and the levels of support required for each type to increase the chances of successful implementation.

VI. Policy recommendations

Table 2: Policy recommendations for Smart Water Management implementation

Strategies	Policy direction
SWM for an improved quality of life (Society)	**1.** Facilitate adoption of SWM tools, especially in developing countries, to support access to basic services, and to support equality for poverty reduction, public health and quality of life. Include capacity development, technology sharing, collaborative business models and community governance and decision-making opportunities.
	2. Build trust and community engagement using SWM tools in areas where the community feel unsafe using the local water sources.
	3. Empower people in developing countries with smart tools to reduce the time spent on water management and increase farm income and time available for other activities (e.g. further schooling, and additional work opportunities).
Investment in SWM for improved resilience and sustainable development (Economy)	**4.** Strengthen collaboration across and within sectors to provide opportunities for networks to share information and data to assist with effective and efficient water management.
	5.Value non-financial benefits (e.g. environmental, social, governance and technical benefits) as equally important as financial benefits for SWM implementation, as they contribute to building resilience to the effects of climate change and increasing populations.
	6. Support long-term investments for SWM implementation to enable adequate research, development and testing.
SWM for protecting and conserving water resources and ecosystems (Environment)	**7.** Introduce policies, regulations and incentives to drive environmental and ecosystem protection through use of SWM.
	8. Encourage SWM solutions to increase water quality, manage demand and use, water reuse, reducing groundwater depletion and increase energy efficiency, etc.
	9. Introduce SWM solutions for climate adaptation plans for flood and drought planning and management and major storm events.
Support evolving smart technology development and adoption (Technology)	**10.** Develop standards to ensure all SWM technologies are compatible (can communicate) with each other to enable tools to be purchased across various suppliers to enable those implementing SWM to create the right set of tools for each context.
	11. Support on-going research, testing and development of SWM tools to advance them to a point where they are robust and require minimum maintenance and are ready to be commercialized (Government policies that support taking SWM tools from R&D to market).
	12. Support technology to assist in regions without built infrastructure or the adequate resources (e.g. electricity), as currently SWM infrastructure is (almost always) reliant on built infrastructure
Building capacity and networks for increased resilience and collaboration (Governance)	**13.** Empower people, especially those in developing countries, by providing them with SWM tools, data and capacity development and education to enhance/ support local decision-making.
	14. Strengthen the capacity to adapt to climate change by adopting SWM planning and operational technology.
	15. Plan for water disasters in advance by creating proactive policies instead of reactive policies.

Through this analysis several SWM implementation 'types' became evident. As the context of each SWM project is different, understanding the various types of SWM implementation and the tools and solutions for each type is critical for successful implementation. A description of these types is provided in Box 4 below.

Box 4. Smart Water Management Implementation Types

Implementing SWM technology by itself will not always resolve the water challenges faced by a project. In some cases, a two-pronged approach is necessary to address the complex nature of each challenge. The second element of the two-pronged approach can include community engagement, governance schemes or business models, and is equally as important to the success of many of the projects as the SWM tools themselves.

Based on the case studies presented within this report we have categorised SWM technologies into three different types depending on who is using/adopting the technology. Each type requires a different approach to ensure the technology achieves its potential benefits.

Type 1 – Institutional users

Type 1 addresses technologies aimed at major institutional users such as water suppliers, water managers, mines, water treatment plants, etc. (e.g. SIAAP, K-HIT, China). The implementation of these technologies is mostly straightforward as industries and utilities can be encouraged to adopt SWM through incentives (improving efficiency, environmental benefits) or drivers (meeting regulations or targets) introduced by governments or the agencies themselves. Regulations and policies that encourage these institutions to develop and implement SWM technologies are relatively easy to introduce (depending on the government), and the institutes will more easily fund the necessary research (often with government support) to develop and successfully implement SWM.

Type 2 – Individual users

The second type is the technologies aimed at a large number of individual users such as households and farmers (e.g. Africa and Canada). These are far more complicated to implement, as they require a very large number of individuals to change what they are doing, and they do not always respond in the same way to economic incentives. Often the main benefits are to the society at large, rather than the individual. The savings from introducing smart technologies in homes might be small compared to the cost and inconvenience of adopting it, however the total impact might be significant and therefore the societal benefit high. In this second type, a two-pronged approach is more critical in order to achieve the potential societal benefit.

Type 3 – Institutional and individual users combined

The third type involves a combination of both the institutional and individual user. This is seen when an institution develops and implements the SWM technology but the success of the technology partly relies on the individual user (e.g. Mexico and IWA). This approach requires some engagement, but is less dependent on a second-prong than Type 2, due to the implementation being conducted by the institution.

EXECUTIVE SUMMARY

VII. Links to the Sustainable Development Goals (SDGs)

As part of developing a stronger understanding of how SWM can assist with moving towards the global aim of sustainable development, it was important to assess how each of the projects presented within this report can assist with achieving the Sustainable Development Goals (SDGs). Beyond the expected links to SDG 6 (Clean Water and Sanitation) and SDG 11 (Sustainable Cities and Communities), the analysis of these SWM projects has shown the breadth of targets that can be assisted through the use of SWM, in areas of poverty, hunger, gender equality, reducing inequalities and climate action.

The following table highlights the targets that the ten SWM projects within this report contribute to. With the continued success of SWM implementation around the world, it is expected that SWM will continue to provide an even greater contribution to reaching the SDGs in the future.

Table 3: SWM links to the Sustainable Development Goals (SDGs)

SDG	Links to Smart Water Management
1. No poverty	**Target 1.4 – Supporting equal rights to economic resources, natural resources and new technology** through introducing smart soil moisture monitors to assist farmers in increasing irrigation efficiency leading to increased crop productivity, income and improved land management (Africa) **Target 1.5 – Building resilience to climate related extreme events** through adopting flood and drought planning using satellite data across transboundary basins (FDMT) and smart integrated water resource management for national river basins (K-HIT) **Target 1B – Supporting policy frameworks based on pro-poor and gender sensitive development** through supporting community capacity and decision-making opportunities for women in farming (Africa)
2. Zero hunger	**Target 2.3 – Increasing agricultural productivity and incomes of small-scale food producers** through increased irrigation efficiency and reduced nutrient loss using smart soil monitors and Agricultural Innovation Platforms (Africa) **Target 2.4 – Moving towards sustainable food production and resilient practices** through increasing farmers' awareness of sustainable water management and irrigation (China and Africa) and reduced fertilizer use (Africa) and water reuse for aquaculture (see Uganda text box in report)
3. Good health and well-being	**Target 3.9 – Reducing the number of deaths and illness from water pollution and contamination** through improving water quality for drinking purposes (Mexico, France, Paju)
4. Quality education	**Target 4.4 – Increasing the number of youth and adults who have relevant skills including technical and vocational skills for employment, decent jobs and entrepreneurship** through job creation in the field of SWM technology development and implementation (Seosan), capacity building in design for water professionals (France), and technical capacity building for youth and adults in the use of SWM technology and implementation (Africa and FDMT).

5. Gender equality	**Target 5.5 – Increasing women's participation and equal opportunities for leadership at all levels of decision-making** through increasing awareness and knowledge-sharing using real-time data leading to better decision-making opportunities for women (Africa)
6. Clean water and sanitation	**Target 6.1 – Achieving universal and equitable access to safe and affordable drinking water for all** through increasing awareness and receptivity to drinking tap water through knowledge-sharing using real-time data (Paju, Mexico). **Target 6.2 – Achieving access to adequate and equitable sanitation and hygiene for all** through ensuring efficient treatment of sanitation using real-time monitoring and automated treatment (France and Mexico). **Target 6.3 – Improving water quality by reducing pollution** through monitoring and filtering contaminants using real-time sensors and treatment (Paju, Mexico, France, SW4EU and Canada). **Target 6.4 – Substantially increasing water-use efficiency** through improved irrigation efficiency (Africa), reduced leakages (Paju, Mexico and SW4EU), reduced consumption (Seosan, China, Mexico and SW4EU), capture and reuse of rainwater (Canada) and increased storage capacity (K-HIT). **Target 6.5 – Implement integrated water resources management at all levels** through integrated river basin and dam management (K-HIT), sanitation and water management network integration (France), transboundary flood and drought management and planning using satellite data (FDMT) and Agricultural Innovation Platforms for integrating governance (Africa). **Target 6.6 – Protect and restore water-related ecosystems** through reduced pollutant loads in wastewater through smart monitoring and treatment, restoring ecosystems and fish populations (France), and reduced stormwater pollution reaching waterways through smart cisterns (Canada). **Target 6A – Expand international cooperation and capacity building to support developing countries** through supporting transboundary basin agencies with flood and drought planning and management using satellite data (FDMT) and replicating successful SWM projects in developing countries (e.g. Seosan project replication in Indonesia) **Target 6B – Strengthening the participation of local communities in improving water and sanitation management** through involving local stakeholders from the beginning of the project (Africa, FDMT and Mexico) and learning from community experiences (China).
7. Affordable and clean energy	**Target 7.3 – Doubling the global rate of improvement in energy efficiency** through energy optimization (SW4EU) and increasing water efficiency, thereby reducing energy intensive processes (Paju, Seosan, Mexico, France, SW4EU and Canada).
8. Decent work and economic growth	**Target 8.1 – Sustaining per capita growth in accordance with national circumstances** through increased job opportunities in research and development, project management and construction (Paju Smart City). **Target 8.2 – Achieving higher levels of economic productivity through diversification, technological upgrading and innovation** through supporting research and development in SWM technology (France and Paju Smart City). **Target 8.5 – Achieving full and productive employment and decent work for all women and men, including for young people and persons with disabilities** through increasing capacity building and reducing the time required for low skilled tasks (e.g. irrigation), thereby increasing the time available for further education and employment opportunities for women and youth in particular (Africa) **Target 8.6 – Substantially reduce the proportion of youth not in employment, education or training** through capacity building and further education (Africa).

9. Industry, innovation and infrastructure	**Target 9.1 – Developing quality, reliable, resilient infrastructure to support economic development** through integrating SWM technologies to traditional infrastructure to improve accuracy and reliability (K-HIT, France and Mexico) **Target 9.4 – Upgrading infrastructure for resource efficiency** through leak detection and water consumption monitoring (Paju Smart City, Mexico and SW4EU).
10. Reducing inequalities	**Target 10.1 – Providing support and income growth for the bottom 40% of the population** through improving agricultural techniques (e.g. efficient irrigation, higher value crops and improve market integration) to increase crop productivity and income (Africa) **Target 10.2 – Empowering and promoting social, economic and political inclusion for all** through providing data to all water users and enabling local stakeholders to be involved in decision-making (Paju Smart City, Africa and China) **Target 10.3 – Promoting opportunities for women and youth** through increased education opportunities, increased decision-making and increased high skilled employment (Africa).
11. Sustainable cities and communities	**Target 11.4 – Strengthening efforts to protect and safeguard the world's cultural and natural heritage** through reducing the impact of natural disasters such as droughts and floods (K-HIT and FDMT). **Target 11.5 – Significantly reducing the number of deaths and numbers of people affected by disasters, including water-related disasters** through integrated operational water management (K-HIT) and future planning for floods and droughts using satellite data and weather predictions (FDMT). **Target 11A – Supporting positive economic, social and environmental links between urban, peri-urban and rural areas by strengthening national and regional development planning** through transboundary planning with local basin authorities using satellite data (FDMT). **Target 11B – Substantially increasing the number of cities and human settlements adopting and implementing integrated policies and plans towards resource efficiency, adaptation to climate change and resilience to disasters** through planning (FDMT), increased resource efficiency (China, SW4EU, Mexico) and local storage of water (Canada).
12. Responsible consumption and production	**Target 12.2 – Achieving the sustainable management and efficient use of natural resources** through efficient water use (China), leak reduction (Paju, Mexico, SW4EU), energy optimization (see SW4EU and China) and reduced reagent consumption (France). **Target 12.8 – Ensuring that people everywhere have the relevant information and awareness for sustainable development and lifestyles in harmony with nature** through increased community engagement and knowledge dissemination using real-time data and results (Paju, Mexico, SW4EU and China).
13. Climate action	**Target 13.1 – Strengthening resilience and adaptive capacity to climate-related hazards and natural disasters in all countries** through optimizing infrastructure to manage crisis situations (France), reducing pressure on centralised infrastructure in the case of flooding (Canada) and by integrating SWM into adaptive planning and forecasting (FDMT). **Target 13.2 – Integrating climate change measures into national policies, strategies and planning** using data and forecasting to integrate plans for future flood and drought events at a national and transboundary level (FDMT). **Target 13.3 – Improving education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning** through increasing community awareness of the importance of water and their role in its management (Paju, Mexico, SW4EU) **Target 13B – Promoting mechanisms for raising capacity for effective climate change-related planning and management in least developed countries and small island states** through increasing awareness using real-time data on water consumption and access and future challenges (Mexico and FDMT).

14. Life below water	**Target 14.1 – Preventing and significantly reducing marine pollution of all kinds, in particular from land-based activities, including nutrient pollution** through reducing non-point source pollution (e.g. fertilizer in Africa; stormwater contaminants in Canada); and treating wastewater before returning it to the waterways (France).
15. Life on land	**Target 15.3 – Combating desertification, restoring degraded land and soil, included land affected by drought and floods** through flood and drought planning tools (FDMT) and integrated operational flood and drought management (K-HIT) **Target 15.5 – Taking urgent and significant action to reduce the degradation of natural habitats, halting the loss of biodiversity** through integrated flood and drought management (K-HIT).
16. Peace, justice and strong institutions	**Target 16.6 – Developing effective, accountable and transparent institutions at all levels** through increasing access to data for all water users (Paju Smart City and Mexico) **Target 16.7 – Ensuring responsive, inclusive, participatory and representative decision-making at all levels** through providing a forum for water users to contribute their ideas and access information and real-time data (Africa, Paju Smart City, Mexico, SW4EU, Canada)
17. Partnerships for the Goals	**Target 17.6 – Enhancing regional and international cooperation on and access to science, technology and innovation and enhance knowledge-sharing** through collaborations between local and international agencies (FDMT, Africa, China) and capacity building for local workers (Paju Smart City, Africa and FDMT). **Target 17.7- Promoting the development, transfer, dissemination and diffusion of environmentally sound technologies to developing countries on favourable terms** through enhancing knowledge-sharing through partnerships (K-HIT, Mexico, France and China).

VIII. Conclusions and next steps

The SWM projects included within this report have shown the considerable potential for SWM to assist with numerous water challenges, across various scales, geographic locations and developing and developed regions while also creating social, economic, environmental and governance benefits. These projects have also demonstrated the enormous potential for SWM to assist with achieving the SDGs, across a number of goals and targets.

While it is important to recognise that each project is set within its own context, the overarching lessons that have emerged as part of this report highlight the similarities between case studies to show how SWM can be successfully implemented around the world, and what challenges there are still to face.

As SWM is still an emerging field these projects demonstrate the untapped potential of what can be achieved using innovative SWM technology and solutions. As the field progresses and technologies evolve, the potential for SWM adoption across all contexts will continue to grow, leading to increased opportunities for both developed and developing regions, and innovative solutions for our current water challenges.

In order to continue learning from these case studies, it is important to follow them on their journey to see how challenges are addressed as the technology evolves, and what impact introducing SWM continues to have in their region. This is important when trying to scale up or down, or transfer existing SWM solutions to new locations, baring in mind the adaption necessary to the local context and challenges.

It will also be interesting to see how SWM technology and solutions can move from the research and development stage to the testing stage and finally to market. In other words, how SWM can become self-sustaining without reliance on initial government support in the early phases.

At this stage, many of these projects have shown the potential for SWM technology to successfully resolve water challenges. It is important to now build and develop the business cases for adopting, scaling and transferring these solutions. This is why the monitoring and measuring SWM benefits must continue. The next phase of research would be aimed at capital investors to help them see the benefits and potential of SWM, leading to increased possibilities for future investment.

Now that a wider number of smart tools are on the market, integrated smart networks will start to emerge, and with them increasing opportunities for sustainable cities and regions to integrate their various smart infrastructure, such as smart energy grids. While retrofitting existing cities is possible, the opportunity offered by urbanization and the creation of new cities and suburbs means that these new urban environments offer the greatest potential for smart technology integration.

This report demonstrates how far SWM has already come in a short time and the considerable benefits it can provide in both developed and developing regions, especially when coupled with strong policy support and community engagement. It also explores some of the constraints and barriers encountered to date. In the end, however, it is certain that SWM has nearly unlimited potential to contribute to the realization of the goals of integrated water resource management and sustainable development through smarter management of water.

CHAPTER 1. Introduction

Contents

1. SWM Introduction

1.1 What is Smart Water Management?

Smart Water Management (SWM) is the use of integrated, real-time Information and Communication Technology (ICT) solutions, such as sensors, monitors, geographic information system (GIS) and satellite mapping and other data sharing tools in water management. Over the past decade governments, industries and utilities have moved towards real-time-data collection and use to optimise their operations and knowledge. SWM can provide with them integrated water management solutions, at all scales and across various contexts to resolve current water challenges in both developed and developing countries.

The potential application of smart systems in water management is wide and includes solutions for water quality and quantity, efficient irrigation, pressure and flow management, ecosystems protection, flood and drought management, stormwater and sewage management, future planning and much more. SWM can also address water infrastructure by integrating it into broader networks in order to share data to reduce water and energy consumption, to provide targeted irrigation for agriculture, and to be more efficient in wastewater treatments. In developing countries, it is specifically relevant for taking into consideration urban and regional data and water consumption so that governments can improve public health through the possibility of checking water quality, water resource availability and water distribution in all neighbourhoods of developing cities, towns and rural communities – especially where informal dwellers are settling.

In this report, SWM solutions are presented from a diversity of projects, across both developed and developing regions, from the micro scale (e.g. household) through to the transboundary scale. These case studies demonstrate the potential for SWM solutions to assist in the advancement and integration of traditional water infrastructure in urban settings, with providing simple to use irrigation solutions in rural agricultural settings, along with providing support for improved planning, management and operation of water management for water suppliers and users.

SWM is a high-tech strategy to deal with economic, social and environmental urban and regional issues as a way to better use our water resources while protecting the most vulnerable places and creating innovative types of economy and management. At a time when data is part of people's everyday life, it is a natural step for decision makers to include SWM into their policy strategies in order to provide a more adapted response to urban and regional organization. Taking into consideration current issues communities face, and global commitments under the United Nation's Sustainable Development Goals (SDGs), SWM can provide support to any contemporary integrated water resource management strategy. As such, policy makers around the world are increasingly integrating smart principles into their urban, rural, regional and national strategies, which will in time provide them with a better understanding of the dynamics of cities and regions, leading to more resilient, sustainable and safer living environments.

While interest in SWM has increased rapidly over the past decade, the adoption of SWM into policy has been slower than for other sectors such as energy and transport. To amend this, decision makers must be provided with the research on the benefits of SWM, and how policy can support successful SWM implementation. It is therefore essential that reports such as this one provide these insights for policy makers, while also sharing the knowledge with the broader water community interested in implementing SWM solutions.

The sharing of SWM successes (and challenges) also support water industries, utilities and other users and to better understand the enabling factors and barriers to successful SWM implementation, leading to a greater uptake of successful SWM projects in the future. As SWM has continued to grow over the past decade we are now seeing a variety of SWM solutions, across all scales for a wide range of water challenges and contexts. To assist with the continued growth of SWM, this report aims to share these insights from around the world, to support the continued implementation of SWM and to promote the use of innovation and smart solutions for future water management.

1.2 What is the potential of Smart Water Management?

Water challenges affect everyone in the world, with both developing and developed regions facing increasing challenges in relation to water security, access and management. This is anticipated to increase as climate change results in an increase in frequency and intensity of floods and droughts that must be planned for and managed. In developing regions water quality and security reduce the liveability of certain areas for vast populations, while leak detection, sewage and stormwater management affect urban areas in developed regions.

At the same time smart technologies are developing rapidly around the world providing an evolving suite of innovative and integrated solutions. While sensors and monitors have become standard for energy monitoring, the idea of using smart technology in water management is only a recent one. As technology is developing rapidly, so are the opportunities for smart solutions to an array of water challenges, from the household scale (e.g. smart monitoring of water use or rainwater collection), to the site and city scale (e.g. leak detection and water quality monitoring) through to national and transboundary scales (e.g. flood and drought monitoring and management). SWM solutions have the potential to allow for major advances in water solutions, through integration of solutions into broader networks. SWM solutions may also add value to current water projects, reducing the need for new infrastructure, and may allow us to access and act on a situation in real-time, increasing knowledge and security for our water systems. SWM also has the potential to improve future planning through increased localised data and climate scenarios based on real-time data.

Other sectors could also be addressed by SWM including urban resilience, agricultural efficiency and coastal water management. Indeed, many environmental risks are now linked to either too little or too much water. Droughts, storms and floods are more intense and more frequent and some regions are more exposed to risks related to water. Overall, SWM should allow for the better identification of those disasters and a more efficient response to it, as SWM has the potential to integrate several solutions to provide a holistic approach. The possibility to generate water stocks in case of drought would allow countries to reduce the consequences of such hazards, allowing essential activities such as irrigation for agriculture to occur to ensure adequate food supply. Conversely, the ability to reuse and better manage floodwater may provide wetter regions a complementary and sustainable source of energy.

In the face of climate change, a more sustainable use of water is essential. The risk of water scarcity and poor water resources, as well as water pollution due to high industrial activities is real. SWM focuses on an integrated management system, allowing all water departments to communicate and share their data. Adapting existing networks and infrastructure is a way to shift over to a more modern, sustainable and smart economy. Indeed, SWM has the potential to put water into a data cycle, going from freshwater resources, to treatment of wastewater and management of irrigation and floodwater.

As water plays such a crucial role in the future sustainable development of the world, it is no surprise that 11 of the 17 Sustainable Development Goals directly relate to water. SWM can offer innovative water management solutions to assist with addressing these goals, and potentially to assisting in other areas of sustainable development including community building and capacity development, efficient energy use and improved livelihoods for people in developing regions.

1.3 Purpose of the report

The purpose of this report is to test whether these assumptions are accurate. Through this research we aim to better understand why people are investing in SWM, what their expectations are for SWM, and whether SWM can provide the solutions as expected. To do this, this report brings together the knowledge and insights of water experts and practitioners from around the world who have led the way in implementing SWM solutions to resolve current water challenges. The case studies and projects presented within this report show the successes achieved (and challenges faced) in these SWM projects, to demonstrate the potential for smart, integrated solutions to resolve these water challenges and to support the continued successful implementation of SWM projects in the future.

The report contains 10 case studies from around the world, from across all scales to demonstrate the variety of SWM solutions available and the impact these solutions can have in various contexts. Beyond the traditional technical challenges faced in water management, this report demonstrates how SWM can also assist with challenges such as community involvement and engagement, building community trust and increasing opportunities and capacity. In doing so, this report shows the potential for SWM to assist decision makers, water utilities and industries to achieve not only their economic and technological benefits, but also social, environmental and governance benefits.

Through analysing these case studies, the report provides insights into the drivers for SWM adoption, the enabling factors supporting successful SWM implementation and also the barriers that have slowed or prevented SWM projects from succeeding. By sharing these findings, it is hoped that those interested in adopting SWM will reduce, and possibly avoid many of the challenges faced by these projects. For those interested in supporting SWM (e.g. governments and the private sector), it is hoped that the report will provide an insight into how they can best contribute to supporting the successful implementation of SWM in the future.

In addition to supporting future successful SWM adoption, one of the key focuses of this report is to identify what support SWM can offer in achieving the Sustainable Development Goals (SDGs). With water playing such a key role in achieving the SDG targets, it is with great interest that we identify the ways in which SWM can assist with this process, as we work together over the next decade to move towards achieving the SDGs.

In summary, this report aims to:

1. Demonstrate the potential for SWM implementation in a range of contexts, geographic locations, scales, and water challenges in both developing and developed countries.
2. Provide cross-case analysis of the case studies to illustrate the various enablers, barriers and lessons learned in each project during SWM implementation and operation.
3. Provide policy recommendations based on the findings of the analysis to support future SWM implementation.
4. Demonstrate the potential for SWM in reaching the Sustainable Development Goals (SDGs).

It is hoped that the insights provided within this report, along with policy recommendations built on those insights, will support the continued implementation of SWM and promote the potential for the use of innovation and smart, integrated solutions for improved water management around the world.

1.4 Who is involved?

The Korea Water Resources Corporation (K-water) is the government agency for comprehensive water resource development in the Republic of Korea, with a large pool of practical engineering expertise regarding water resources. Over the past decade the Korean government and K-water have made a serious commitment to developing and implementing SWM technology solutions. By drawing upon Korea's advanced technology and knowledge, K-Water has been able to become a leader in SWM and an advocate for SWM implementation in both developed and developing countries. Through SWM Korea has been able to address some significant challenges in the Korean water sector, including infrastructure maintenance, drought, the economic and environmental waste of non-revenue water and bottled water use, and community perceptions of potable water quality.

The International Water Resources Association (IWRA) is an international NGO consisting of a broad network of scientific and policy experts in the field of water resources, and focusing on sharing knowledge on all issues related to water with its broad network of water experts and the broader water community.

K-water and the IWRA worked with water experts from around the world, from universities, NGOs, water utilities, the private sector, local farmers and international agencies, from both developed and developing countries, and from a wide range of contexts, to present this report on successful SWM case studies from around the world. In addition, a panel of IWRA experts in the Smart Water Management Task Force was instrumental in the design and analysis of this report.

1.5 Methodology of the report

This Report adapted a multi-framework approach, using multiple-case study design (Yin 2006) to structure the study and a Logic Model framework (see Weiss 1997) as the basis for contextualising each SWM case study.

Logic Models have been at the core of sustainable development evaluation for decades, providing a clear illustration of the steps taken to achieve desired outcomes and impacts in sustainable development programs and projects. Weiss' theory on the use of Logic Models for evaluation and planning spurred the development of numerous variations of the framework, spanning several fields. While Logic Model frameworks vary, the core concepts of a Logic Model (i.e. the inputs, outputs, outcomes, impacts, assumptions and external factors of a project) remain the same. In addition to understanding the core concepts of each project, it was considered valuable to explore the enabling factors and barriers each of these projects faced to gain a better understanding of how SWM projects can best be supported, and what can slow, or stop completely, the successful implementation of SWM projects.

1.5.1 Research Design

The development of the SWM Case Study Report was designed to follow three stages: Phase 1 (Design), Phase 2 (Development) and Phase 3 (Analysis). In Phase 1, a greater understanding of the Smart Water Management concept and current achievements in this area was prioritised. This allowed for the creation of a thematic Case Study Matrix to be developed, ensuring a diversity of SWM case studies were selected for the research and report. During this phase a Case Study framework was also developed outlining the key themes to be addressed by each of the case study authors. Phase 2 focused on the selection and development of the SWM case studies with support provided throughout this phase by IWRA to case study authors. In Phase 3, the final phase, the case studies were brought together and analysed using cross-case analysis. A flowchart outlining each step within the phases is shown in Figure 1 below.

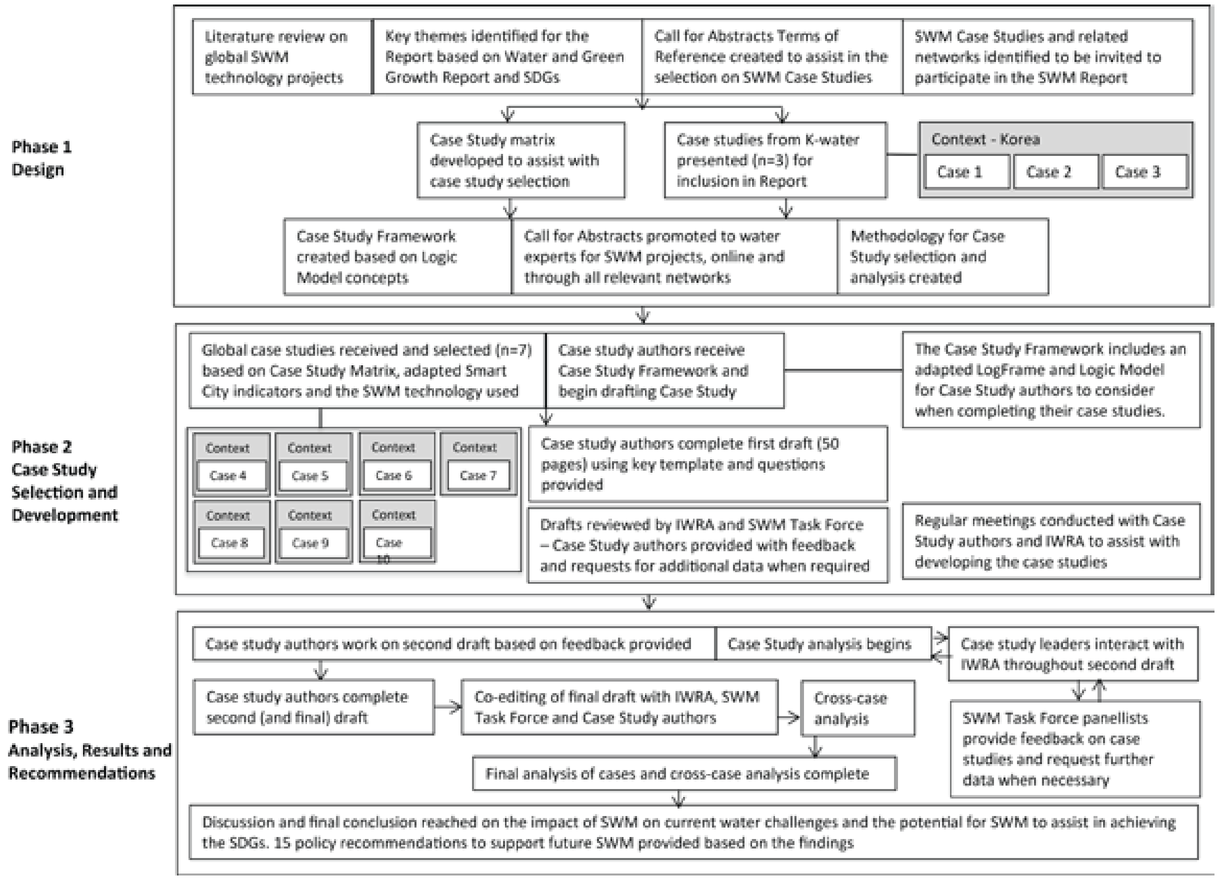


Figure 1. Research design for SWM Case Studies Report

1.5.2 Case study selection

The SWM Case Studies Report analyses 10 SWM projects (three from cities within Korea and seven from selected countries around the world), of varying scale, geographic location and technical SWM solution. Selecting cases from various countries and regions enables to the report to highlight the diversity of SWM technology and uses currently being implemented around the world.

The selection of Case Studies was assisted by K-water, who identified three key projects within Korea with which they are currently involved. The additional seven cases from various regions around the world were selected based on a Call for Abstracts, which was distributed by IWRA and K-water to relevant networks, water experts and promoted online. In addition to this promotion, exemplary case studies were identified during the literature review at the beginning of the project, and were directly approached via email with an invitation to submit an abstract. SWM projects of all scales, geographic locations, technical solutions and water challenges were encouraged to submit an application.

In the Call for Abstracts, a definition of SWM was provided to ensure the projects would align with the definition used for this report. While definitions of SWM vary to some extent, for the purpose of this report the definition of a SWM project was decided as any water project that *'uses* (near) *real-time, automated and integrated information and communication technology (ICT) solutions to address current water challenges'.* It is important to note the *use* of data in SWM, as there are many cases of water management projects worldwide that collect and monitor data (e.g. weather management, water quality monitoring etc.) without using the data for improved sustainable water management. In SWM, it is the use of this data to improve sustainable water management that sets it apart.

To determine the content of the potential case studies, each abstract author was provided with a series of key themes to address regarding their project. These themes included a contextual background of the project (i.e. social, environmental, economic, political and technical factors); details of the project (e.g. inputs, outputs, outcomes and impacts); enabling factors and barriers faced within the development of the project; and any identified links between the project and the SDGs. For this final request, a link to the SDGs was provided for each author to assist with this task.

During the six-week Call for Abstracts period, 32 projects were received. After a thorough selection process, seven projects from around the world were selected to participate in the report as in depth case studies and nine projects selected for inclusion within the report as 'upcoming projects in SWM'. This coupling of both in depth case studies and upcoming projects enabled the projects to show their successful, while also providing a greater insight into the diversity of SWM projects, and interest in including SWM into other projects, currently seen around the world.

To ensure a diverse selection of case studies was selected for the report, a Case Study Matrix was developed to classify each case study by: geographic location, scale and water challenge. Technical SWM solutions (e.g. sensors, GIS and satellite mapping or monitors) used by each case study were also considered to ensure a mixture of solutions within the report. In addition to the Matrix and technical solutions, a set of indicators developed to monitor Smart City solutions (CITYkeys, Horizon 2020 project) was considered during the selection process, and adapted to reflect the broader scope of Smart Water management. These indicators were considered relevant as Smart Water Management stems from the Smart Cities concept. To reflect the broader scope of Smart Water Management, the Smart Cities indicators were adapted to include water challenges faced outside of the urban setting, including agriculture, irrigation, water access and water quality in regional and remote areas (see Box 1 below).

Box 1. Smart City indicators (CITYkeys) adapted to reflect the scope of SWM

People: *health, safety, access to water, education and quality of life*
Planet: *water quality, climate resilience, ecosystem, and disaster management*
Prosperity: *employment, equity, green economy, economic-performance, innovation, attractiveness and competitiveness, water-food-energy nexus*
Governance: *organisation, community involvement and multi-level governance*
Propagation: *scalability and replicability*

Within our report we have adapted the smart city indicators to look at people, planet and prosperity within the context of the triple bottom line (society, economy and the environment), while addressing the governance actions that can support the successful scaling and replication of integrated SWM.

1.5.3 Data collection

Data collected for the SWM Case Studies Report followed a semi-structured approach, with each case study author provided a Case Study Framework to guide them with their writing. The Framework consisted of key themes and questions for the case study authors to reflect on, while also allowing the authors the freedom to provide an individualised narrative for their case study. This supported interesting stories to emerge for each case study, while also enabling comparability across the cases for analysis. Case study authors were also provided with a Logic Model framework to review and complete as part of their case study. While it was anticipated that all authors would consider the themes of the Logic Model while writing their case studies, it was not expected that case study authors would complete a detailed Logic Model framework, as most of these projects were not based on the Logic Model methodology and therefore to retroactively request the authors to shape their projects into this framework is both challenging and often unhelpful. Instead, the authors were asked to consider the themes within the Logic Model methodology while writing their case studies, and to reflect on the inputs, outputs, outcomes and impacts across all of the factors mentioned (i.e. social, economic, environmental, governance and technological).

During Phase 1 of the case study development process, case study authors were encouraged to work with IWRA to fully develop their case studies. To achieve this, case study leaders discussed their progress with IWRA regularly to reflect on ideas that had emerged during the writing stage. After a three-month writing period, a full draft was provided to IWRA and the SWM Task Force to review, and returned within a month with feedback and questions to ensure the case study provided the data required for strong analysis and represented the full story. Case study leaders were then provided with a final three months to complete their case studies (Phase 2) prior to the final analysis stage (Phase 3).

As in all case study research, the context surrounding each SWM case study provides great insight into the project itself, and the related successes and challenges faced within the project. As such, key questions on the external factors impacting each study were addressed. These factors include, but are not limited to: the GDP (Gross Domestic Product) of the region, population and growth rate, research and development (R&D) access, cultural, political and environmental climate and the priorities in the region. These factors were considered to paint a picture of the context of the project, however it is reasonable to assume that not all of the factors that impact each project are represented in these background context summaries.

1.5.4 Analytical framework

This Report uses a multi-framework approach for the contextualisation and analysis of each case study. The core analytical framework for the study applies Weiss' Logic Model theory (1997), and adapts it to include links to the Sustainable Development Goals. In addition to the Logic Model, a LogFrame was provided to the case study authors and adapted to include a ranking system to allow for key (social, environmental, economic, political, governance and technological) factors to be assessed in terms of perceived importance. Since its introduction in the early 1970's, the Logic Model framework has been used to evaluate program and project success in a number of areas including sustainable development. This framework allows for clear analysis of the value provided by projects, programs, events and institutions against key goals set. Knowlton and Phillips (2008) state that the Logic Model framework is beneficial in evaluation as it: 1) documents and emphases explicit outcomes, 2) clarifies knowledge about what works and why, 3) identifies important variables and 4) offers a strategic means to critically review and improve thinking. The Logic Model is useful in project evaluation as it illustrates a sequence of cause-and-effect relationships, between inputs, outputs, outcomes and impacts. While visually Logic Model frameworks vary depending on the project's needs, all Logic Models contain the same core elements. These elements include: the situation the project plans to address (problem statement), the resources you have available to address it (inputs), the activities you plan to conduct with these resources (outputs), the results you aim to achieve within the project (outcomes) and the longer-term results you hope the project will contribute to in the broader context (impacts). In addition to these elements, Logic Models also address the external factors that may impact the project, and the assumptions that may have been made about the project and its participants during the planning and implementation stages.

The Logic Model framework was selected for this project for three reasons: 1) it allowed each case study to unpack their projects into stages, identifying the key factors that impacted their projects; 2) it enabled a clear cross analysis of each case across the factors, highlighting which stages of the implementation process were critical in SWM and which were flexible; and 3) it provided the ability to link the projects impacts to the SDGs.

To provide an overall analysis of the case studies, the following key questions were assessed across each case study:

1. What were the drivers and enabling factors, which lead to this projects success?
2. What challenges or barriers did this project face that either delayed, or halted the progress or success of this project?
3. What were the lessons learned by the project team during this project?
4. How can this project assist with achieving the Sustainable Development Goals?

For each case study these questions were explored in detail, and as themes emerged key findings were established across these four questions to show whether certain themes were consistent between cases, geographic locations, scales, or solutions. Cross analysing the case studies in this manner is considered to be a reliable approach to provide greater insight into a topic across various contexts (Yin 2003).

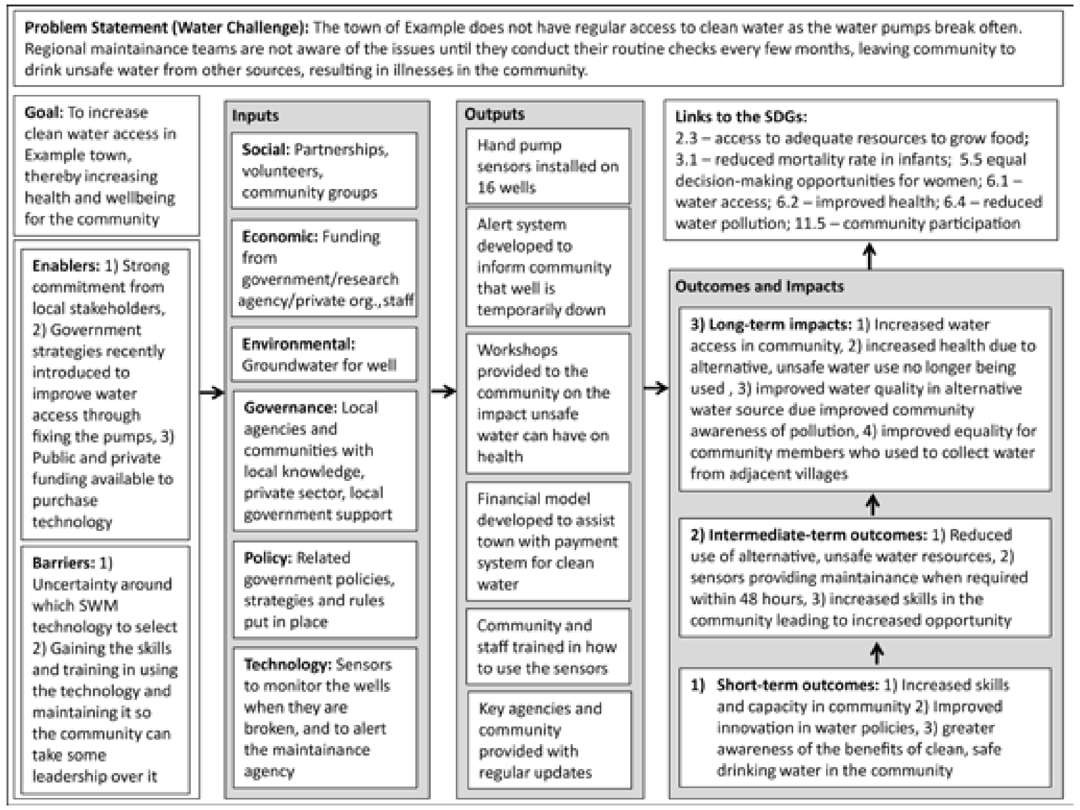


Figure 2. Example Logic Model concepts based on example case study

1.6 Structure of the Report

Following this introduction and methodology, the report presents ten case studies from around the world. As Korea, and indeed K-water, have been instrumental in championing SWM for the past decade one of the key ideas behind this report was to share the lessons Korea have learned along the way through this report. Therefore we open the case studies by presenting three case studies from Korea that address a variety of water challenges and smart solutions. The first case, based on a national project titled 'K-HIT', addresses integrated flood and drought management; the second case in Paju Smart City addresses community perception of potable water quality and reducing bottled water use; and the third in Seosan Smart City addresses the issue of leak detection and non-revenue water. Through these case studies we can see the incredible results achieved by K-water and the Korean government through SWM solutions, including an increase in tap water drinking rates from 1% to 33% in Paju City in three years, and a decrease in non-revenue water by 20% in Seosan City. These case studies show the potential for rapid and dramatic results when using real-time, SWM solutions.

Following the case studies from Korea, we have seven international case studies from around the world, from both developed and developing countries. These case studies have been order based on their 'Implementation Types of SWM' (see Box 2 below).

Box 2. Smart Water Management Implementation Types

Implementing Smart Water Management technology by itself will not always resolve the water challenge faced by a project. In some cases, a two-pronged approach is necessary to address the complex nature of the challenge. The second element of the two-pronged approach can include community engagement, governance schemes or business models, and is equally as important to the success of many of the projects as the SWM tools themselves.

Based on the case studies presented within this report we have categorised SWM technologies into three different types depending on who is using/adopting the technology. Each type requires a different approach to ensure the technology achieves its potential benefits.

Type 1 – Institutional users

Type 1 addresses technologies aimed at major institutional users such as water suppliers, water managers, mines, water treatment plants, etc. (e.g. France, K-HIT, China). The implementation of these technologies is mostly straightforward as industries and utilities can be encouraged to adopt SWM through incentives (improving efficiency, environmental benefits) or drivers (meeting regulations or targets) introduced by governments or the agencies themselves. Regulations and policies that encourage these institutions to develop and implement SWM technologies are relatively easy to introduce (depending on the government), and the institutes will more easily fund the necessary research (often with government support) to develop and successfully implement SWM.

Type 2 – Individual users

The second type is the technologies aimed at a large number of individual users such as household users and farmers (e.g. Africa and Canada). These are far more complicated to implement as they require a very large number of individuals to change what they are doing, and they do not often respond in the same way to economic incentives. Often the main benefits are to the society at large, rather than the individual. The savings from introducing smart technologies in homes might be small compared to the cost and inconvenience of adopting it, however the total impact might be significant and therefore the societal benefit high. In this second type, a two-pronged approach is more critical (i.e. combining the use of SWM tools with engagement, governance and/or a strong business model) in order to see a total societal benefit.

Type 3 – Institutional and Individual users combined

The third type involves a combination of both the institutional and individual user. This is seen when an institution develops and implements the SWM technology but the success of the technology partly relies on the individual user (e.g. Mexico and FDMT). This approach requires some engagement, but is less dependent on a second-prong than Type 2, due to the implementation being conducted by the institution.

The ‘implementation type’ for each case study was chosen based on the analysis of each case study during the cross-case analysis. The implementation types were then discussed with each case study author for their input.

While SWM is a relatively new idea in each of these projects (though some cases such as France can be seen retroactively as SWM) the results seen in most of these case studies are in the short- to medium-term. Despite this, the results seen so far show great promise for the medium- to long-term results and impact of SWM. The projects that do have results across a longer time span (8+ years; e.g. France and Mexico) have clearly shown the benefits of SWM solutions. We have also included text boxes of a number of projects where SWM is starting to or could make a difference, with the right support.

In addition to the ten case studies selected as part of this report, embedded within the report are examples of water management projects, which highlight a certain aspect of SWM. These include projects where:

- SWM would be an advantage in the future
- SWM has improved an element of the project
- Small scale cases that could be up-scaled or replicated

By sharing these upcoming projects and the support they require for continued success, it is hoped that they can receive further support from their governments to ensure they are provided with the new opportunities for successful SWM implementation.

The case studies and upcoming projects are followed by a detailed discussion and analysis of the 10 case studies, which looks at the social, economic, environmental, governance and technology factors that enabler and create barriers for successful SWM implementation. The output of this discussion is a set of 15 policy recommendations, which provide decision makers with the tools to support the future implementation of successful SWM projects. Following the discussion is a short summary of the conclusions and next steps for SWM.

This report is aimed at different audiences to enable them to gain insights from its findings to support them in moving forward with SWM. For the decision makers, the Executive Summary and Discussion and Analysis sections provide the key elements required to support upcoming SWM projects (such as the Policy Recommendations). For water utilities and industries, the factors for success and enablers and barriers provide insights into the areas that can be used to support SWM, and the areas that still require support. For those interested in implementing SWM projects in both developed or developing regions, the case studies provide detailed lessons on what has worked and what has not been as successful, with recommendations on where to from here. As such, it is hoped that this report can act as a guide for all of the readers interested in SWM implementation and the impacts it can provide in improving sustainable, integrated water management and helping to achieve sustainable development.

DR

CHAPTER 2. Case Studies

Contents

Textboxes

Warren Wong

K-water's Integrated Water Resources Management System

(K-HIT, K-water Hydro Intelligent Toolkit)

Mr. Sukuk Yi, Dr. Munhyun Ryu, Dr. Jinsuhk Suh, Dr. Shangmoon Kim, Mr. Seokkyu Seo, Mr. Seonghan Kim, K-water (Korea Water Resources Corporation)

South Korea

Summary

Water management is a challenge in Korea due to limiting geographical features, such as short watercourses, and high rainfall variability across the regions and seasons. Korea also faces regular water-related disasters such as extreme flooding and droughts, increasing in intensity due to the change in climate thus creating increased necessity for national water management and security.

To address this, Korea has placed great effort to resolve temporal and regional variability through the construction of multi-purpose dams and multi-regional water supply systems. Such an investment in water resources in Korea has increased the water supply for industrial and domestic use alongside supporting Korea's national economic development.

K-water is responsible for managing flood water and for supplying water through the operation of water resources infrastructure including: 34 multipurpose and water supply dams, 4 flood control dams and reservoirs, 16 weirs, and one estuary barrage (similar to a low dam wall). Of these, the multi-purpose dams operated by K-water account for 62% of total dam supply and 94% of flood control capacity.

In order to protect the people from drought and flood disasters through more efficient water resource management, K-water has constructed a scientific river operation system which links the rivers in the connecting watersheds. The aim of this system is to implement integrated water resource management technology in rivers for the purpose of increasing water quantity and water quality concurrently.

In 2002, the K-water Hydro Intelligent Toolkit (K-HIT) was introduced, to provide an integrated water management system based on Information and Communication Technology (ICT). K-HIT has five functions including real-time hydrological data acquisition, precipitation forecasting, flood analysis, reservoir water supply, and hydropower generation. By using K-HIT, K-water can minimize the flood damages by storing more water during the flood season and can prevent droughts by supplying stored water during the dry season through the use of scientific and effective operation of this system.

Through the introduction of K-HIT, K-water have been able to effectively deal with floods that occurred in 2012, 2013 and 2015. In this way K-HIT also contributes to the achievement of sustainable development goals including SDG 6 (availability and sustainable management of water) and SDG 11 (making cities inclusive, safe, resilience and sustainable) by preventing disasters such as floods and securing water in droughts.

1. Background

1.1 Climate and Water Management Characteristics of Korea

1.1.1 Topography and Precipitation Features

Water management in Korea is broadly divided into 6 zones: the Han River in the Seoul metropolitan area and Gyeonggi, Geum River in Chungcheong, Seomjin River and Yeongsan River in Jeolla, Nakdong River in Gyeongsang and Jeju/Ulleung islands (see Figure 1).

Figure 1. Six zones in Korea

Rivers in Korea experience severe fluctuations in terms of river flow throughout the seasons, with rainy season in particular creating an extreme challenge for water management due to the high flood levels and runoff. In contrast, the dry season results in very low river levels, which creates its own water management challenges. As shown in Figure 2, Korea experiences highly concentrated rainfall in the summer (June - August) while precipitation is very scarce in the winter (October - January).

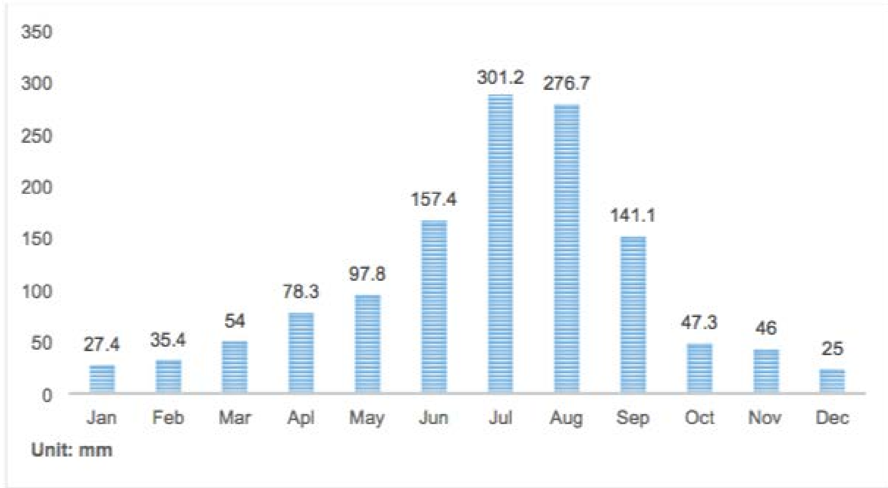


Figure 2. Monthly Rainfall in Korea
(Source : MoLIT (2017), The 4th Long-term Comprehensive Plan for Water Resources (2001~2020), 3rd revision.)

Table 1 shows a comparison of flow variation coefficients between major rivers in Korea and in other countries.

Table 1. Flow Variation Coefficients in Rivers

River	Flow Variation Coefficients	River (Country)	Flow Variation Coefficients
Han River	90 (390)	**Tone (Japan)**	115
Nakdong River	260 (372)	**Seine (France)**	34
Geum River	190 (300)	**Rhine (Germany)**	18
Seomjin River	270 (390)	**Nile (Egypt)**	30
Yeongsan River	130 (320)	**Mississippi (U.S.A)**	3

* Note: figures in parenthesis refers to coefficients before multi-purpose dams were constructed
Source : MoLIT (2017), The 4th Long-term Comprehensive Plan for Water Resources (2001~2020), 3rd revision.

An analysis of the patterns of precipitation change, as shown in Figure 3, indicates that the average rainfall over a 10 year period is increasing (by approximately 4% since the 1970s) and rainfall variability has been gradually increasing from the 1990s. The annual average rainfall over the past 100 years shows a large range of variability, from the minimum of 754mm (in 1939) to a maximum of 1,756mm (in 2003). In careful consideration of these natural precipitation characteristics, Korea has placed great effort to resolve temporal and regional variability through the construction of multi-purpose dams and multi-regional water supply systems.

(Unit: mm)

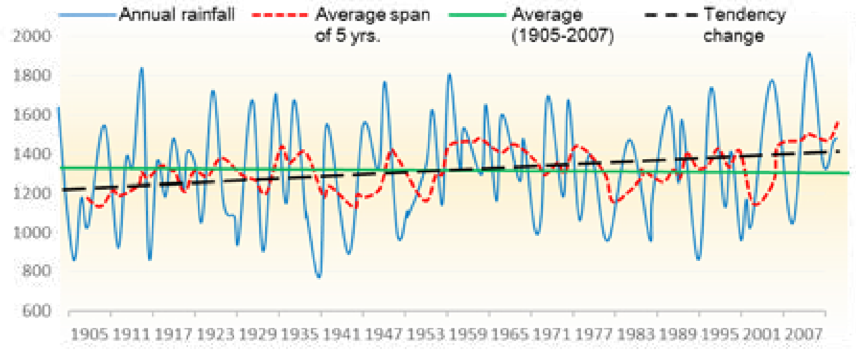


Figure 3. Average Rainfall in Korea (1905-2007)
Source : MoLIT (2017), The 4th Long-term Comprehensive Plan for Water Resources (2001~2020), 3rd revision.

Furthermore, weather anomalies such as extreme floods and droughts, which seem to be intensifying due to climate change, are occurring more frequently. Recently, Korea has been suffering from a severe drought. As Table 2 indicates, annual rainfall in 2013 was 11% lower than the average annual rainfall, and in 2014 it was 10% lower. By August 2015, the annual rainfall was only 64% of the annual average. Due to the increasing frequency of extreme weather conditions, Korea faces many challenges in terms of managing water resources and ensuring water security.

Table 2. Annual Rainfall (2006-2015)

	2006	2010	2011	2012	2013	2014	2015.8
Rainfall(mm)	1,424.3	1,444.9	1,622.6	1,479.1	1,162.9	1,173.7	659.4
Percentage compared to the average annual rate	109%	110%	124%	113%	89%	90%	64%

Source : MoLIT (2017), The 4th Long-term Comprehensive Plan for Water Resources (2001~2020), 3rd revision.

1.1.2 Water Resources Availability

The average annual rainfall rate in Korea is 1,274mm (calculated between 1973-2011), 1.6 times the world annual average. However, due to high population density in Korea, the average annual rainfall per capita is only 2,660 ㎥, approximately 16% of the world average. Per year, Korea has a total water supply of 132.3 billion ㎥. In 2007, the total amount of water-use was 37.2 billion ㎥ (dam 20.9 billion, groundwater 4.1 billion, river 12.2 billion), which accounts for 28% of the total amount of water resources available. Total water-use is 1.8 times the normal water runoff (runoff that occurs outside the rainy season; 21.2 billion ㎥), and thus flood runoff (runoff that occurs during the rainy season of June to September) is reserved in impoundments such as dams and other reservoirs to be used when necessary. The total water-use for domestic, industrial and agricultural water is about 25.5 billion ㎥ per year, which is approximately 34% of the total available water resources.

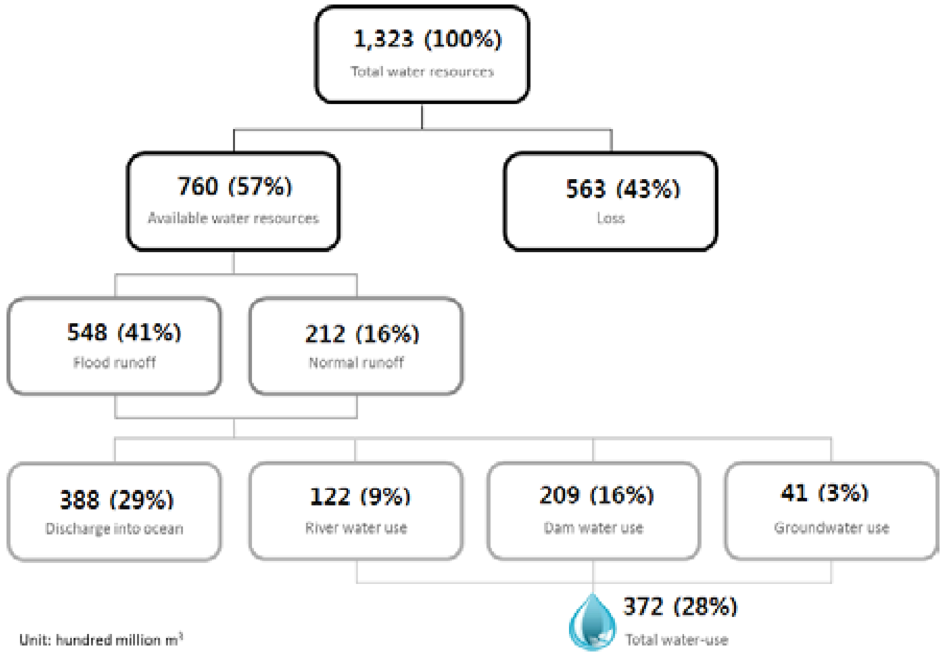


Figure 4. Water Availability in Korea
Source : MoLIT (2017), The 4th Long-term Comprehensive Plan for Water Resources (2001~2020), 3rd revision.

1.1.3 Water-Use by Purpose

In terms of water-use by purpose (see Figure 5), agricultural water accounts for the largest proportion at 48% of the total water-use, followed by domestic water 23%, then river maintenance water 23% and industrial water-use accounts for 6%. It is also notable to mention that river maintenance flow continues to increase over time. As aforementioned, the total water-use for domestic, industrial and agricultural purpose accounts for 25.5 billion ㎥ per year.

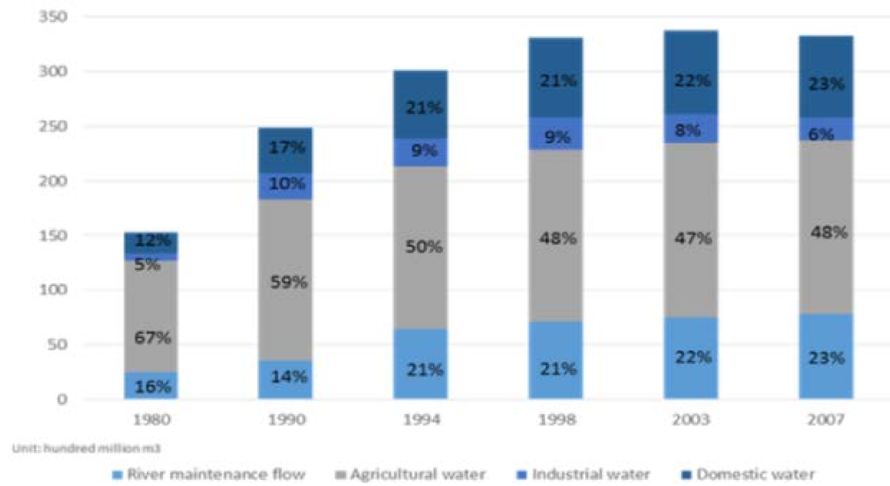


Figure 5. Water-use by Purpose
Source : MoLIT (2017), The 4th Long-term Comprehensive Plan for Water Resources (2001~2020), 3rd revision.

The water abstraction rate for domestic, industrial and agricultural purposes stands at 34%, which confirms the categorisation that Korea is a "water-stressed" country (Table 3). The high abstraction rate creates a greater vulnerability for water security, and excessive water abstraction increases the difficulties in managing water quality and conserving river ecosystems.

Table 3. Water Stress Level by Country

Abstraction Rate	Degree of Water Stress	Country
Below 10%	Low	New Zealand, Canada, Russia
10-20%	Middle	Japan, U.S.A., U.K., France, Turkey
20-40%	Mid-high	Korea, China, India, Italy, South Africa
40%	High	Iraq, Egypt

Source : MoLIT (2017), The 4th Long-term Comprehensive Plan for Water Resources (2001~2020), 3rd revision.

1.1.4 Flood Risks

It is essential to take preemptive measures and preparation in order to mitigate the effects of natural disasters given that weather anomalies and vulnerability driven by climate change are aggravated in Korea.

Approximately 70 to 80% of the total annual rainfall is concentrated in the summer making Korea highly vulnerable to water-related disasters. The average annual damage caused by water-related disasters over the last 10 years is estimated at 2,084.5 billion KRW (USD 1.895 billion). As Figure 6 notes, Korea's flood risk index is much higher than other countries resulting in the need for systematic and proactive responses in order to prevent extensive damages caused by disasters and climate change.

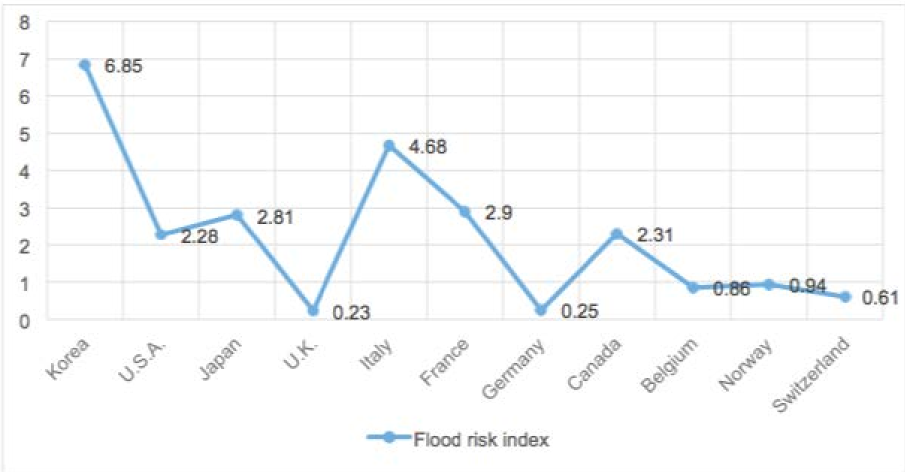


Figure 6. Flood Risk Index by Country
Source : Based on UNDP (2004), Reducing Disaster Risk. A Challenge for Development

1.2 Economic Growth

Box 1. Economic Growth in Korea

Over the past 50 years Korea has transformed from an agricultural country to industrialised country with rapid urbanisation. The per capita GDP grew by an average 10.95% of a year (USD 253 in 1970 to USD 27,805 in 2015), and the urbanisation rate reached 81.9% in 2011 from 40.7% in 1970. The agriculture and forestry industry was the largest industry with 28.9% in 1970 but sharply decreased to 2.3% in 2015 and the manufacturing industry grew from 29.5% to 148.8%.

Table 4. GDP and Urbanisation Rate

Year	1970	1975	1980	1990	2001	2011	2015
GDP (Billion)	2,795	10,505	39,471	197,712	688,165	1,332,681	1,564,124
Urbanisation Rate (%)	40.7	48.0	56.7	73.8	79.6	81.9 (2010)	

Source: Analysis of the effects of water resources development in Korea's economic development process, Dec. 2016, Choi Han-ju

Table 5. Industrial Structure (%)

	1970	1975	1980	1990	2001	2011	2015
Agriculture and Fisheries	28.9	26.9	15.9	8.4	4.1	2.5	2.3
Mining and Manufacturing	20.4	23.4	25.6	28.0	27.8	31.6	29.7
(Manufacturing)	18.8	21.9	24.3	27.3	27.6	31.4	29.5
Electricity, Gas and Water Supply Business	1.4	1.2	2.2	2.2	2.9	2.0	3.2
Construction Industry	5.0	4.5	7.6	9.5	6.1	4.8	5.1
Service Industry	44.3	44.1	48.7	51.9	59.0	59.1	59.7

Source: Analysis of the effects of water resources development in Korea's economic development process, Dec. 2016, Choi Han-ju

1.3 Water Resources Investment

Korea's investment in water resources has increased alongside its national economic development. Figure 7 shows the annual investment (based on construction amount) and the trend of gross domestic product (GDP) for water facilities from 1977 to 2014 based on a construction industry survey. Water investment has increased, though irregularly, as GDP growth continues.

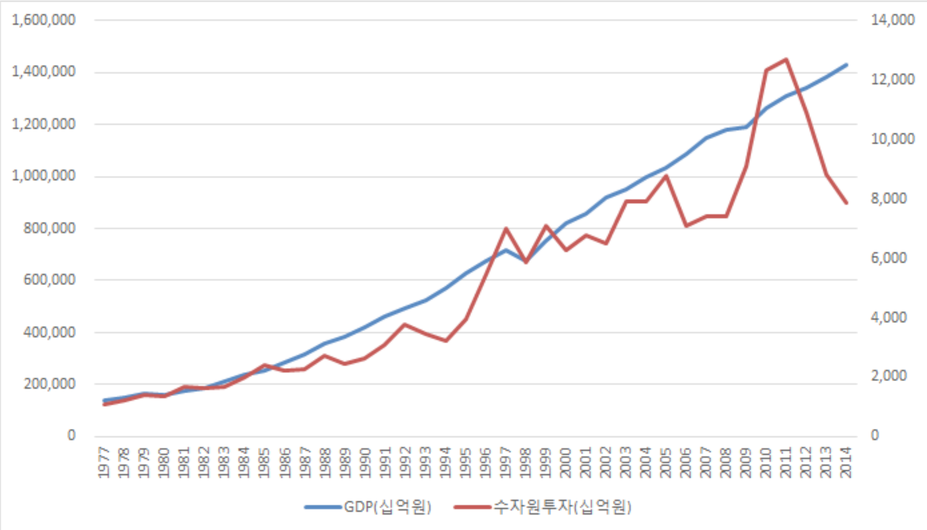


Figure 7. Water Investment and Gross Domestic Product Trend (1977~2014, yearly basis)
Source: Analysis of the effects of water resources development in Korea's economic development process, Choi Han-ju, K-water Researcher, 2016

Box 2. Water Resources Investment in Korea

Economic Development Period (1960 ~ 1980)

Water development during this period was actively promoted to support economic development. It was designed to meet a variety of demands such as supplying electricity using hydroelectric power, supplying stable industrial water, and establishing industrialisation and urbanisation bases through flood control. Andong Dam (1976), which is a multi-purpose dam, was constructed in order to provide a stable supply of industrial water and domestic water. Over this period, water usage tripled from 5.12 billion m^3 to 15.3 billion m^3 in 1980, and the water supply rate increased from 16.9% in 1960 to 54.6% in 1980.

Economic Growth Period (1980 ~ 2000)

The construction of multi-purpose dams, which had been sluggish due to the government's tightened budgets in the early 1980s, has increased rapidly since the mid to late 1980s due to the expansion of social overhead capital. Between 1980 and 2000, ten multi-purpose dams were constructed to secure a total volume of 3.7 billion m^3 and to supply 3.3 billion m^3 of water for industry, agriculture and domestic use. However, despite the increase in the number of multi-purpose dams constructed at this time, the size of the dams has been reduced compared to the total capacity of the 5 dams that were previously built for the purpose of flood control. Since the 1980s, multi-purpose dams have been constructed with a focus on water supply.

The main goal of water resource development in the 1980s was to respond to the surge in water demand due to industrialisation and urbanisation. In 1980, the urban population ratio was 68.7%, while the water supply rate was only 54.6%. By 2000, the water supply rate increased to 87.1%, which is close to the urban population ratio of 88.3%.

Economic Growth Period (2000 ~ present)

Water resources development has also been transformed from quantitative development based on supply to qualitative diversification with an emphasis on water quality, river ecology and environment. The increase in the cost of construction of dams, such as the exhaustion of land and compensation for resettlement due to the large areas of land required for reservoirs, and the increase in public demand for water quality and environment have made the dam construction conditions more difficult. During this period, only 5 small to medium-sized dams were constructed and the development of new water sources such as sewage reuse was actively promoted.

In 2009, the Four Major River Restoration Project (4MRRP) was promoted as part of the Korean-style Green New Deal for green growth, in which the central government sought fundamental preemptive measures to mitigate flood and drought damages caused by climate change. Unlike a single-purpose river project, the aim of 4MRRP was to contribute to the revitalisation of the rivers and economic revitalisation through the development of water resources infrastructure, increased water storage capacity for enhanced flood and drought management, improvement of water quality, and the creation of new waterfront leisure and culture spaces. With a total investment of 22.2 trillion won, 520 million m^3 of underwater dredging was conducted, 16 weirs were built in the main rivers and flood control areas and riverbed reservoirs were constructed to secure 11.7 billion m^3 of water resources to improve dimensional safety and water utilisation.

1.4 Population and Water Supply Rate

The population of Korea increased from 31,435,000 in 1970 to 52,419,000 in 2014. In that time the water supply rate increased greatly from 31.2% (10,430,000 people) in 1970 to 96.1% (31,372,000 people) in 2014.

Table 6. Population and Supply of Water (Unit: Capita, %)

year	1970	1975	1980	1990	2001	2011	2014
Population (thousand)	31,435	34,709	38,124	43,520	48,289	51,717	52,419
People of water supply(thousand)	10,430	14,961	20,809	33,631	42,402	48,938	50,373
Water supply rate(%)	31.2	43.1	54.6	77.3	87.8	94.6	96.1

Source: Analysis of the effects of water resources development in Korea's economic development process, Dec. 2016, Choi Han-ju

1.5 National Water Resources Management System

Box 3. Stakeholders

The Ministry of Land, Infrastructure and Transport (MoLIT) is responsible for water quantity management such as flood control, the instream flow of rivers, and the development of water resources. Whereas, the Ministry of Environment is responsible for water pollution regulations and water quality management such as drinking water and wastewater. K-water is responsible for managing flood water through dam operations and requires approval from the Flood Control Office, which is in charge of river flood control, to open the gates of dams. When the gates are opened, stakeholders and local governments must be notified of discharging information.

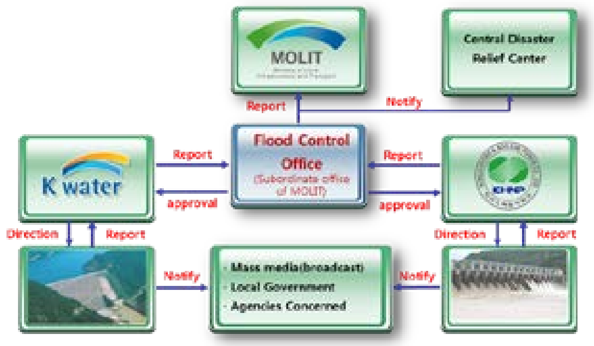


Figure 8. Dam operation procedures in Korea

Figure 9. Water Management Center of K-water

Korea has 17,759 dams in total. These dams supply 18.8 billion m^3 of water annually, 56% of Korea's annual water use (of 33.3 billion m^3), and they control floods with a capacity of 5.3 billion m^3. Of these, the multi-purpose dams operated by K-water account for 62% (117 billion m^3) of total dam supply in Korea and 94% (5 billion m^3) of flood control capacity.

The flood control process of multi-purpose dams is based on the rainfall data from the hydrological data management system connected with the weather information system and the real-time online network of the dam basins of K-water. K-water also performs rainfall-runoff analysis through the flood analysis system. This system is used to make full use of the flood control capacity by determining the appropriate controlled discharge amount and timing. To do this K-water consider the capacity of the dam downstream of the river, and conduct flood control of the entire water system in consultation with the related organisations such as the Flood Control Office.

K-water operates and manages important water resources infrastructures including 34 multi-purpose and water supply dams, 4 flood control dams and reservoirs, 16 weirs, 1 estuary barrage (see Figure 10), all of which are government assets.

The basin areas managed by K-water account for 48% of the nation's total land area, 95% of the nation's entire flood control capacity and 65% of the total water usage. As the number of dams K-water manages continues to increase, K-water needs to consider ways to combine dam operations to effectively conduct water resources management in river basins.

Figure 10. Dams and Weirs of K-water

2. Challenge Description

Increasing Frequency and Severity of Water Related Disasters

The frequency of severe floods and droughts in Korea has increased in recent years due to the changing climate. The measurement of this phenomenon is difficult to calculate due to a broad range of uncertainties, however the increase in water related disasters such as intensive precipitation and irregular drought cycles are significant and urgent issues that Korea is now facing.

The financial cost of the damage caused by natural disasters over the past 10 years in Korea, 87% of which were water related, was 1.7 trillion won per year (USD 1.55 billion), 5.3 times greater than in the 1980s and 3.1 times greater than in the 1990s. The annual restoration cost was even higher (approximately 2 trillion won; USD 1.82 billion). In addition, as 62% of dam facilities are over 30 years old, water management hazards are rapidly increasing creating a further serious water management and safety issue.

For example, four typhoons (including three in close succession at the end of the rainy season) struck the Korean Peninsula in 2012 for the first time since 1962 causing precipitation almost twice the monthly average from the middle of August to the middle of September. In 2013 the rainy season was the longest on record since weather observation data was first collected in 1904 with heavy rain in the middle region of Korea, while insufficient rain in the southern region of Korea resulted in a regional deviation of over 200mm. The most severely impacted was Jeju Island, which experienced approximately USD 300 million in drought damages, for the first time in 90 years. According to the 4th assessment report of the Intergovernmental Panel on Climate Change, it is expected that the risks of flooding and drought disasters in high latitude countries in the northern hemisphere, such as Korea, as well as the intensiveness and fluctuation of rain will continue to increase significantly.

Significant change of water management conditions after the Four Major Rivers (restoration) Project
In addition, the water management condition in Korea changed significantly as a result of the *Four Major Rivers (restoration) Project*, which was completed in 2012. K-water used to control floods and water-level control with linked operation among more than 30 multipurpose and water supply dam and river stations in the past. After the project, the changes made to river facilities (e.g. weirs and river-crossing sections) affected the stream flow of the river, increasing the consideration factors for flood control and algae bloom.

Box 4. Water cycle management in weirs and dams

Water has a hydrological cycle starting from precipitation to evaporation then eventually runoff. Thus, a water management system that is able to accurately analyse the water cycle is the key for successful water management. This is especially true for the effective operations in dams and weirs, which are an important element of many multi-objective water resources systems, an must ultimately create a balance between flood risks and other system objectives such as water supply or hydropower production.

3. Smart Water Management Solution

3.1 Input

3.1.1 Economic Factors

The (Smart) Water Management Center for the Integrated Operation of Dams and Weirs
In 2002, K-water established the Water Management Center, with 39 experts on water resources including water management, ICT, power generation, and weather. With the opening of a comprehensive water control room, K-water greatly enhanced its water resource management capabilities by integrating the operation of dams. The Water Management Center expanded its management staff to 55 people in 2010 and 67 people in 2016 due to the expansion of management facilities and functions.

The Water Management Center performs the following step-by-step work during normal and floods times.

- Normal stage: one person is on duty after working hours (18:00 – 09:00) if there are no forecasted weather issues
- Caution stage: If the national rainfall forecast requires the operation of dams and weirs for flood control, 8 people will operate the facilities (in groups of four)
- Alert stage: If weather report is issued and water discharge is needed to carry out flood control, 13 people will operate (in three groups)
- Serious stage: If nationwide floods and massive flood damage occur, 24 people (split into two groups) will be operate the system

CASE STUDIES
K-WATER'S INTEGRATED WATER RESOURCES MANAGEMENT SYSTEM

Flood Control Capacity Enhancement Project
The Flood Control Capacity Enhancement Project on existing dams is the project for prevention of disasters from excessive flood due to changes in the climate and thus protects lives and property damage by increasing the safety of dams.

To prepare for the increasing frequency of heavy rain due to recent climate changes, the standard of design flood[1] has been changed from frequency of flooding (100/200yrs) to Probable Maximum Flood (PMF). PMF is the amount of flood that results from the maximum possible amount of water, which is the theoretical maximum precipitation that can physically occur in any given period of the year for a given watershed area at a given location over a given time duration. Therefore, the design flood has been enlarged due to this change.

The amount of inflow into dams is much higher than the designed capacities when dams were initially constructed. As a result, flood control capacity enhancement is required to guarantee the permanent safety of dams. The types of measures include spillway expansion, auxiliary spillways and parapet walls.

The Flood Control Capability Enhancement Project for 24 dams, which was first implemented in 2003, is still in progress. As of 2017, 17 dam projects have already been completed, three dams are under construction and four dams are being planned.

3.1.2 Policy Factors

Establishment of Operational Regulations for Dam-weir Operation
In order to integrate the water facilities' operation with the existing dam management regulations, regulations on linked operation between the dams and the weirs have been developed to ensure the water resources facilities can be more efficiently managed.

Scientific and systematic operation is implemented to both secure additional water resources for the future, and to allow water facilities to preemptively discharge water for the purpose of flood control.

For the management of weirs, it is necessary to operate with consideration for river inflow situations, discharge situations of upstream dams, and river water quality.

Drought Response Guideline
A step-by-step 'Drought Response Guideline' has also been developed for dam operators to enable them to preemptively prepare for drought situations and to carry out the necessary measures required to manage the water supply. The Guidelines ensure the proper water supply is provided during droughts in order to minimise any social impacts including public inconvenience.

The 'standard' daily storage volume required for the dams to stably supply water for the next year is set in the Guideline. If at any time the actual storage volume is lower than the standard volume, the amount of water discharged from the dams is reduced in stages in accordance with the advice of relevant agencies.

- Ordinary season: water supply reductions are flexibly implemented to supply water through conjunctive dam operation in the river basin based on the capacity of each dam.
- Shortage for Water Supply: If conjunctive dam operation is unable to satisfy the water demand, dam water supply is reduced in order to prevent the interruption of daily or industrial water supply in the future.

1. The design flood is the engineering design standard for the river facilities considering the characteristics of the flood, frequency of occurrence of flood, potential damage due to flood, and economic factors.

In Korea, monthly operation plans for multi-purpose dams are confirmed by the prior approval of a joint committee called the 'Collaborative Operation Committee with Dams and Weirs'.

Drought response stages and major action plan in each stage are as follows:

1. Notice stage: adjustment of water supply to contracted quantity, real-time monitoring and progress sharing with relevant agencies.
2. Caution stage: reduction of river maintenance water, support water supply to the public such as bottled water and campaign of water saving by media
3. Alert stage: Reduction of irrigational water and structural countermeasures such as development of underground well, leakage improvement
4. Serious stage: restrict domestic and industrial water supply and develop sustainable countermeasures including building new dams and diversification of water sources.

- Applied Model : SAMS(Stochastic Analysis Modeling and Simulation) 2007
- Extension of inflow maintaining statistical characteristics using the observed data

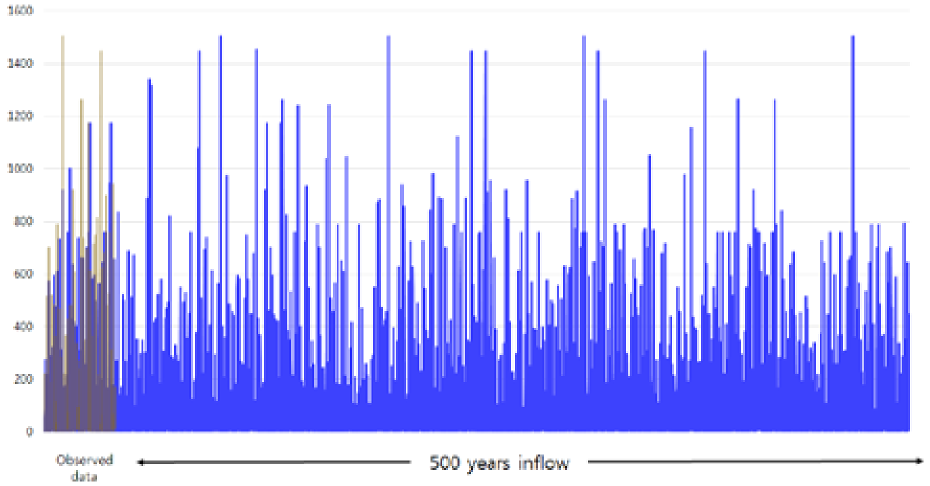


Figure 10. Estimation of long-term inflow for 500 years by stochastic analysis
Source : K-water

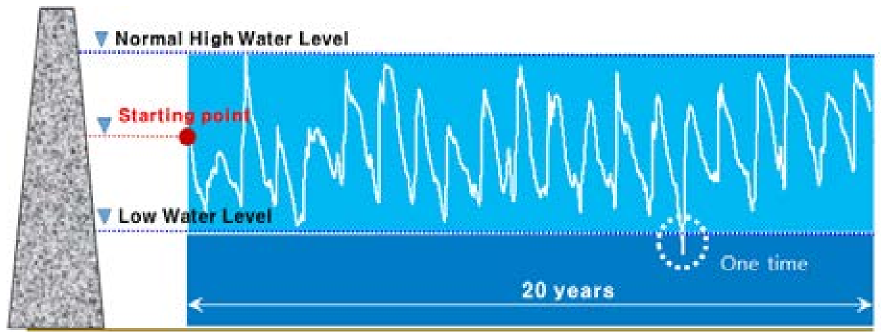


Figure 11. 95% safety for water supply (1 year shortage out of 20 years)
Source : K-water

The standard storage volume is the minimum volume required to supply water in accordance with the drought stage, as estimated by trial and error methods considering safety for water supply (95%, 475yrs out of 500yrs).

CASE STUDIES
K-WATER'S INTEGRATED WATER RESOURCES MANAGEMENT SYSTEM

If a dam storage approaches the standard storage volume, the reduction of water supply will be implemented in accordance with the drought response guideline after approval of 'Collaborative operation committee with dams and weirs'. The order of reduction is primarily river maintenance, irrigational, domestic and industrial water as shown in Table 8.

Table 8. Required reduction in stages

Stage	Required Reductions
Notice	Surplus water (only contracted water quantity provides)
Caution	River maintenance water
Alert	River maintenance water + Irrigation water
Serious	River maintenance water + Irrigation water + (Domestic & Industrial water) ratio

If the water supply reaches the caution stage during the reduction process, the reduction will continue until it exceeds the normal stage (with exceptions at the request of the relevant agencies). If the dam storage exceeds the normal stage, the water supply should be recovered up to the contracted water quantity volume in consultation with the relevant organisations.

3.1.3 Technical Factors

The development of the IWRM System

Korea relies heavily on the supply of surface water by rivers and dams for 90% of the total annual water resources supply (approximately 33.7 billion ㎥). During most of the year (except during the flood season), a number of major rivers, including the Han River, are controlled by the supply volume of multipurpose reservoir groups located in the upper middle area of the basin. Therefore, in order to protect the local people from drought and flood disasters through more efficient water resource management, it is essential to construct a multi-purpose dam with a reservoir and a scientific river operation system in a watershed or a metropolitan watershed which links the rivers.

K-water has constructed this system in three steps with the aim of implementing integrated water resource management technology in rivers for the purpose of increasing water quantity and water quality at the same time.

1. Phase 1 (2001 - 2004): Development of the 'real-time watershed management system' - a database-based modularised analysis system consisting of simulation models of reservoir groups and watershed runoff, and Integrated Water Resources Management System (IWRMS).

2. Phase 2 (2004 - 2007): A Geographic information system (GIS) and a real-time Reservoir Turbidity Monitoring and Modeling System (RTMMS) implemented in parallel with the calibration of the elemental technologies developed in Phase 1 by applying the Geum River and Nakdong River basins.

3. Phase 3 (2007 - 2011): Research and Business Development (R&BD) level technology developed through generalisation and commercialisation of various technologies and systems for analysing water quality and to improve the water resource management capacity of dams and rivers connected in a watershed with consideration for water ecology and ecosystems.

Box 5. The system construction phases

Phase 1) Build infrastructure for water management technology

To acquire stable data such as hydrological data generation, processing, transmission, etc., it is necessary to replace old sensors such as water gauge and rain gauge with the latest products and install power and lightning protection facilities, data acquisition, storage and transmission functions such as the Smart-TM Configuration. The Smart-TM system also has a single structure for small dams and rivers, and redundancy for large and medium-sized dams and rivers, depending on the dam and river size.

*Smart-TM (Tele-meter) is an intelligent hydrologic observation system for installing power and lightning protection facilities and data acquisition, storage and transmission functions for stable production data by replacing sensors such as water gauge and rain gauge Configuration

Phase 2) Construction of real-time hydrological information and image system

Establishment of an integrated database of dam hydrological data, production of data through a system that includes data verification and correction, real-time hydrological information (RHDAPS) based on user-customised Graphic User Interface (GUI), and real-time video system to support decision making

Phase 3) Building a decision-making system

Water management technologies such as flood analysis, water supply, drought information, safety management shall be constructed considering the situation of water use and water control by country. In addition, flood analysis model and early flood warning system through integrated Database analysis shall be established and monitoring and warning criteria are settled by visualisation of expected water level and flood range in conjunction with GIS

Phase 4) Integrated Water Management Center with ICT

The Integrated Water Management Center is designed to integrate the collected data and to respond quickly to major situations through real-time hydrological information such as hydrological data and CCTV images and decision-making systems. In case of Generation Integrated Operation System (GIOS), independent and integrated according to the level of independent operation and communication infrastructure of plant facilities are as follows.

- Independent configuration: It is adopted when independent operation is advantageous, or when there is a lack of communication infrastructure.
- Partially integrated configuration: if several power plants are operated in one area, partial integration in the area or center will be implemented.
- Integrated configuration: Considering the integrated operation of power plant operation from the remote center in the central center, the national communication infrastructure should be good and the operator's skill level should be high.

3.2 Outputs

3.2.1 K-HIT, K-water Hydro Intelligent Toolkit

The main aim of this project was to maximise efficient water supply and to minimise flood disasters. To achieve this we developed the K-water Hydro Intelligent Toolkit (K-HIT), an integrated water management system based on Information and Communication Technology (ICT). The multiple functions of this system can be operated by anyone, anywhere, at anytime. This system is also sharable and smart-phone compatible. K-HIT consists of 5 sub-systems including 1) real-time hydrological data acquisition, 2) precipitation forecasting, 3) flood analysis, 4) reservoir water supply, and 5) hydropower generation.

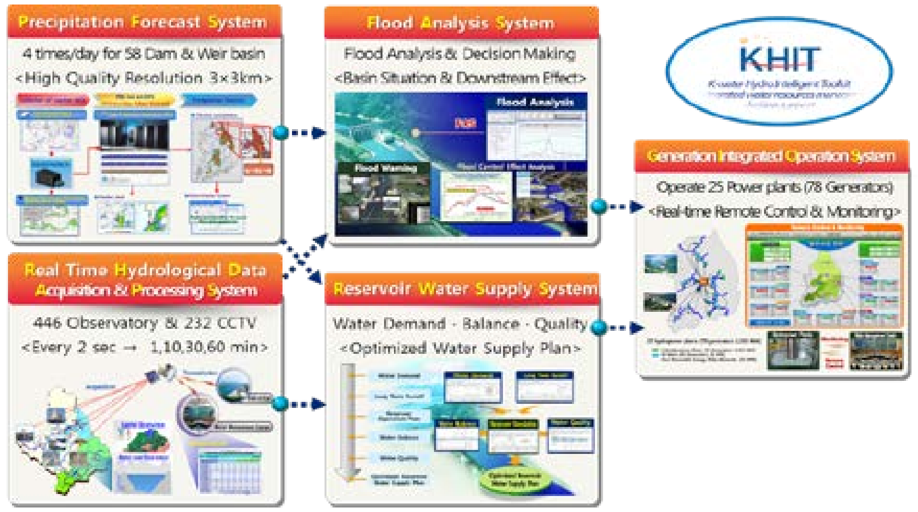


Figure 12. K-water's water resources management procedures based on K-HIT
Source : K-water

The K-HIT procedures are applied in several steps to operate our dams, weirs and hydro power plants. First we gather and process the data from our observatories using the Real-time Hydrological Data Acquisition and Processing System (RHDAPS). Then we forecast the rainfall for dam and weir basins using the Precipitation Forecasting System (PFS). These observed and forecasted data are used for flood control and water supply. Then, based on the results of the Flood Analysis System (FAS) and the Reservoir Water Supply System (RWSS), we decide the volume of dam discharge, the gate opening time, and withdrawal of the water from dams. Finally, we use the Generation Integrated Operation System (GIOS) to efficiently operate the hydropower generation facilities to consider the discharge from the dams and weirs into our water management operation.

3.2.2 Precipitation Forecasting System (PFS)

The Precipitation Forecasting System (PFS) was developed by K-water to forecast the average precipitation levels of the dam and weir basins. The Korea Meteorological Administration (KMA) and the National Oceanic and Atmospheric Administration (U.S.) (NOAA) provide the initial data including temperature, humidity and wind speed and these data are then used as input data for K-PPM, a 3km×3km high spatial resolution forecasting model.

PFS provides precipitation forecast information for the following five days, updated four times a day, using a HPC (High Performance Computer) and makes various weather maps including rainfall prediction maps. In addition, it analyses the predicted rainfall for each basin with the resulting data applied to the flood analysis model.

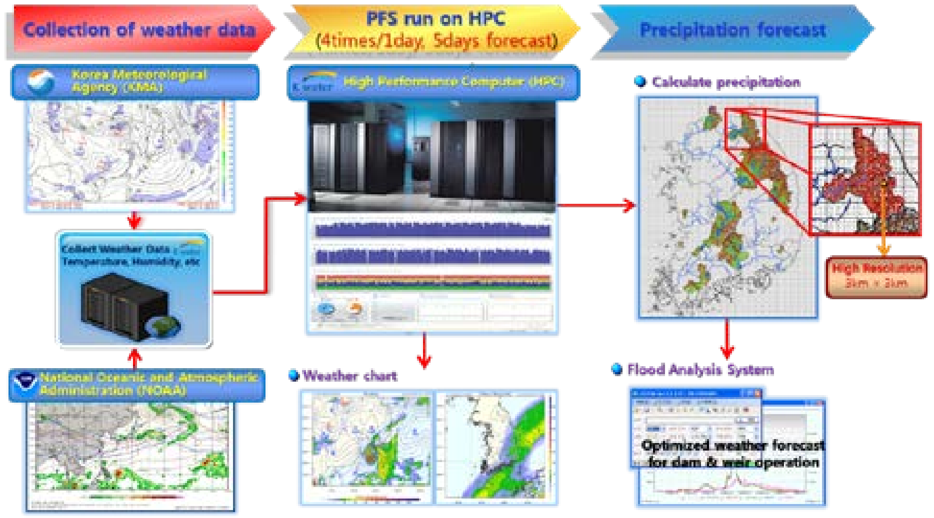


Figure 13. Precipitation Forecasting System (PFS) for Dam and Weir Operation
Source : K-water

3.2.3 Real-time Hydrological Data Acquisition and Processing System (RHDAPS)

All data related to dam operations and precipitation, water level and hydraulics are saved in the Database server at the Water Management Center and are managed by the Real-time Hydrological Data Acquisition and Processing System (RHDAPS), as shown in Figure 15. Real-time hydrological data such as rainfall, water level, inflow and outflow is collected every two seconds from over four hundred observatories. RHDAPS then produces user-friendly operational data in one, 10 and 30 minute intervals. As such, this system enables our operators to be familiar with key data on inflow, outflow and the operational status of the hydro-structures. To Increase the safety and reliability of data gathering, a dual communication network has been established using both satellite and Code Division Multiple Access[2] (CDMA).

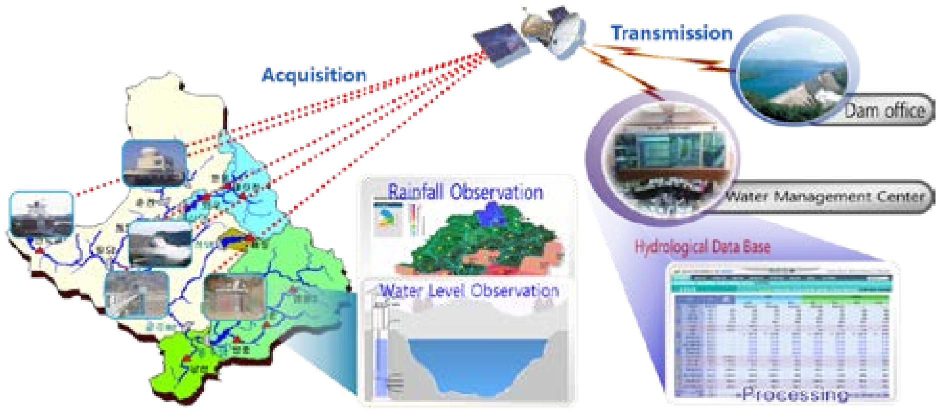


Figure 14. Real-time Hydrological Data Acquisition and Processing System (RHDAPS)
Source : K-water

3.2.4 Flood Analysis System (FAS)

K-water built the Flood Analysis System (FAS), for flood control and dam and weir operation. FAS performs flood analyses using rainfall forecasting data provided by PFS and hydrological information obtained through RHDAPS. As the first step, the system decides the operation methods for each reservoir through rainfall-runoff analysis using storage function and hydrological channel tracking. Next, PFS operates a joint operation model for the reservoir system to prevent flood damages by minimising peak flow downstream. At this time, discharge is decided upon using optimisation techniques. Simulations are preformed to determine the optimum discharge plan to be performed with consideration to the field site constraints. After this simulation, the discharge plan is revised and the hydraulic model is operated by applying the reservoir operation plan and tide level. After the assessment on whether or not the flooding of rivers will occur, a final discharge decision is made. Through these processes, an optimal release plan is realised.

2. CDMA is an example of multiple access, where several transmitters can send information simultaneously over a single communication channel. It is used as the access method in many mobile phone standards.

After determining the optimal release schedule, the dam's discharge schedule is disseminated to the local government, broad casting companies and people who live in the downstream area of the dam at least three hours before the gates are opened. After completing the flood control measures, we also evaluate and communicate the result of the release plan to make people aware of the positive effects of the dam operation.

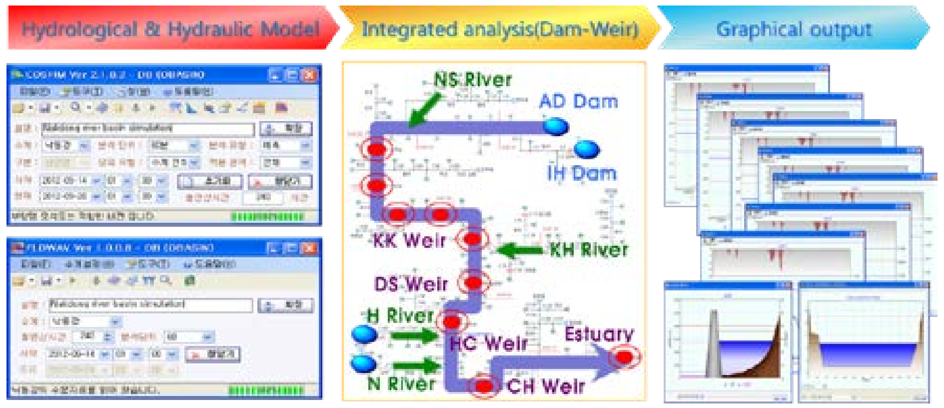


Figure 15. Flood Analysis System (FAS)
Source : K-water

The rainfall-runoff simulation in FAS is applied to the storage function model, which is a non-linear and concentrated model. A one-dimensional numerical model considering dynamic waves is also applied to the hydraulic analyses in FAS. Using these models we are able to operate a detailed simulation of dam-weir coordinated operations.

Box 6. Establishment of integrated flood management system for municipalities

Due to the warming of the Korean peninsula, precipitation and stormy days (more than 80mm / day) are continuously increasing. With 85% of natural disaster damage caused by floods, small rivers are the most impacted by the damage. Between 2007 and 2011, 98.7% of flood damages occurred in small, local rivers.

TABLE 9. Flood Disaster Status
Unit: KRW million (Divide by 1000 for approx. value in USD)

Rivers	Total	2007	2008	2009	2010	2011
National rivers	5,439 (1.3%)			962		4,477
Local rivers	230,172 (53.8%)	26,435	5,274	49,667	32,260	116,536
Small rivers	192,169 (44.9%)	24,480	9,120	43,109	27,290	87,810
Total	427,780	51,275	14,394	93,738	59,550	208,823

Source: Problems and Improvement Tasks of River Disaster Management Project ('12 .8, National Assembly Budget Policy Department)

The Korean government's preventive investment has increased rapidly to the level of developed countries, but the safety of individual residents is still insufficient. Between 2008 and 2012, the average disaster prevention investment ratio compared to the government budget of Korea was 2.0% (greater than that of Japan at 1.7%). However, the preliminary response to the safety measure of the individual was less than 40.9% (2014, NEMA). In particular, municipalities only invest 90 million won (USD 82 thousand) annually in order to establish a preemptive disaster recovery system.

In Korea, the management laws and administrative departments of national, provincial, and small basins are very diverse, resulting in inefficiency and difficulties to implement integrated water management. While the proportion of local rivers (49%) managed by local governments is lower than that of national rivers (81%), there is a lack of national investment. Developed countries recognise that there is a limit to structural measures when coping with localised floods, and so are changing the paradigm of flood disaster management by implementing unstructured measures. It is therefore essential to prepare a preventative flood response system by using science and technology since current flood management is predominately focused on the recovery after the flood damages occur, instead of proactive measures to prevent the damage in the first place.

Flood integration management project for local governments

The purpose of this project is to build a system that can optimise the best decision making alternatives by observing and analysing flood information in real-time, while considering the characteristics of local governments. As of 2017, the project has been implemented in five municipalities with 27 additional municipalities currently in the process of implementation.

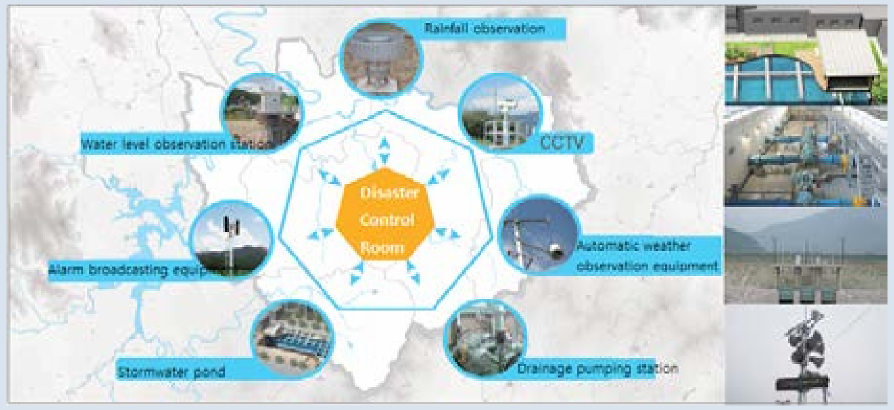


FIGURE 16. Integrated flood management system concept (Source : K-water)

1. Real-time situation monitoring and remote control (water level, rainfall, CCTV) and remote control of repair facilities (drainage pumping station, water gate and storm water storage).

2. Link with relevant organizational data
K-water, Flood Control Office, Meteorological Agency, and other local governments to manage floods including the upstream and downstream of the jurisdiction

3. Establish flood analysis and response standards
Prevent flood damage by establishing flood countermeasures optimised for small and medium streams by using past weather and hydrological data to conduct flood analysis

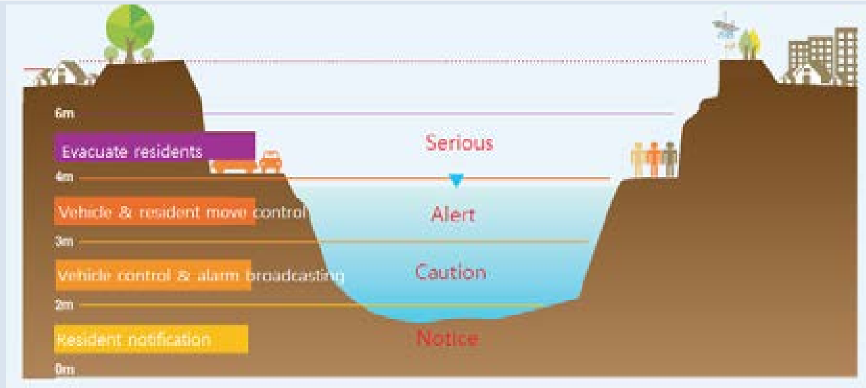


FIGURE 17. Establishing flood response standards (Source : K-water)

K-water has concluded a contract to transfer accumulated flood management technology to local governments, establishing customised flood disaster monitoring systems (diagnosis and construction of flood disaster monitoring facilities, and integrated monitoring systems) for disasters and damage patterns in basins.

3.2.5 Reservoir Water Supply System (RWSS)

Water management during the dry season is based on a system for stable water supply during an unexpected drought.

The Reservoir Water Supply System (RWSS) was developed to make optimal water supply plans from reservoirs considering water demand, water balance and water quality. First, long-term rainfall-runoff is analysed for the entire basin, including the consideration of long-term predicted rainfall. Then, medium- and long-term operation plans are made based on analysed runoff situations and water demand. With this operation plan, water quality in rivers and weirs is examined and if it does not meet the criteria, the operation plan is re-produced. Once the water quality meets the criteria, the plan is given to the joint operation council after consultation with interagency organisations. The council then comes to a decision based on the consideration of general water resources usage in entire basins and operation situations, and the final operation plan on water resources facilities for stable water supply is completed. For reservoirs, the operating plan by RWSS is checked by water level standards. Guidelines are set in advance for unexpected severe droughts, with regular severe droughts anticipated every 20 years.

By applying the 'sequent peak method' (a method used to determine the reservoir capacity required to meet demand over a given period) monthly water level guidelines are calculated to supply water stably taking into consideration the design drought inflow (expected inflow in drought). If water levels in the guideline are higher than the restricted water levels of reservoirs, inflow and water supply resume.

Figure 18. Reservoir Water Supply System (RWSS)
(Source : K-water)

3.2.6 GIOS, Generation Integrated Operation System

K-water developed Generation Integrated Operation System (GIOS), to enhance competitiveness in the electric power market in 2005. Using GIOS 25 hydropower plants (and 78 generators) are remotely operated and monitored from the Water Management Center on a real-time basis. While hydroelectric energy is small in regards to the total amount, it contributes to the stable electricity supply since it plays a pivotal role when managing peak demand situations. In peak demand, the GIOS automatically reacts to ensure energy demands using hydropower. To ensure the system is protected against breakdown or cyber terrorism, GIOS has a failover function and security system, alongside dual servers and networks to ensure continuous service and an anti-virus program and surveillance cameras for system security.

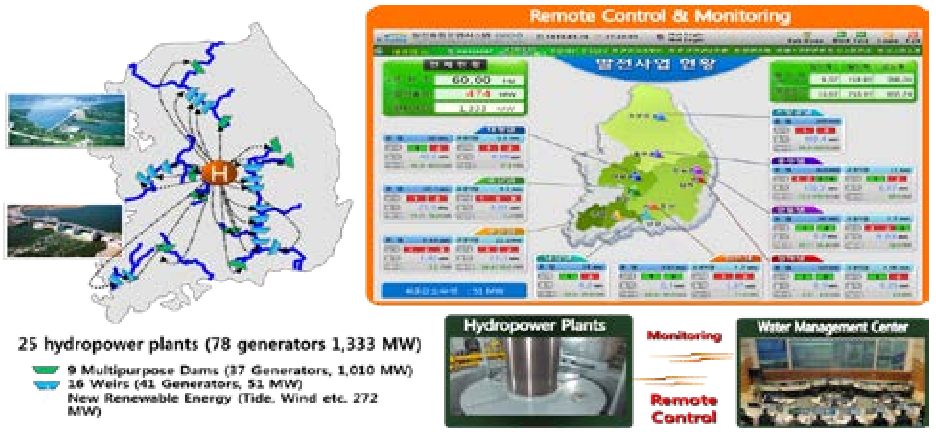


Figure 19. Generation Integrated Operation System (GIOS)
(Source : K-water)

4 Outcomes & Impact

4.1 Operation of dams against floods

4.1.1 Flood control in 2012 and 2013

Due to insufficient precipitation in June 2012, the rainy season started later than usual (July instead of June) and it finished earlier than usual. After the rainy season ended, precipitation was significantly higher than usual due to the passing of continuous troughs of low pressure and three consecutive typhoons, which occurred for the first time in meteorological observation history. Accumulated precipitation nationwide in multipurpose dam basins in 2012 was 1,402mm, approximately 110% the annual average, 967mm of which occurred during the rainy season.

Due to the close cooperation system between the upstream and downstream facilities, K-water only needed to release 29% of the total inflow through the floodgates during this period, which played a major role in the reduction of flood damages. In other words, K-water stored most of the inflow in dams and only released water when the flood discharge of downstream decreased, so the water level at the main point downstream decreased down to the required maximum of 5.1m.

Table 10. Flood control effects in 2012

Main stations		Without dam		With dam		Reduction effect	
		Flood (m^3/sec)	Water level (EL.m)	Flood (m^3/sec)	Water level (EL.m)	Flood (m^3/sec)	Water level (EL.m)
Han River	Yeoju	9,075	35.7	6,305	34.4	2,770	1.3
Nakdong River	Jindong	20,350	14.3	13,230	11.3	7,120	3.0
Geum River	Geumnam	6,374	18.0	1,851	12.9	4,523	5.1
Seomjin River	Gurye	3,304	5.3	1,484	3.7	1,550	1.6

Source : K-water

Overall, K-water minimised the flood damages through the use of scientific and effective dam operation, storing 0.6 million ㎥ of water during the rainy season and by discharging 0.8million ㎥ of the total inflow (1.4million ㎥). Discharge (excluding the amount required for water supply, instream maintenance and irrigation) in this period was approximately 38% of the total discharge and 23% of the total inflow. This approach contributed to ensuring stable flood control as well as securing the storage water needed for supplying water during the dry season and for improving the quality of the water quality supplied.

In 2013, despite only 80-90% of the annual average precipitation occurring in most basins, (with the exception of the Han River basin), the Geum River basin secured the average annual level of water storage, with other basins securing more than the average, due to K-water's previous efforts to secure additional water in preparation for insufficient rain before the rainy season. As a result, K-water secured 119% of the average water storage and 105% of the goal at the end of rainy season. In addition these efforts securing water for dry seasons, by storing water prior to the rainy season K-water also decreased the water level of each river by 3.2m in the Han River, 2.1m in the Nakdong River, 1.2m in the Geum River and Seomjin River as shown in Table 11, reducing the water discharge during the rainy season and thereby reducing the potential for flooding.

Table 11. Dam flood control effects

River systems	Rainfall event	Precipitation(mm)	Flood control effect(m)
Han River	12th~17th Jul.	128	3.2
Nakdong River	2nd~8th Jul.	137	2.1
Geum River		90	1.2
Seomjin River		225	1.2
Yeoungsan River		252	Dam does not exist

Source : K-water

Prevention of drought damages

Water reservoirs provide a stable water supply by setting the monthly operation level of the dam water before the rainy season (end of June) against the backdrop that severe droughts occur on average every 20 years and climate change could increase the frequency.

The method of operating the dams' water supply has shifted from determining the discharge amount for each individual dam separately, to considering the hydrological situation of the upstream dams and the water demand required when determining discharge volumes. To this end, a 'real-time water management system' was constructed to take into consideration the hydrological situation of the water system, the reservoir water volume, the inflow and outflow status, the power system condition and water quality and demand. The operating system includes a watershed analysis model, a river water quality prediction model, and an optimal operation model, so that runoff analysis and reservoir operations are systematically carried out.

Existing flood-related dam operations were initially focused on flood control and securing control capacity and would manage this by emptying the reservoir completely and gradually recovering the water level in the latter half of the rainy season. This approach can have an impact on the quality of life of the inhabitants around the dams, and the ecosystems within the basin areas. Therefore, the focus for dam operations now includes social and environmental considerations to ensure the increase in quality of life and the preservation of ecosystems.

As the rivers, and the factors impacting them (such as green algae) are all highly connected, an integrated approach is needed to operate the dams as weirs in order to preemptively cope with increased drought and the occurrence of green algae in the summer months due to the changing climate.

For this reason, the regulations for dam operation were improved as follows. First, by setting the target level of the dam water to ensure dam stability and downstream flood control is not affected in the first half of the flood season (at the end of July), it becomes possible to increase the water storage capacity. In the latter half of the rainy season, when flood control is the highest priority, additional water storage can be ensured by setting a stable flood control level (in relation to the flood level limit) through power generation discharge without discharging flood water. This ensures that each dam is closely connected to other dams, allowing integrated water management in the basin while also ensuring adequate water supply and water quality throughout the year.

In July 2012, there was a severe drought in the central region of Korea, the most severe in 104 years. K-water followed the operating procedure for drought in advance with the rainfall and runoff forecasting provided by PFS and RWSS. This enabled us to plan the reservoir operation for the drought and to supply 11 billion ㎥ of water from multipurpose dams, 5% more than we would have been able to had we not followed this procedure.

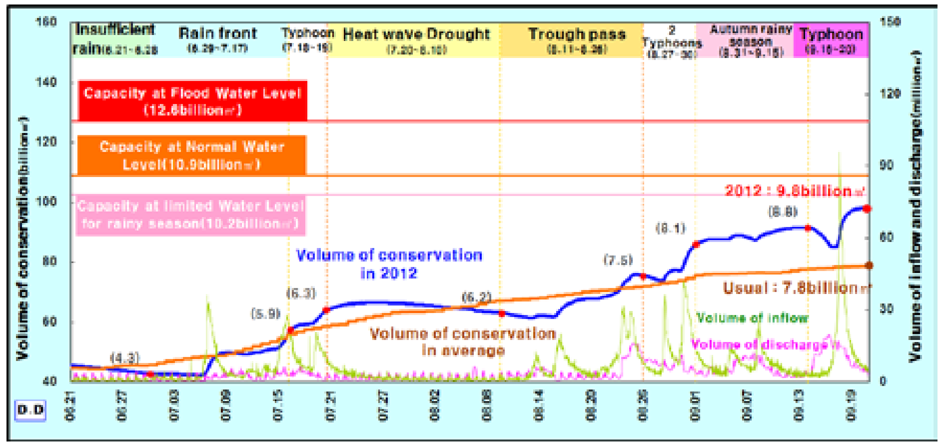
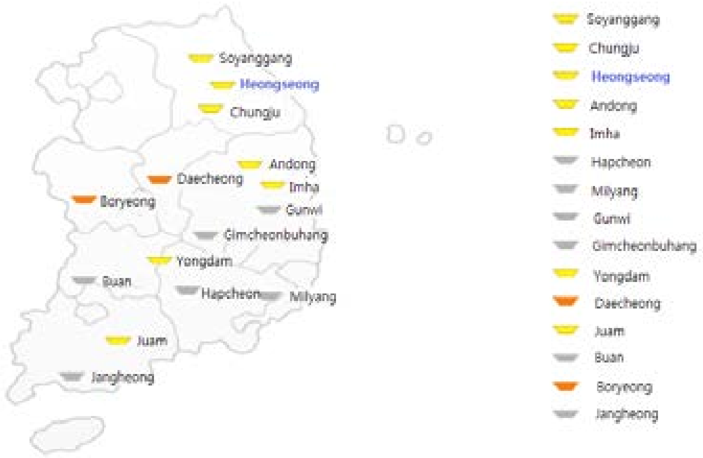


Figure 21. Status of volume conservation in 2012
(Source : K-water)

A total of 8.6 million ㎥ water was supplied additionally to drought prone areas in advance for the prevention of drought damages, with the flexible operation of the weirs allowing stable intakes despite of the severe drought conditions. We also supplied 2.7 million ㎥ of emergency water to 29 municipals by way of waterworks. Moreover, K-water played a key role in water governance by hosting periodic meetings with related organisations and water users. With these efforts, there were no damages despite the severity of the drought.

In 2015, rainfall and water levels of major dams in Korea marked the lowest record in history, and has since been described as the record-breaking drought. While a 20-year frequency drought inflow has traditionally been used to design the dam storage volume for water supply, in 2015 most inflow into the dams was less than the 20-year frequency drought inflow, officially classifying it as a natural disaster. Continuous drought conditions since 2014 have threatened normal dam operations.

In order to efficiently cope with the drought, water supply adjustment criteria for times of drought were established by K-water.



Stage		Water Supply by each stage
	Normal	Supply more than actual demand
	Interest	Supply actual demand
	Caution	Reduce instream flow
	Alert	Reduce instream flow, agricultural water
	Serious	Reduce instream flow, agricultural water, domestic & industrial water

Heongseong dam	Reserved water (million m3)	Stage	Standard reserved water for each stage				
			Interest	Caution	Alert	Serious	Back to normal
2016-03-08	27.645		28.4	26.7	16.5	16.5	31.9

Figure 22. Example of real-time drought information on K-water's homepage. Top) Drought level of multi-purpose dams; Bottom) Water supply adjustment plan according to the drought stage
Source : K-water

There are four uses of water supply from a multi-purposed dam, 1) domestic, 2) industrial, 3) irrigational, and 4) instream flow, in order of priority. K-water made an effort to preferentially secure the domestic, industrial and irrigational water by reducing instream flow as the first three directly relate to the economy and the public daily life. In order to increase public awareness of the drought, real-time drought situations for each K-water dam are presented on K-water's website (see Figure 22).

Despite an unprecedented extreme drought spreading across the country, K-water has been able to stably supply water to the public through the use of comprehensive countermeasures. If K-water had hesitated to carry out these anticipatory actions, interruption of water supply would have likely occurred. With anticipatory and active actions against drought, an additional storage volume (2.4×10^9 m^3) was secured among nine dams and drought damage was mitigated.

4.1.2 Improvement of water quality and efficiency

Water quality improvement

Improvement of water quality by way of water discharges in Korea first started in 1991 due to a phenol accident. In March 1991, the Nakdong River Gumi Industrial Complex was flooded with phenol from the Nakdong River to the Dasa Water Supply Plant in the Daegu Metropolitan City. As a result, approximately 7 million m^3 of water from Andong Dam was discharged over four days to improve the river water quality. In the case of the phenol spill, Gamcheon, Andong Dam, Imha Dam and Hapcheon Dam were operated in conjunction with the discharge of 26 million tons. This was seen again in 2011 and 2012 when approximately 185 million tons of water was discharged from the Soyanggang Dam and Chungju Dam to improve water quality in Paldang Lake.

Since the Four Rivers Restoration Project (December 2008 to April 2012), there has been a need for a more sophisticated water quality management response system due to changes in the physical environment of the rivers and the water management environment due to the introduction of new river facilities. Public interest in water quality and aquatic ecosystems also continues to grow due to algal blooms and has become a social issue.

In an effort to prevent algal blooms from worsening, K-water opened the gates of the weirs and discharged river water simultaneously or sequentially where the green algae had generated. It should be noted that these operations were carried out by considering the water supply capacity and discharge amount of the dam located in the upstream.

As it was found that the increase of discharge through dam-linkage operation is effective for water quality improvement, we had planned for the scientific water management system of K-HIT to examine the water quantity of dams and weirs, to establish a linkage management system between dam-weir, weir-weir and dam-dam to secure an additional 98 million tons of water to be supplied for the improvement of water quality, resulting in Chl-a reduction of up to 25%.

When water is abundant in the rivers, dam and reservoir water is discharged (every 1 - 5 days) for the purpose of reducing green algae, and the water level of the weirs is maintained (with the water level not affecting the surrounding ground water), it is predicted that the cyanobacteria will decrease by 22-36% in the Nakdong River, by 21-23% in the Yeoungsan River and in case of the Nakdong River, the number of days in which green algae occur will be decreased to a quarter (average 3.8 → 1.0 day) and the number of days exceeding the alert level (more than 10,000 cells / mL) will also decrease slightly 51 → 44 days)[3].

Table 12. Example of dam-weir linked operation against green algae

Time	Reason for Increase Discharge	Amount to Increase
2013.7.19	Nakdong River, green algae	Sangju Weir, Nakdan Weir 2.9 million m^3
2013.7.25	Nakdong River, green algae	Sangju Weir, Nakdan Weir, Gumi Weir 17.1 million m^3
2013.8.2~4	Haman Weir, Algae alert stage	Namgang dam 10 million m^3, Nakdong River 8 weirs 9 million m^3
2013.9.10.~13	Haman Weir, Algae alert stage	Namgang dam 8 million m^3, Haman weir 15 million m^3
2013.9.13~15	Haman Weir, Water quality forecast, alert stage	Dalseong Weir, Changnyeong Weir, Haman Weir 25 million m^3
2014.6.28	Haman Weir, Algae alert stage Changnyeong Weir, Water quality forecast, alert stage	Gumi Weir, Chilgok Weir 11 million m^3

Source : K-water

4.1.3 Improvement in efficiency in Management

By adopting a system such as K-HIT, an increase in efficiency is also gained as dams and weirs can be operated with fewer people. For example, the hydropower plants are now operated by 1/5th of staff previously required. This result can be see across the whole operation of the dams and weirs.

3. Announcement of the result of the research service "Operation plan of dam- and weir connection", Ministry of Environment Press release

4.2 Link with Sustainable Development Goals

The ultimate goal of Smart Water Management is to achieve sustainable development. This case is mainly linked to SDG 6 and SDG 11 to prevent disasters such as floods and to secure water in case of droughts systematically through the integrated management of dams and weirs in rivers. SDG 6 (to ensure the availability and sustainable management of water and sanitation for all) relates to securing the availability and sustainability of water resources through water management, and SDG 11 (to make cities and human settlements inclusive, safe, resilient and sustainable are safe and sustainable) is associated with water-related disaster prevention.

Table 13. A list of the SDGs and their specific targets that relate to K-HIT

Sustainable Development Goals and Targets	
SDG 4: Increase opportunities and job creation **Ensure inclusive and equitable education and promote lifelong learning opportunities for all**	
4.4	By 2030, substantially increase the number of youth and adults who have relevant skills, including technical and vocational skills, for employment, decent jobs and entrepreneurship
SDG 6: Clean water and sanitation **Ensure availability and sustainable management of water and sanitation for all**	
6.1	By 2030, achieve universal and equitable access to safe and affordable drinking water for all
6.4	By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity
SDG 11: Resilient and sustainable cities **Make cities and human settlements inclusive, safe, resilient and sustainable**	
11.5	By 2030, significantly reduce the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations
SDG 12: Sustainable consumption **Ensure sustainable consumption and production patterns**	
12.2	By 2030, achieve the sustainable management and efficient use of natural resources

Specifically, if we look at the goals for SDG implementation, Target 6.1 of SDG 6 ensures a universal and equitable approach to safe and available drinking water, and is an indicator for measuring the proportion of the population receiving safe and controlled drinking water. Target 6.4 also aims to reduce the number of people suffering from water shortages by providing sustainable water intake and water in response to water shortages. In this case, the percentage of safe drinking water supplied through K-HIT was not confirmed. However, in the case of severe drought in 2012 and 2015, case studies showed that the dams and the weirs were operated in conjunction to supply water to a province that was experiencing water shortage, thus contributing to this goal.

This case also relates to the integrated management of Target 6.5 of SDG 6, which relates to Integrated Water Resource Management (IWRM). IWRM is a process that promotes the coordinated development and management of water, land and related resources, in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems (2000, GWP). Integrated water management therefore involves integrating upstream and downstream interests that are influenced by flood control as well as the integration of water quality and water quantity. Thus, as in this case, integrating the management of quantity and quality of rivers in basins can be seen as part of integrated management. Target 6.5 presents the realisation of integrated water management and the degree of integrated water resources management implementation as an indicator.

The goal of SDG 11 is to make cities and human habitats inclusive, safe, resilient and sustainable. In this regard, Target 11.5 aims to reduce the number of casualties and direct economic losses due to water disaster. More specifically, Indicator 11.5.1 measures the number of casualties, missing persons and affected persons per 100,000 people. Indicator 11.5.2 also indicates economic losses due to disasters (damage to critical infrastructure, number of disruptions to basic services). The flood mitigation action from 2012 and 2013 are examples of times when the loss of life or property due to floods were prevented.

In this way, K-HIT contributes to the achievement of sustainable development goals by efficiently supplying water to drought areas by applying ICT to water management and minimizing damages caused by water disasters in preparation for floods.

5. Lessons Learned

The role of the public sector is important in implementing SWM
Actual data and new technology are the most basic elements for realising integrated water management, and it is possible to design short- and medium-term plans based on information on the water management situations in the field. Even though these actual data and new technologies cannot be completed in a short period of time, their importance and develop should be recognised through steady investment.

K-HIT is a system for realising integrated water management, which requires long-term investment and budgeting. While private investment could be a possibility for SWM implementation, the OECD (2011) notes that market mechanisms alone will not provide an appropriate amount of support for eco-innovation, such as SWM technology, at the right time. This is because the private sector would be unable to reap all of the benefits of their innovations, and environmental benefits may not always be appropriately valued. As this is the case policy interventions and public sector support are required[4].

As the profit from K-HIT has a public nature, due to providing flood prevention and the reliable supply of water, it is also in the interest of the public sector to support these innovations. This is beneficial, however this public nature also limits the private sectors role in the construction of the system, which can be limiting for expanding and replicating SWM technologies.

Step-by-step system construction is more financially efficient and worth considering based on the economic situations of each country
Since a large amount of money is needed to build an integrated water management system, it is necessary to build a system step-by-step in order to apply the integrated water management system after each improvement of the existing water management system in consideration of the economic conditions and budget of the relevant country. As a result of this K-water has developed a successful approach to implementing the system construction in several phases (see Box 5). SWM also relies on extensive coverage of ICT and the capacity to maintain and operate the system. A recent OECD report (2017) confirms that while this may be possible in developed countries such as Korea, this may create difficulties in developing countries where capacity and availability to technology may differ, and therefore when implementing SWM systems in other countries it is important to take into account the social and economic context of each country to ensure its success.

4. OECD (2017), OECD Studies on Water, Enhancing Water Use Efficiency in Korea.

In order to efficiently and effectively cope with the drought collaboratively in an integrated approach, it is also important to establish a step-by-step action plan
Having a shared action plan with easily recognizable criteria for each drought stage provides the relevant stakeholders (including all dam operators) with the tools needed to identify the particular standard water levels for an entire year and also provides a step-by-step water supply adjustment plan according to the drought stage. As a result of this criteria, the speed of the decision making process, such as reducing the water supply, has become much faster, and dam operators can now work together collaboratively to ensure a successful, integrated water management approach.

To prevent the drought getting worse, it is necessary to set up measures appropriate to the characteristics of each basin
Despite of anticipatory actions, various countermeasures were carried out as the drought condition expanded across the whole country and the situation was getting worse. In the Han River basin, which is the main water source of the Seoul metropolitan area, water from a hydropower dam was substituted as a domestic water supply source instead of multipurpose dam water due to the gradual drop of the multipurpose dam's water level. Furthermore, essential water was only provided by joint investigation with the government ministry and relevant local government authorities for actual downstream extraction.

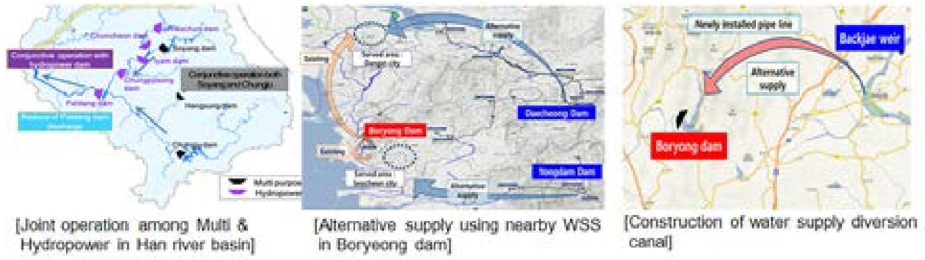


Figure 23. Additional countermeasures during the severe stage of drought
Source : K-water

In the Nakdong and Geum River basins, irrigation water from dams had been supplied based on actual demand since September 2015. In addition, dam water discharges were minimized while maintaining the water level downstream without interruption to the extraction of water by conjunctive operation among dams, weirs and barrage. In the Seomjin River basin, a hydropower dam used to produce power generation by diverting water to another area with high head had changed its release direction to the main stream in order to fill the downstream dam storage volume. In order to prevent water supply stoppage from the dam, various and urgent projects are sometimes required, to prevent the drought from worsening. Despite this, with effective management plans, integrated SWM tools and collaborative stakeholders, these additional measures can be significantly reduced.

Reflecting on the successes and challenges of past, the project can effectively accomplish the integrated approach of SWM technologies
In order to cope with the continual changing water management situation, the flood analysis system was extended from the existing four major rivers to five major rivers including the Yangsan River basin, and the flood analysis points in the existing 124 rivers were expanded to 164. In particular, since K-water committed itself to the integrated operation and management of weirs in 2012, river management is more focused on overall river management in comparison to focusing on dam-oriented operation. In order to improve the accuracy of the water level - flow curves, data were collected in connection with sensors, meters and so on were carried out based on the results of the flow survey team. The system has been improved by reflecting on the performance of the Four Major River Restoration Project (4MRRP) and on the expansion of its function.

6. Conclusions

In Korea, two thirds of the annual rainfall is concentrated in the summer, thus floods are more frequent and efficient water supply is essential to protect and supply water for the growing population and to continue economic development. Therefore, for decades, we have worked on the establishment of facilities including dams and weirs in rivers and the introduction of efficient water management. In recent years, since the frequency of heavy rainfall and drought are increasing due to climate change, the need to effectively manage water resources has increased. To address this, it has become essential to secure the optimal operation of water gates for continuous measurements and analysis of information or rainfall inflow and outflow weather conditions and water quality. In accordance with this need, K-HIT was introduced in 2002, and since then, the system has been upgraded continuously to expand the management of rivers and functions.

K-water's flood control capacity accounts for 95% of the gross domestic flood control capacity or 4.9 billion m^3 a year, with K-water's water supply capacity comprising 66% of the gross domestic water supply capacity or 12.4 billion m^3 a year. Through the introduction of smart water management and the establishment of countermeasures against floods and droughts, we have been able to effectively deal with floods that occurred in 2012, 2013 and 2015. Consequently, the capacity to operate and manage that system effectively determines Korea's resilience to water risks. SWM can enhance that capacity by collecting and sharing real-time data on water use, expected rainfalls and available room in reservoirs. This application enhances K-water's capacity to deliver its mandate on water quantity management and prevention of scarcity and flood risks (OECD, 2017).

In this way, K-HIT has systematically implemented SWM by introducing information and communication technology to flood management, water supply and hydroelectric power generation thus improving the efficiency of water management in the watershed by enhancing decision making capabilities. In addition, we have also been able to improve productivity through efficient power generation operations. Finally, we can increase profits by reducing the staff required to manage the system and by improving efficiency with the centralization of hydrology and power generation controls.

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Appendix

As over 65% of the national territory is mountainous, river gradients are relatively steep.

The topography of Korean mountain ranges show that eastern mountain slopes are sharp whereas western slopes are gentle; rivers along the eastern coast side have short and steep watercourses whereas rivers along the western coast side have long and gradual watercourses

The rainy season in 2013 was the longest rainy season in recorded meteorology observation history. Starting in the middle region of Korea for the first time in 32 years, regional heavy rain occurred several times resulting in large regional deviations.

Average precipitation during the 2013 rainy season was 489mm for all multipurpose dams, which is 107% of the annual average, but the data was biased since it was centered on dams located in a specific river system, namely the Han River. The average precipitation rate in other river systems ranged from 80 to 90% of the average. Especially, average precipitation of water supply dams located in southern areas was only 69% of the annual average.

Most of the 16 multipurpose dams, except for 3 dams, which discharged flood by opening floodgates, were operated centered on securing a reserved amount of water. About 60% of total inflow was discharged and flood control by way of floodgate operation was only 6.6% of the total inflow and 11% of total discharge, as shown in Figure 21.

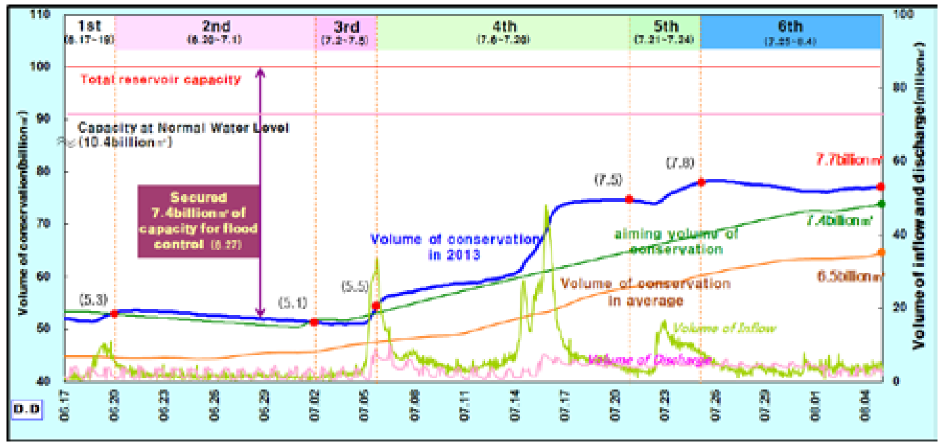


Figure 20. Status of volume conservation in 2013
Source : K-water

We can assess the degree of implementation of IWRM through surveys. Surveys on IWRM are structured in 4 components as follows:

1. Enabling environment: Includes policies, laws, plans and strategies that create an environment for integrated water management.
2. Organisation: Includes the size and role of political, social, economic and administrative bodies that support the realisation of integrated water management.
3. Administrative tools: Tools and activities that enable decision-makers and users to make decisions based on informed and alternative choices
4. Finance: Budget and finance for the development and management of water resources in various sources.

Within each component there are questions with defined response options giving scores of 0-100. Questions scores are aggregated to the component level, and each component score is equally weighted to give an aggregated indicator score of 0-100.

TEXT BOX

Smart Water Management in Azerbaijan: The Jeyranbatan ultra-filtration water purification facility complex

Country: Azerbaijan
City/region where project is based: Baku
Population (of area where the project is based): 561,450
Key organisations /stakeholders involved in the project: "Azersu" Open Joint Stock Company
Authors: Farda Imanov and Rashail Ismayilov
Links: www.azersu.az - www.sukanal.az

Water challenge

There are no natural sources of drinking water in the Absheron peninsula, where the capital of Azebaijan, Baku, is located. To supply this city of more than 2 million people with drinking water, four pipelines lead water into the city from different regions of Azerbaijan. Most of the raw water supply of Baku requires treatment before it can be supplied to end users.

Project approach

To adress this problem, Azersu, the country's water and sanitation company, developed an automated water purification facility. The initial purification of the raw water supplied to the purification facility is carried out in the mechanical filter facility and then water is accumulated in the reservoir.
The water transferred to processing is first treated by 200 micron filters and then filtered into the main purification modules of the facility. The water is cleaned within a total of 20 seconds by passing through special filters of 0.02 microns installed inside the modules.

In order to ensure the continuity of the treatment process in the facility, the filters are washed periodically and cleaned from suspended matters. Filters are cleaned with backwash and chemical dosing pumps. The process is carried out in turns, i.e. while backwash and chemical dosing is carried out in one part of the facility, the water processing continues in other sections. This, in turn, ensures the continuity of the treatment process. The total capacity of the 5280 modules built in the facility is 6.6 cubic meters per second. All treatments are fully automated and regulated within the facility.

Results and next steps

The construction of the Jeyranbatan Ultra-Filtration Water Purification Facility Complex is complete and it is producing high quality water at full volume.

The Jeyranbatan reservoir collects water from the Samur-Absheron channel and transmits it to the treatment plant. Water is mechanically processed without any chemical treatment, its natural mineral content is maintained, and water is cleaned of bacteria, viruses, some unsaturated salts and heavy metals. The water processed in ultrafilters fully meet the drinking water quality standards adopted by the World Health Organization. This facility purified 0.6 km^3 water since it was built in October 2015 and provided clean and safe water for 25 percent of the population (561, 450 people).
The only technical obstacle that remains is that plankton forms in raw water in the Jeyranbatan water reservoir in spring when the water temperature is between 17-22°C. This plankton clogs 200 micron filters, creating the need for additional washing of filters.

In the future, the installation of additional modules, as well as the increase of the processing capacity by 7.5 cubic meters per second can be achieved through introducing an electromechanical system and some additional technical solutions.

SWM solution

The water treated within the facility is fully enclosed and regulated automatically.
The quality of drinking water coming from the filters is controlled in an online mode. For this purpose, special analysis panels (real-time sensors) have been installed so that they transmit water quality parameter signals (2 times every 1 second) directly to the SCADA control room.
On the basis of the experience gained from this project, similar projects are planned to be implemented in other regions of the country.

Case Study of Seosan Smart Water Management

Mr. Sukuk Yi, Dr. Munhyun Ryu, Dr. Jinsuhk Suh, Dr. Shangmoon Kim, Mr. Seokkyu Seo, Mr. Seonghan Kim, K-water (Korea Water Resources Corporation)

Summary

Water management has become increasingly important over the past decades with increase of the natural hazards and disasters caused by climate change, deteriorating water management facilities, and increased water consumption due to population growth and urbanisation in Korea. To solve these water challenges and improve the efficiency of water management, K-water has introduced ICT (Information and Communication Technology) in their water management. Water management using ICT, known as Smart Water Management (SWM), enables sustainable water supply to every citizen by water resource monitoring, problem diagnosis, efficiency improvement and harmonising management.

The Smart Seosan City project started when Seosan city asked for a smart metering system for the Seosan local water supply system as a drought measure in January 2016. Seosan city decided to employ smart metering to the local water system when regional and national drought reaction plans were established according to laws and plans. Before this project, K-water was operating smart metering as a pilot project in the Goryeng area (from January to May 2015) and had consigned Seosan's local water supply. K-water suggested smart metering to Seosan city and the city accepted this suggestion. The main purpose of the project was to construct smart water management systems, which focus on reducing water leakages and consequently improving revenue water ratio by using remote metering, smart meters and Information and Communication Technology. Unlike a human read meter, which relies on a person to manually check the data on a meter on site, these smart meters deliver a user's hourly water usage via digital meter (smart meter) and wireless communication technology (ICT).

Consequently, the project results show 20% improvement in the revenue water ratio and 190,000 m^3 of water per year decrease in leakage. This results in a benefit of USD 590,000 over the next 8 years and the cost benefit is expected to increase. By switching to using remote meters for water use and quality, customers' satisfaction has been improved as it has become possible to handle complaints promptly and also to provide additional water quality management services. Government support played a major role in the implementation of this project, as the planning and execution of the drought policy, existing laws and system helped state and local government and public institutions plan measures systematically and react in a concerted manner. In addition to this, the government budget support for the project was essential in facilitating the project's implementation. Seosan smart water management required early facility investment and operating costs but in the long term, an increase in net profit is expected. As the smart water market is becoming more active with many companies competing, future costs are expected to decrease. Smart metering enables a sustainable water supply by reducing water leakages and saving water and energy. When water supply is reduced or limited by drought or other challenges, new water resource development is needed to supply water stably.

1. Background

Country: Republic of Korea (South Korea)
Population: 51.25 million
City: Seosan City, South Chungcheong Province
Population of Seosan City: 173,715
Climate: Humid continental

1.1 The importance of Water Management

Water management has become an issue of increasing importance over the past decades as a number of factors including climate change induced natural hazards and disasters, deteriorating water management facilities, population growth and megalopolitanisation continue to impact already scarce water sources. This reduced water availability leads to an increase in famine and disease, and creates increased water insecurity and conflict in predominately developing countries. Water insecurity is also felt in the Republic of Korea, where drought caused by the changing climate is causing concerns for water access in many areas.

1.1.1 The changing climate in Korea

As the 5th evaluation report published by the Intergovernmental Panel on Climate Change (IPCC) in 2014 predicted that if the average global temperature increased by 2 degrees increases in coastal flooding would create a risk for food production, species and ecosystem protection, and land loss, it is of great concern that Korea's average temperature has already risen by almost half of this (0.89 degrees) over the past 112 years (1990 to 2012).

In addition to increased temperatures, average annual precipitation over the past three decades has also increased from 1,310mm (in the 1980s) to 1,382mm (since 2000). According to the Representative Concentration Pathways (RCP) 4.5 scenario[1] the Korean peninsula will have a higher annual average precipitation growth rate than the world average, increasing by 10.3% in the mid 21th century (2041-2070) and by 19.6% in the second half of the century (2071-2100). At the same time, great regional deviation is expected.

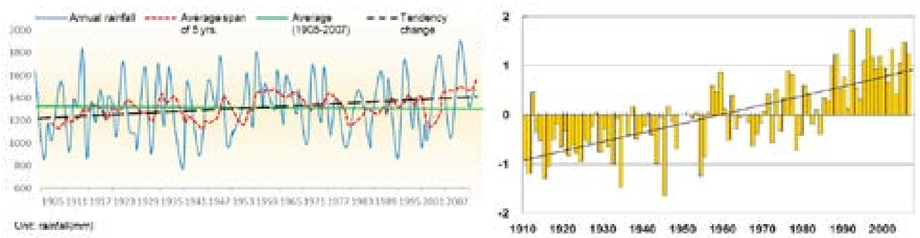


Figure 1. Changes in rainfall and average temperature (6 cities) in Korea (Source: MOLIT (2017) The 4th Long-term Comprehensive Plan for Water Resources (2001-2020), 3rd Revision

1.1.2 Population growth and urbanisation

As the population of Korea has increased from 31.4 million in 1970 to 49.7 million in 2015 (a 58% increase), water shortages already play a major role in Korea. In addition to the rapid population growth rate, a significant increase in both the water supply rate (from 31.2% in 1970 to 98.8% in 2015) and urbanization in Korea over the past 50 years (from 40.7% in 1970 to 82.5% in 2015) has resulted in the strong need to focus on water management in Korea.

1. The Representative Concentration Pathways (RCPs), which IPCC introduced for the 5th Assessment Report, describe four different 21st century pathways of greenhouse gas (GHG) emissions and atmospheric concentrations, air pollutant emissions and land use. RCPs include a stringent mitigation scenario (RCP 2.6), two intermediate scenarios (RCP4.5 and RCP6.0), and one scenario with very high GHG emissions (RCP8.5). RCP4.5 means that the carbon dioxide concentration is 540ppm and the greenhouse gas reduction policy has been realized considerably.

CASE STUDIES
CASE STUDY OF SEOSAN SMART WATER MANAGEMENT

Table 1. Population and urbanization rate in Korea

Year	1970	1975	1980	1990	2000	2010	2015
Population (thousand)	31,435	34,678	37,406	43,390	45,985	47,041	49,705
Urbanization rate (%)	40.7	48.0	56.7	73.8	79.6	81.9	82.5

Source: Statistics Korea, KOSIS (Korea Statistical Information Service)

1.1.3 Deterioration of water management facility

Annual financial loss due to the deterioration of water management facilities and infrastructure in Korea is estimated at USD 500 million dollars (comparable in per capita terms to the 3.4 billion dollars in the United States, with over 6 times Korea's population). As it is has been predicted that deteriorated water management facility replacement and repairs will cost the United States 334.8 billion dollars over the next 20 years (EPA, 2009); Korea is quickly working towards ensuring they do not also face these high long-term costs for deteriorating infrastructure.

1.2 Present conditions of Seosan

1.2.1 General conditions

The geographical scope of this project is Palbong-myun, Seosan city, Korea. Seosan city is located in the Taean peninsula, north-west of Chungchungnam-do on the west coast of Korea (see Figure 2). Mountains such as Mt. Gaya and Mt. Palbong surround it to the north and the south. Its annual average precipitation is 1,285.7mm and annual average temperature is 17.3°C. Seosan city covers an area of 741.21 km^2 and (when including Palbong-myun (51.34km^2); it consists of 1 eup (town), 9 myun (townships) and 5 dong (neighbourhoods). It has a long and complicated coastline and two lakes, Lake Ganwol (2,164 ha) and Lake Bunam (1,021ha), which were created by the Chunsu gulf reclamation project.

The west coast area, including Daesan Seaside Manufacturing Area, is now developing due to a newly constructed west coast highway and active trade with China; Seosan has therefore emerged as a main city of Chungchungnam-do. The local economy is booming due to the newly built manufacturing area, which includes such companies as Daesan petrochemical complex, Seosan Techno Valley and the recent transfer of the head offices of big enterprises such as Hyundai Oil bank, Hanhwa Total and Hyundai Powertech.

Figure 2. Location of targeted area (Palbong-myun, Seosan city (Source: K-water)

1.2.2 Population Growth and Seosan City's Economy

In line with the national population growth rate, the population of Seosan City has increased by 5% in only four years, from 164,345 in 2011 to 175,132 in 2015. The Gross Regional Domestic Product (GRDP) of Seosan City is 51.5396 trillion won (USD 47.7 billion), which is predominately created through the commerce and services industry (69.3% of the workforce), along with mining and manufacturing (30.1% of the workforce). Only 0.4% of the population works in agriculture and fisheries, demonstrating the highly urbanised nature of Seosan city.

1.2.3 Water supply, drainage facility and water source

Since 2006, Seosan City consigned its water facility to K-water and has been receiving 67,200 m^3 of filtered water per day (Statics of waterworks, 2015) from the multiregional water supply of Boryeong Dam, without its own treatment facility. The pipeline of Seosan water supply is 2,041km long and includes 10 distributing reservoirs, 23 booster stations and 22,487 hydrants. In Palbong-myun, the length of the pipeline is 218km and the number of hydrants is 1550. In 2015, Seosan city's water distribution rate was 92% and water consumption per person was 262.5 litres. Respectively, the water distribution rate and water consumption per person in Palbong myun were 97.7% and 191.7 litres. Revenue water ratio of Seosan water supply facility improved dramatically after consignment. Comparing to a rate of 65.3%, before consignment, the revenue water ratio of 2016 had dramatically increased, reaching 82.8%.

Box 1. Water supply system of Korea

In Korea, K-water functions as a wholesaler and supplies multiregional water supply. On the other hand, the local water supply system is supplied by the municipal government, which functions as a retailer. K-water withdraws water from dams and rivers to supply multiregional water supply and industrial waterworks while local government supplies water to residents through its own water source or multiregional water supply. Some of the local water supply system is managed by K-water by consignment[1].

Multiregional water supply

K-water withdraws water from water dams and multipurpose dams, and treats it. It supplies water to local governments and industries. Local governments deliver this water to households. In 2014, K-water operated 35 multiregional water supplies. 60.2% (8,285,000 m^3 per day) of the total capacity (13,860,000m^3per day) was concentrated in metropolitan areas, consuming 52.9% of the total water supply.

Local water supply system

The Seosan water supply system receives its water from both outside Seosan (from multiregional sources) and local water sources, and supplies its water to households and industries.

In December 2013, there were 162 local water suppliers in Seosan (7 metropolitan cities, 1 metropolitan autonomous city, 1 special self-governing province, 75 cities and 78 districts). The water supply ratio was 98.5% and penetration rate of sewage treatment equipment was 92.1%.

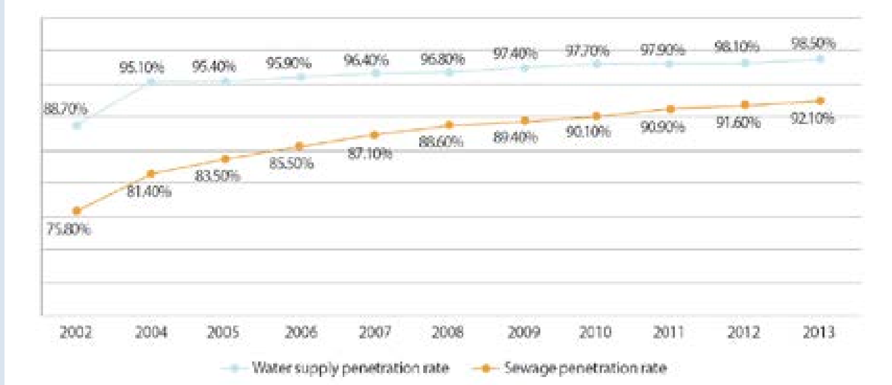


FIGURE 3. Water supply & sewer service ratio

Boryeong dam is the main water source for Seosan city, supplying 240,000 m^3 of water per day to the west area of Chungcheungnam-do's 8 cities[2] and districts (480 thousand people) including Seosan city and 5 thermoelectric power plants. Seosan city is the largest consumer demanding 18 millions m^3 of water per year and Chung-yang district is provided smallest amount, 1.2 millions m^3 annually. Boryeong dam is quite a small basin area (163.6 km^2) despite this it provided approximately 90 million m^3 of water to 8 cities and districts in 2013. It provides 84% of its supply capacity, which is approximately 106 million m^3 per year.

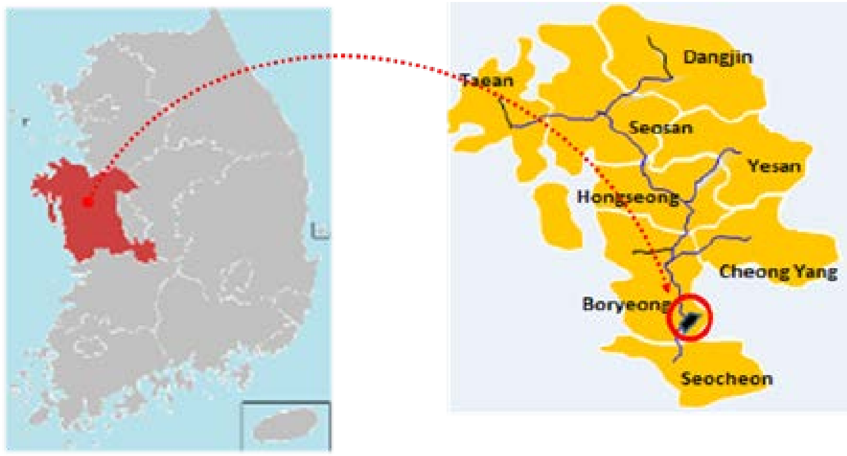


Figure 4. Boryeong dam and the 8 cities supplied water from the dam (Source: K-water)

Status of Facilities in Palbong

Palbong distributing area supplies water to its neighbourhood with 2,099 hydrants supplying 2,431m^3 per day. Its revenue water ratio before the SWM Seosan project was estimated at approximately 60%. The whole pipe consists of polyethylene (PE) pipe, which was installed between 2009 and 2011, and small calibre under 15mm supplying 97% of the water.

Table 2. Pipe conduit and hydrant in Palbong

mm	13	15	20	25	32	40	50	Total
Hydrant	2,006	23	47	13	7	2	1	2,099
%	96%	1%	2%	1%				100%

Source: K-water

2. Boryeong, Seosan, Yesan, Hongseong, Taean, Seochun, Dangjin, Chungyang

Palbong is a large mountain area of 54 km^2 with a non-metallic pipeline of about 218 km, making leakage management very difficult. In addition, despite night minimum flow being relatively high (approximately 47 m^3/hour) flow and leakage analysis during the night is limited to two points only (P-A and P-B, see Figure 6).

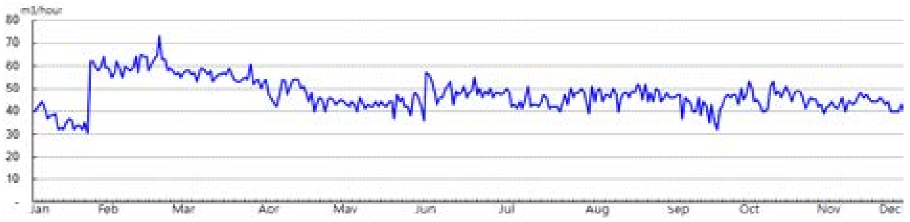


Figure 5. Minimum night flow of Palbong district (m3/hour), 2015 (Source: K-water)

The District Metered Area (DMA) P-A uses water from a small population of about 1,550 service connections in a large mountain area. On the other hand, the DMA P-B usually consists of larger users such as apartment blocks, shopping malls and the army force accounting for 50% (23 thousands m^3/month) of the total supply, and therefore has a higher requirement for regular monitoring.

While the distributing reservoir is located in the hillside (HWL 89m) most of the Palbong district consists of waterfront lowland (EL. 10~30m). Therefore high hydraulic pressure is required (more than 588.4 Kilopascals) in the pipe conduit.

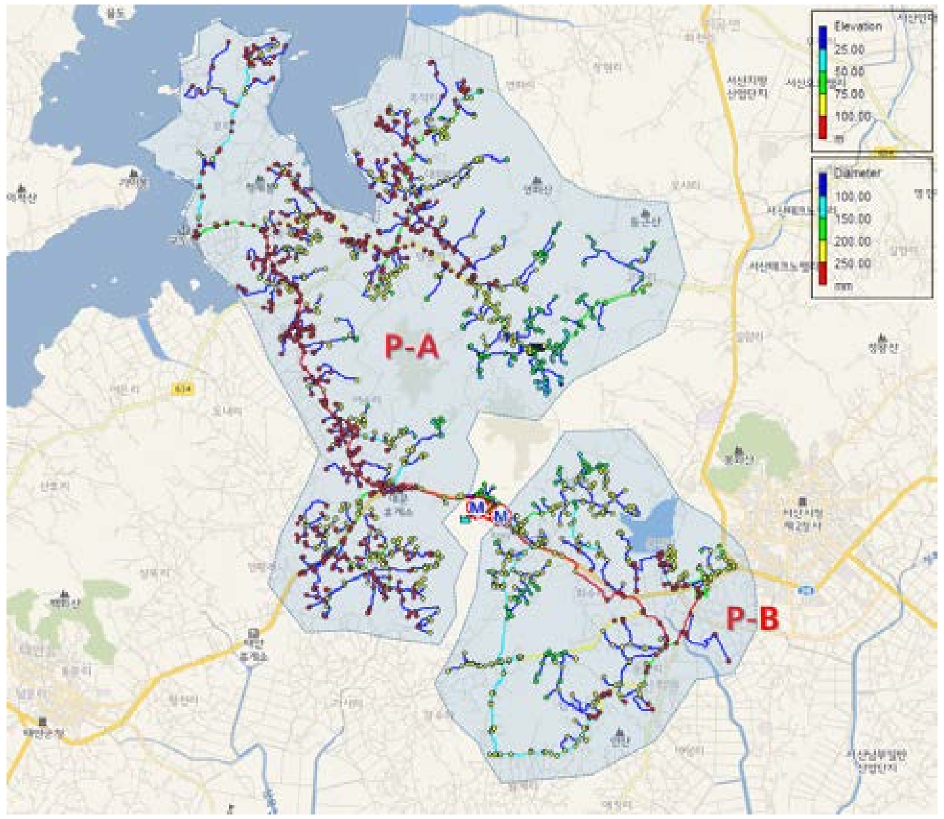


Figure 6. The area of P-A and P-B DMA (Source: K-water)

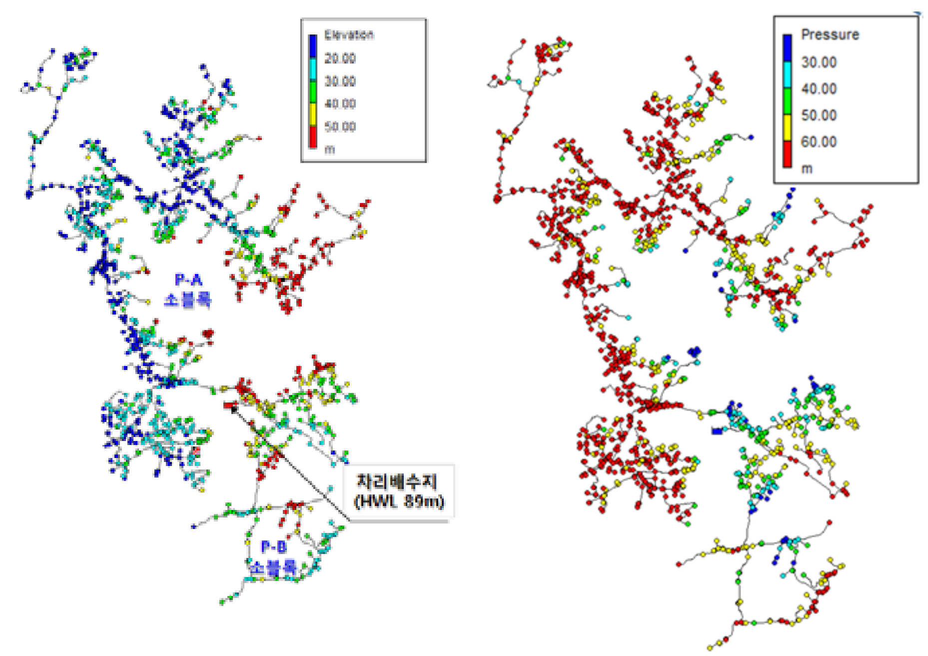


Figure 7. Hydraulic pressure and invert height in distributing area (Source: K-water)

1.3 Challenge description

1.3.1 Drought

Korea has experienced damage caused by intensifying climate variability and increasing frequency of floods and droughts over the past 100 years. Change in precipitation shows a growing tendency from the 1990s with annual precipitation showing considerable variations over the past 100 years from a minimum of 764mm (1939) to a maximum of 1,756mm (2003).

In addition, drought conditions have intensified with 2013 recording only 89% of the average annual precipitation and 2014 recording 90%. In 2015, average precipitation (965mm) was only 72% of that in a normal year (1,342 mm), 3rd lowest in recorded history. Droughts have occurred every 5 to 7 years nationwide since the 1970's and unlike floods, which occur only during summer, droughts can occur throughout the year.

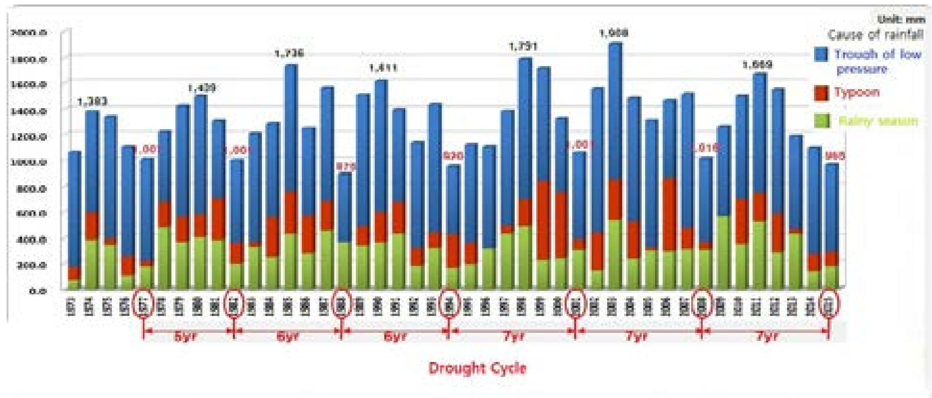


Figure 8. Precipitation by year

Table 3. Regional precipitation in 2015

Area (mm)	Nationwide	Seoul, Gyunggi	Gangwon Youngseo	Chungnam	Jeonnam	Gyungnam
Precipitation	964.9	746.8	787.2	811.5	1266.2	1320.3
Average year	1342.0	1359.3	1327.2	1310.9	1403.4	1498.8
Percentage (%)	71.9	54.9	59.3	61.9	90.2	88.1
The Lowest rank	3	1	2	2	18	17

Source : K-water

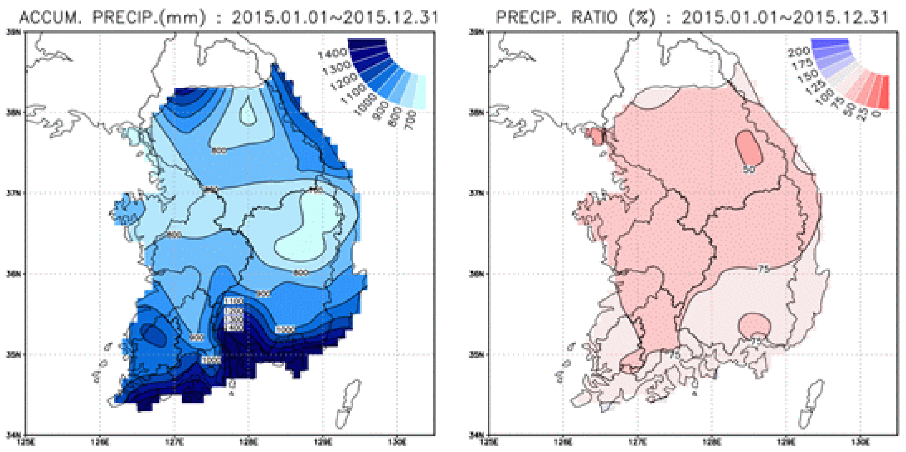


Figure 9. 2015 Korean annual average accumulated precipitation (left) and precipitation ratio compared with that of average year (right)
(Source: K-water)

Box 2. Water challenges in Korea

Water shortage caused by lack of precipitation from 2014 to 2015 started from the upper region of the Han River and spread to the whole country including the Nakdong River. The successive low precipitation of 2014 and 2015 made the drought more serious. In Korea, the accumulation of two years of consecutive precipitation (of 2,162mm) was only 81% of the annual average (2,684mm) and recorded the 5th lowest precipitation in history. A drought in 2015 caused by a shortage of precipitation resulted in 60% of the precipitation occurring during typhoon and rainy season. In the early to mid-rainy season the rain front was located in the southern part of Korea due to the North Pacific high (a semi-permanent, subtropical anticyclone), and did not pass until the late rainy season when the North Pacific high weakened.

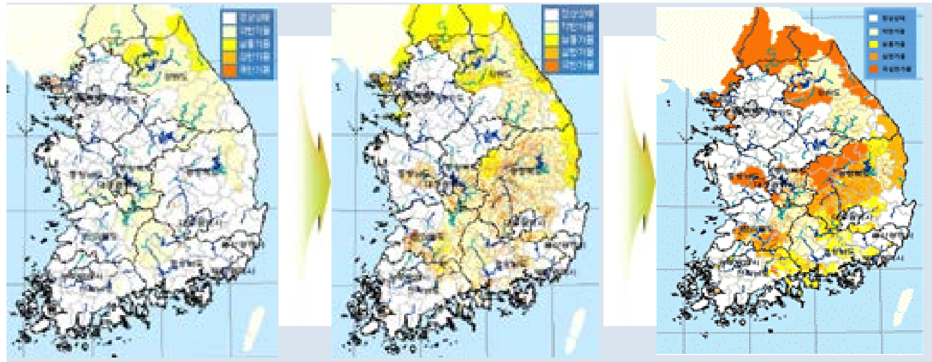


FIGURE 10. Change in Water Supply Drought Index[2]

TABLE 4. Regional precipitation in 2014-2015

Area (mm)	Nationwide	Seoul, Gyunggi	Gangwon Youngseo	Chungnam	Jeonnam	Gyungnam
Precipitation (2014~2015)	2162.2	1549.1	1508.3	1881.7	2781.0	2923.7
Average year	2684.1	2718.5	2654.4	2621.7	2806.8	2997.5
(%)	80.6	57.0	56.8	71.8	99.1	97.5
The Lowest rank	5	1	1	1	22	22

Source: Since 1973, based on 56 local offices of Korea Meteorological Administration (KMA)

In 2015, the total inflow rate in the Boryeong dam was 7.83 billion m^3 (43.7% of the average year) and during the summer (July to September), the inflow rate was only 3 billion m^3 (25% of the annual average) and drought level of 200 years cycle. After November, the total inflow rate was 7.7 billion m^3 (121.7% of average year) due to frequent rain. On January 1st 2016, nine of 18 multi-purpose dams reported deficient pond levels.

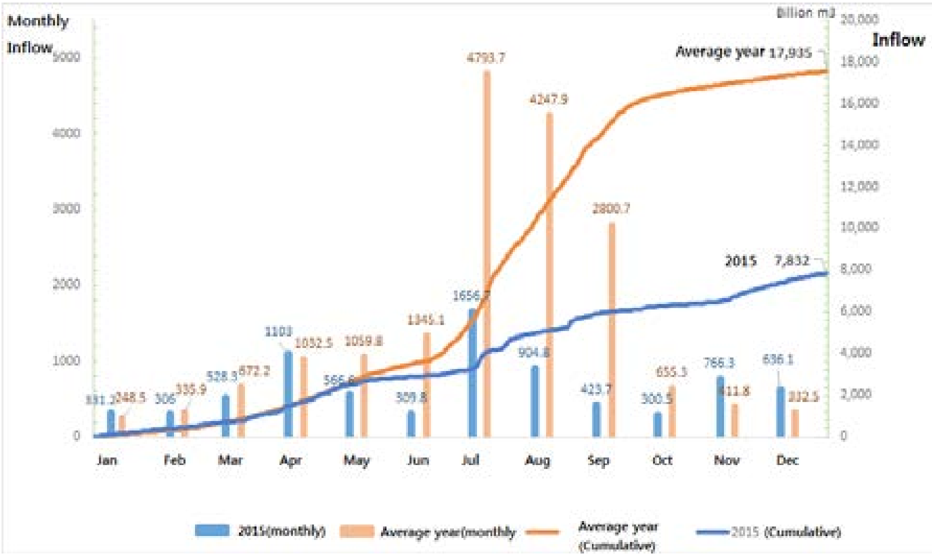


Figure 11. Inflow rate of multi-purpose dam in 2015
(Source: K-water)

1.3.2 Decrease water reserve rate of Boryeong dam and increase supply

The Boryeong dam was constructed from 1998 to April 2016. Investigation results on annual average storage ratios show that the dam storage ratio is decreasing, with the annual average storage decreasing by 25.2% when compared with that in 2014.

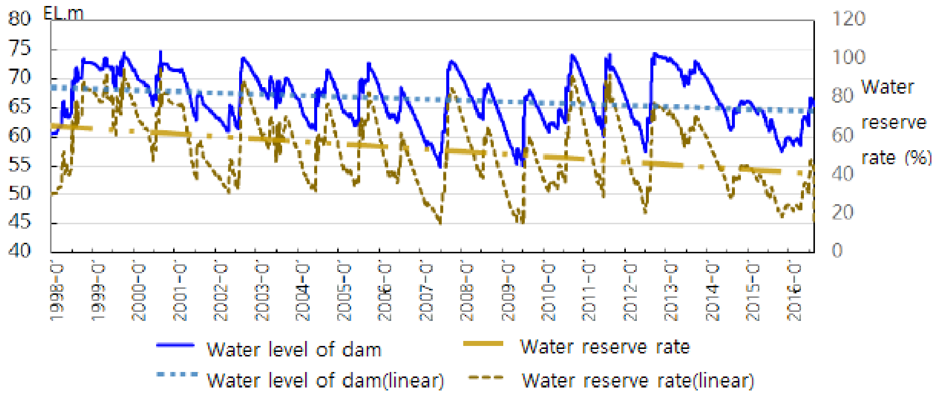


Figure 12. Change in water level of Boryeong Dam and its water reserve rate[3] (Source: K-water)

Due to the development of a new city area (Naepo New Town[4]) and power plant and industrial complex construction, water demand and supply are increasing in the Chungnam area. Results from research on Boryeong's multiregional water supply over a 10 year period show that Boryeong supplied 38.253 million m^3 of water to 15 water supply contractors in 2005 which increased to 71.613 m^3 of water to 23 water supply contractors in 2014. Showing an increase in water supply of 1.87 times compared with that of 2005 and an increase in contracts by 1.5 times[5].

Figure 13. Statistics of annual supply of Boryeong dam multiregional water supply in last decade (2005~2014)
(Source: K-water)

Boryeong dam's water supply capability and effective reservoir capacity are very close, creating a major risk if water withdrawals continue during periods without stable rainfall. A one year drought alone is capable of causing serious damage to the water resource supply. The inflow rate of July 2015 to September 2015 (during the rainy season) was just 15.1 million m^3, 15.3%, of the average inflow rate of average year, worse than the 200 years cycle of drought.

3. K-water, www.kwater.or.kr
4. Naepo is new town of Chungnam. The construction of Naepo New Town, which becomes the new host city of Chungnam Provincial Office and the Province's new hub city. It settled down in an area of 9,950,521m2 over Hongseong and Yesan.
5. A study on assessment water supply capacity of Boryoung dam and drought measures, Chungnam institute, 2016

From January to October 2015, the accumulated inflow rate recorded a minimum after dam construction, and after November, there was 16 million m^3 of water inflow, 4 times larger than that of the average year, while the annual total amount was only 42.5% of that of average year. As the drought continued from 2014, the water of the dam recorded its lowest level in history and caused a water supply suspension crisis (dam exhaustion crisis) in western Chungnam area. On October 30th 2015, it recorded 19.7% of the storage ratio and only had 33% of that in an average year (23.07 million m^3 in basic date and 70.2 million m^3 in average year). This was about 22 million m^3 below the historical record low storage amount of 45 million m^3 recorded the previous year.

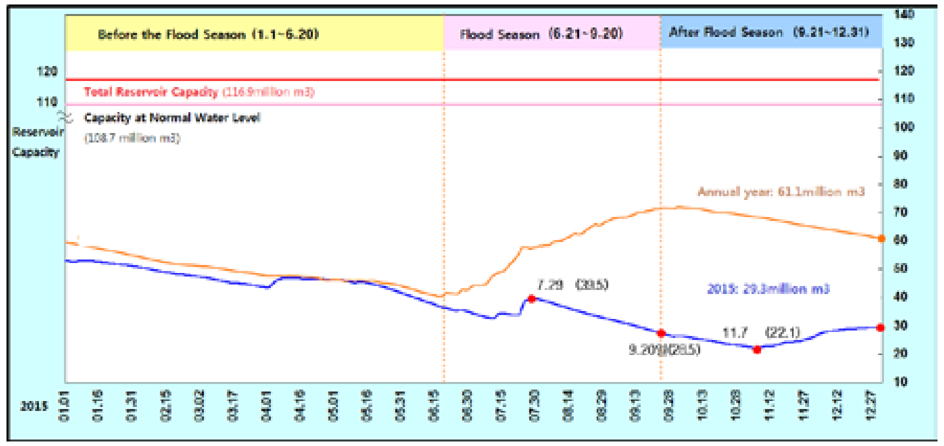


Figure 14. Water reserve rate of Boryeong dam in 2015
(Source: K-water)

Figure 15. Water gate of Boryeong revealing its bottom (2015.10.24)
(Source: K-water)

These drought conditions resulted in severe water shortages and concern for domestic water supply. To address this the Ministry of Land, Infrastructure and Transport (MOLIT), K-water and local government established and promoted a reaction plan for dam supply adjustment, water supply system adjustment and a restriction on water supply.

Box 3. Water restrictions at Boryeong Dam

Water restrictions at Boryeong Dam consisted of three stages. The first stage (serious level 1) started from August 18th 2015 and finished on February 15th 2016, lasting a total of 127 days and resulted in saving 4.047 million m^3 in only 22 days.

- **First stage (serious level 1):** 91% of dam supply and 9% of water distribution system adjustment. Supply 100% of domestic and industrial water
- **Second stage (serious level 2):** 71% of dam supply and 9% of water distribution system adjustment. Supply 80% of domestic and industrial water
- **Third stage (reached low level of water):** 66% of dam supply and 9% of water distribution system adjustment. Supply 75% of domestic and industrial water.

1.3.3 Low revenue water rate and difficulties in metering

Prior to the SWM project, the total revenue water (water produced and not lost through leaks or other losses) of Seosan city was 83%. While this is quite high in comparison to the revenue water of the Palbong area (of 67%) including Palbong-myun (the area where Seoul is located) the geographical characteristics, wide supply area of 54 km^2 and low population density of Seosan (Seoul city is 16,500/km^2 and Palbong-myun is 68/km^2; Seosan has 250 times the supply area per person), make leakage detection and prevention very challenging.

Figure 16. Comparing target area and pipeline length
(Source: K-water)

1.3.4 High water pressure of lowland pipe conduit

While the Palbong distributing reservoir is located in the hillside (High Water Level 89m) most of the area is situated in the lowland closed to waterfront (elevation of 10-30m). This geographical characteristic, along with the use of nonmetal (PE) piping, has resulted in low resistance to water pressure causing more leakage when high pressure is required and generated high water pressure of about 490.3-484.5 Kilopascals.

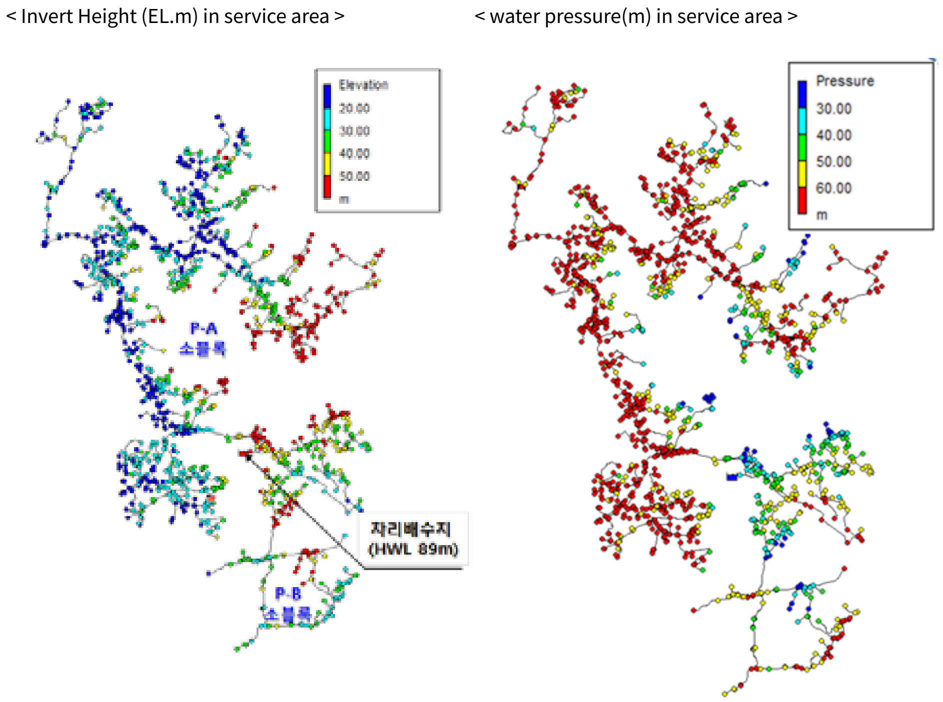


Figure 17. Invert Height and water pressure distribution in service area (Source: K-water)

1.4 Laws and systems related to drought

In Korea, relevant laws and regulations have a central department and local government to establish plans and measures against disaster such as drought. Korean drought measures have been established considering security and disaster management according to the *Framework Act on the management of Disasters and Safety* and *Countermeasures against Natural Disaster Act* (See Box 4 for details).

Box 4. Laws, systems, plans and policies related to drought and water management

Framework Act on the management of Disasters and Safety

The prime minister establishes a basic plan about security management and then each department and public organization establishes an execution plan and develops this into a detailed execution plan. So a safety plan related to natural disasters, such as drought, must include typhoon and flood measures, drought measures and earthquake measures. An implementation plan must then be formulated in 4 stages: prevention, preparation, response and restoration.

Countermeasures against Natural Disaster Act

The Countermeasures against Natural Disaster Act states that the disaster management agency has the responsibility of natural disaster prevention. Therefore the Ministry of Government Administration and Home Affairs, the Ministry of Land, Infrastructure, and Transport (MOLIT), the Ministry of Agriculture, Food and Rural Affairs, the Ministry of Environment, the Ministry of Public Safety and Security, and the Meteorological Administration etc. have to work together to research and investigate drought preventing restrictions on water supply and electricity generation for drought restoring, management and maintenance of facilities and establish mid- to long-term plans for the habitual drought afflicted area.

Comprehensive Plan for Long-Term Water Resource Management (2011-2020)

The Comprehensive Plan for Long-Term Water Resource Management (2011-2020) is the highest plan established to secure stable water resource and intends efficient management in Korea. It presents a future roadmap for water use, flood control, research and development of river environment and water resources. After the 1960's, in its early times, it focused on water resource development and management such as multi-purpose dam development but after the 1990's it established a plan focusing on environmentally friendly and desirable water usage. The 7th plan has now been established.

Within these drought related water management policies, comprehensive plans for long-term water resource management secure a new water resource to counter future water shortages and enhance stable supplies of water resources. These plans also improve efficient use of water, expand multi-purpose water use system as well as construct and advertise smart water management systems to enhance the communities' ability to face future droughts.

Chungnam Water Resource Master Plan (2015.01)

With the national comprehensive plan for long-term water resource management, Chungcheoungnam-do (Chungnam) established a water resource master plan to alleviate permanent water shortages by securing water resources and efficient water use, to develop and preserve rivers. In 2012, when the biggest drought damage occurred in west area of Chungcheongnam-do, they established water resource master plans to alleviate water shortages, thereby securing stable water resources and efficient use, development and preservation of rivers considering regional demands.

According to this plan, the Chungnam area is facing a water crisis in both water quantity and quality and this crisis will be intensified in the future. It is also expected that in this tendency, domestic/industrial water will be face 111.9 thousand m3 of water shortages per day and both deposited water and agricultural water will need 26.4 thousand m3 and 16,318 thousand m3 of water per day. To prepare for water shortages expected in future, Chungcheoungnam-do also focuses on demand management with traditional supply oriented management. The Chungcheongnam-do water demand management comprehensive plan consists of reduction on water supply leakage, water charges rationalization, sewage and wastewater reuse and developing alternative water to enhance water demand management. Including the new city area, it planned to save 50,426 thousand m3 per year (accumulated between 2012-2015) and cost 2.3611 trillion won (2.053 billion USD). This will result in a predicted annual saving of 3.878 million m^3 (10,624 m^3 per day) by 2025.

National Plan on the Management of Safety (2015-2019, 2015)

According to Article 34.6 of the *Constitution*, Article 22 of *Framework Act on the management of Disasters and Safety* and Article 26 of *Degree of the Framework Act on the management of Disasters and Safety*, it is the highest plan which establishes basic direction for disaster and safety management to protect life, property and body of people from disaster and accidents. The purpose of this plan is confronting changing disaster circumstances such as urbanization, concentration of population, climate change, and epidemics of new infectious disease. It provides directions on planning and operating detailed plans for disaster management agencies including central administrative organisations and local governments by presenting solutions, which enable comprehensive operating national disaster and security management policies and key tasks every 5 years.

Due to a change in governmental structure, the water management functions of the Korean central government are now dispersed. The Ministry of Agriculture, Food and Rural Affairs takes responsibility for agricultural water management and Ministry of Trade, Industry and Energy manages water for hydroelectric power, while the Ministry of Public Safety and Security manages typhoons and floods. Each department plans drought measures. For example, related to safety management, the Ministry of Land, Infrastructure and Transport and K-water, which both deal with water resources and projects divide dams and multiregional water supply, evaluate drought situation and plan measures as detailed execution plan[6].

Table 5. Ministry of Land, Infrastructure and Transport (Dam)'s response plan according to drought situation

Order	Drought situation (criteria: water supply)	Reaction plan
1st stage (Attention)	Supply 80-90% of basic plan (supply actual demand of domestic/ industrial water, agricultural water and river maintenance water)	• Install banner for drought overcome • Check the status of drought such as water shortage area • Saving water campaign using broadcast, campaign, brochure • Reduce marginal water of multi-purpose dams and water dams
2nd stage (Caution)	Supply 60-80% of basic plan (supply actual demand of domestic/industrial water and agricultural water) (restriction on river maintenance water supply)	• Establish and operate drought situation room (Ministry of land, infrastructure and transport, K-water) • Identify drought areas and establish support measures and cooperative system between agencies and governments • operate emergency water vehicle and provide bottled water • consider dam's water supply capacity and supply plan • reduce river maintenance water of multi-purpose dam and water dam. If necessary, restrict agricultural water
3rd stage (Alert)	Supply 50-60% of basic plan (supply actual demand of domestic/industrial water) (restriction on river maintenance water and agricultural water supply)	• Restrict water on dam area and multiregional water supply municipality • Request local government to secure own alternative water source • Operate emergency water source such as ground water • Supply actual demand of domestic/ industrial water from multi-purpose dam and water dam. If necessary, reduce actual demand of domestic/ industrial water • Consider how to utilize emergency water of dam
4th stage (serious)	Supply under the 50% of basic plan (Supply dead storage of dam) (supply actual demand of domestic/ industrial water and restrict agricultural water and river maintenance water supply)	• Restrict water supply on dam areas and multiregional water supply municipality • Operate emergency water source • Supply emergency water source of multi-purpose dam

6. Extreme Drought Response and Improvement - Focusing on 2015 Drought, Taewoong Kim, Donghyuk Park, Korean Society of Civil Engineers 63(9), pp25-35 (2015)

Table 6. Major measures related to drought among national plan on the safety management

Measures	Main contents
Prevention	• promote R&D related to drought prevention such as water use and saving management guideline, drought evaluation and prediction model, developing water use management system by facility, developing water saving program, quantifying drought season prediction and warning criteria. • Establish midterm and long-term plan to alleviate the habitual drought afflicted area. The plan includes study of efficient rainwater management, efficient management of water resource facility including dams, securing diverse water resources (ground water and sea water desalination). • improve drought management system and consider water supply prospect and current status of storage dam by water systems.
Preparation	• Vitalize research and investigation such as accumulating base line data, expanding research facilities, R&D for preventing drought by disaster management agency • Manage potential drought area. Secure optimal pumping equipment, weather analysis, observe growth and development of crop and etc. • Support water source exploitation in drought concerns phase, implementation of drought measures such as water saving cultivation in agriculture and transform to drought measures promoting system. • Real time monitoring on drought and establish reaction plan. Construct alliance between departments.
Response	• Establish drought reaction system; operating disaster countermeasures headquarters, emergency duty and etc. • Rapid dissemination of disaster warning and forecast including PR via media • Proceed emergency measures such as temporal use of another water facility including agricultural water, industrial water and power water and utilise ground water wells not in use, emergency water supply facility, water purification system, simplified wide area water supply, private water works and etc., secure equipment and personnel (military, firefighting) for emergency water supply and drinking water manufacturer and etc. • Classify 1st (10%~30% restriction on water supply) to 4th (stop supplying water) stage considering local condition, and establish and proceed step water supply countermeasures for each department and local government • Activate executive measures to minimize damage and spreading of drought • Supply emergency drinkable water to island area using guard ship
Restoration	• Support damaged crops restoration expenditure and installation of water pump and wells. • Investigate and restore drought damage, complement drought management system and make water supply countermeasures

2. Smart Water Management Solution

The Smart Seosan City project was established in January 2016 when the municipality of Seosan city asked K-water (who operated the local waterworks system in Seosan city) for a smart metering system for the local water supply system as a drought measure. Since 2015 the Boryeong Dam, which supplies water to Seosan City, had reached a water storage minimum of 21%, resulting in the need for urgent measures to be taken. Seosan city invested approximately 500 million won in this project (equivalent to approximately USD 467,500), for K-water to integrate ICT technologies such as smart metering, wireless data transmission and decision making system to reduce water leakage rate of pipelines as a way to secure water in Seosan city.

2.1 Innovative Smart Water Management technology solution proposed

To solve the various water-related problems and improve the efficiency of water management in Seosan, K-water considered various technologies. Recently, Information and Communication Technology (ICT) had been adopted to maximise efficiency in the process of water production and distribution (Byeon et al., 2015). In Korea, there are many projects working together to develop a Smart Water Grid (SWG) (Byeon et al.,2015) and technologies that enable sustainable water supply by connecting water sources and optimising water treatment based on ICT support this effort.

Water management using ICT, also known as Smart Water Management (SWM), enables sustainable water supply to every citizen by water resource monitoring, problem diagnosis, efficiency improvement and harmonising management, resolving many water related challenges (ITU, 2014; Heland et al., 2015).

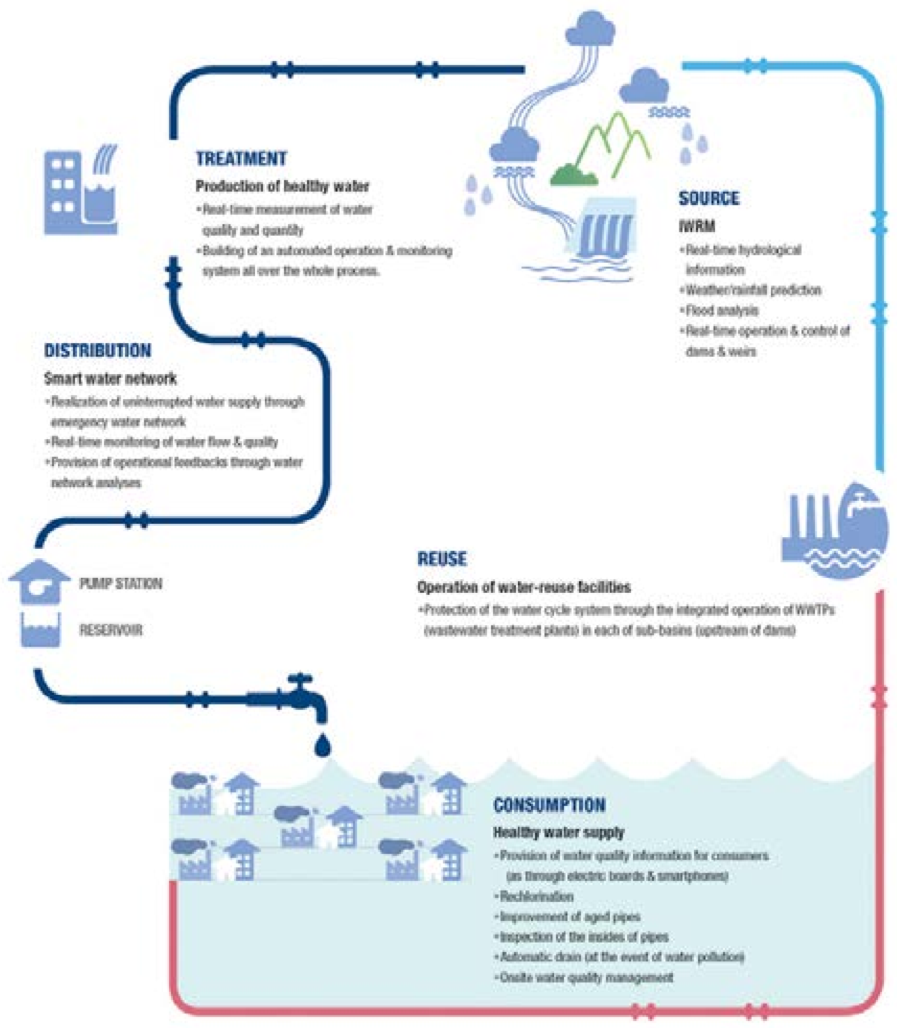


Figure 18. SWM concept map
(Source: K-water)

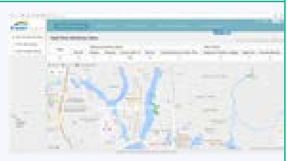
2.2 Introduction of SWM in Seosan city

Prior to the request from Seosan City, K-water was operating smart metering as a pilot project in the Goryeng area (from January to May 2015) when they were consigned Seosan's local water supply. K-water suggested smart metering to Seosan city and the city as a solution to their drought concerns, and Seosan City accepted the suggestion. The aim of the project was to construct a smart water management system to increase water supply for Seosan by improving the revenue water ratio through using remote metering, smart meters and ICT, and in the process to improve customer satisfaction of the water supply.

Unlike a human read meter, which relies on a person to manually check the data on a metre on site, smart metres deliver a user's hourly water usage via digital meter (smart meter) and wireless communication technology (ICT). It is used in revenue water ratio management and remote metering.

Figure 19. Outline of smart metering system (Source: K-water)

Table 7. Smart devices of Seosan SWM

Digital Meter	The digital meter converts measured flow data into electrical signals and transmits them on a time basis. **Function** - Measuring data: accumulated flow rate, flow rate - Detection function: overload, backflow, leakage and unused - Data communication	
Remote Transmitter	The Remote Transmitter collects data from the meter every hour and transmits the data every 4 hours. **Function** - Direct radio path with base station by 1W high-power transmission - 19Ah capacity battery enables 8 years run-time (2Ah /yr. power consumption) - LCD display for meter reading	
Base Station	• Wide area wireless transmission coverage with long distance (Transmission distance: approximately 1.5km) • Low operation cost • Low power consumption, ultra-compact, easy to apply in IoT / M2M	
Monitoring System	The monitoring system shows the connection status and end-user meter gauge on a real-time bases. The gauge reading data can be acquired and analysed hourly, daily, and monthly. The monitoring system calculates supplied water volume and provides information on leakage within the water supply network.	

Source: K-water

2.2.1 Remote metering and data transmitting

The smart meters convert the measured flow data into electrical signals and transmit them on a timely basis (hourly, daily and monthly). They perform precise flow measurements by sensing 8 times per an impeller pump rotation. Smart meters installed at the household level transmit data to the waterworks server through a wireless communication network and monitoring system (remote indication center-> base station-> remote system) automatically transmitting metering information such as hourly, daily, monthly water consumption.

The data-transfer procedure of a smart metering system consists of digital meters installed at the end user sites. These digital meters are connected to the remote transmitter through direct wires. Remote transmitters transmit the collected data to the base station through wireless communication such as pagers. The base station transmits the received data to the server and the monitoring system through the internet service. This final step helps system managers to acquire and analyse the data on the web page conveniently.

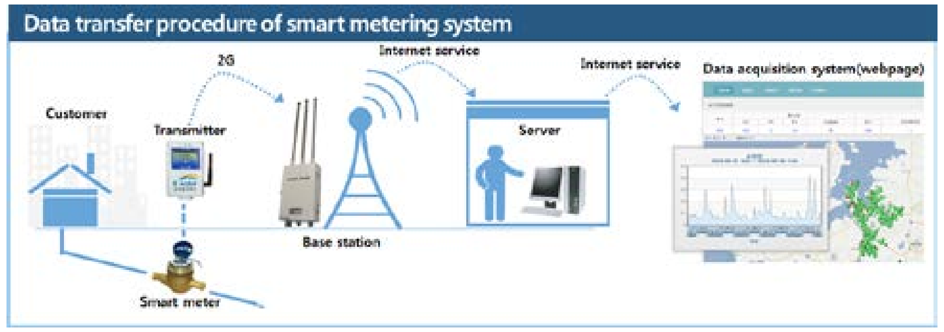


Figure 20. Data Transfer Procedure of Smart Metering System (Source: K-water)

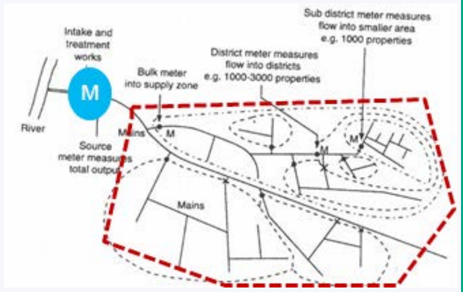
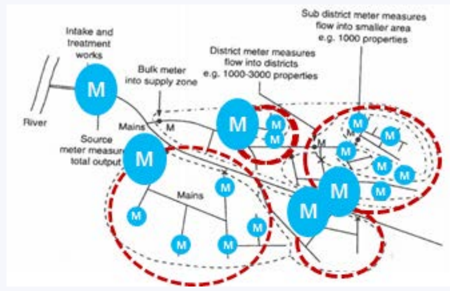
Wireless communication services used in this project use long distance wireless transmission. Long distance wireless transmission has various characteristics and strong points such as wireless coverage of a wide area, clear wireless environment without crossing and interference, cheap modem cost, low communication fees, low electricity use, compact size and adaptability to various IoT/M2M.

2.2.2 Sub District Metering Area (SDMA) system construction based on smart meter

Through using smart meters and DMA subdivision, a sustainable scientific quantity management system is constructed. From April 20^{th} to July 20^{th} 2016, this project constructed 1,550 units of smart meters, 30 base stations, 9 SDMAs and monitoring systems and propelled pilot operation and revenue water ratio improvement projects for the following two months (July – September 2016). DMA subdivision enables water information data taken by the smart meter to find leakage points easily and investigates abnormal data through analysing user's hourly consumption pattern to find the user's interior leakage. It shows smart metering data can be used in a bigger area beyond metering.

This smart technology enables the development of revenue water ratio analysis from a monthly to a daily basis and extends the minimum flow during night point from 3 points to 12 points. It also allows the division of existing DMA (District Metering Area) systems with Tele-Metering (TM) equipment and analogue meters to SDMA (Sub District Metering Area) system (as described below). As a result, existing 2 units are subdivided to 9 units, creating highly data accuracy. SDMA monitors not only allow DMA inflow, but also numerous minimum flows during the night and they manage the daily revenue water ration to ensure an effective and quick response to leakage.

Table 8. Comparison between (existing) DMA system and (Improved) SDMA quantity management system

	Before (DMA system)	After (SDMA)
Metering area management	1 DMA (500 ~ 1500 meters/BL)	1 DMA + SDMA Subdivision (About 200~300 meters/SDMA)
Quantity management (leakage restoration)	• 1 inflowTM minimum flow during night monitoring • Monthly revenue water ratio management • Difficulty in quantity management including leakage detection	• Monitor not only DMA inflow, but also numerous SDMA minimum flow during night • Daily revenue water ratio management • Effective and quick control on leakage
Concept map		

Source: K-water

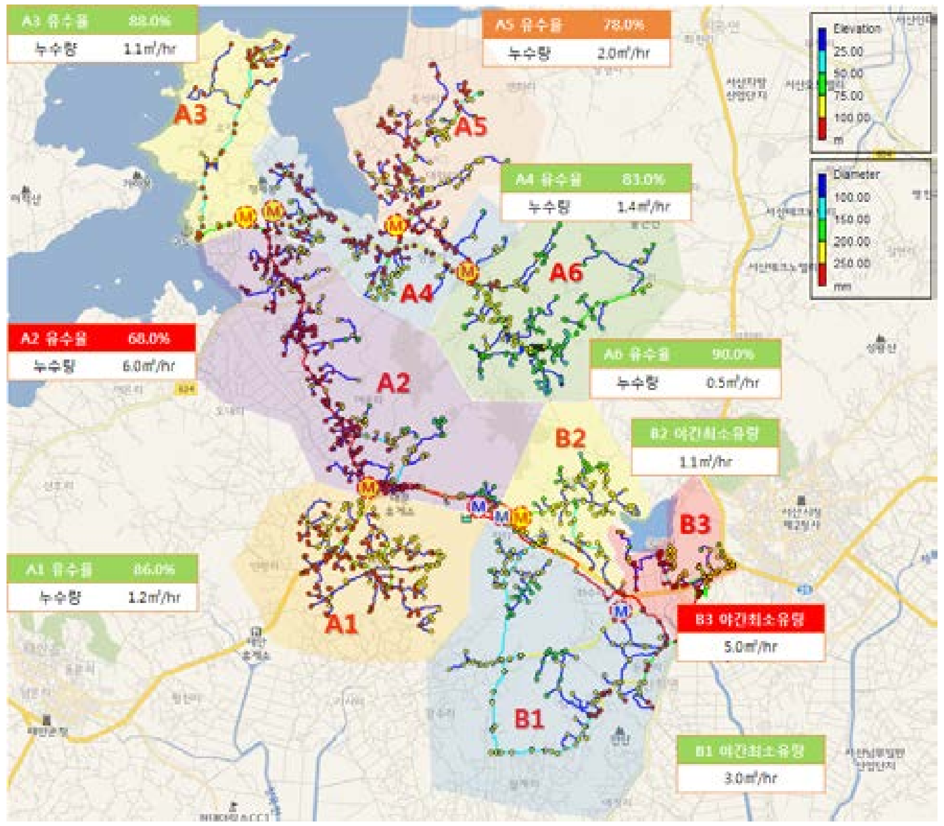


Figure 21. Scientific quantity management by DMA subdivision
(Source: K-water)

2.2.3 Leakage analysis using smart meter data

Nonmetal pipes were buried in the target area, so correlating leakage detection by installing leakage sensors outside of the pipes was inefficient. As a result, a new concept of leakage detection sensors was deployed, in which the sensor is inserted into the pipe using water as its medium. This type of sensor has the advantage of enabling high precision in a low flow velocity with a semi-conductor sensor and it also reduces leakages with a detection and warning function. In addition to this it enables remote meter reading with a built-in communication function.

2.2.4 Construction of water pressure management system with data

By combining smart metering systems with decompression remote control technology it enables the construction of a water pressure management system, which considers the consumption pattern of the user. In order to operate without a booster pump in some of the hillside areas, which were expected to have problems with water supply, K-water installed a Pressure Reducing Valve (PRV) to provide a small decompression amount in every Pressure Management Area (PMA). This enabled us to control decompression in the future based on the pattern analysis of the users.

The system construction consisted of three stages. In the first stage, data on water use was acquired at the critical point of the hillside where problems with water supply were expected when decompression is operated. In the second stage, based on the data, pattern use is analysed and time-based decompression measures were constructed. In the third stage, the pressure is adjusted using an automatic remote control with SCADA, according to the season, holiday period and time of day and flexibly reacts to any water supply problem in the hillside area.

Figure 22. Diagram for water pressure management
Source: K-water

The Pressure Reducing Valve (PRV) is operated by dividing target areas (DMAs) where the water pressure is high (490.3 Kilopascals or more) into four water pressure management areas (turning them into Sub District Metering Areas 'SDMAs'). Water pressure is then decompressed based on each SDMA characteristic, making it possible to prevent pipe breakage due to high water pressure in advance. In addition to this, the amount of background leakage due to unnecessarily high pressure is reduced, which is effective in improving the flow rate.

Table 9. Pressure Reducing Valve Operation

(Unit: Kilopascal)

	SDMA	Control method	First inflow pressure	Second outflow pressure		Decompression
PMA 1	SDMA A1	Time control	637.4 (EL.22)	daytime(03:30~24: 30, 21hr)	490.3	↓147.1
				night(23:30~03: 30, 3hr)	392.3	↓196.1
PMA 2	SDMA A2	Remote control	637.4 (EL.30)	daytime(03:30~24: 30, 21hr)	539.4	↓98.1
	SDMA A4			night(23:30~03: 30, 3hr)	490.3	↓147.1
	SDMA A6					
PMA 3	SDMA A3	Remote control	637.4 (EL.20)	daytime(03:30~24: 30, 21hr)	392.3	↓245.2
				Night (23:30-03: 30, 3hr)	3.5	↓294.2
PMA 4	SDMA A5	Time control	784.5 (EL.5)	Daytime (03:30-24: 30, 21hr)	637.4	↓147.1
				Night (24:30-03: 30, 3hr)	6.0	↓196.1

Source: K-water

<(before)water pressure management: average pressure 6.1kgf/cm^2>

<(improved) before water pressure management: average pressure 4.4kgf/cm^2>

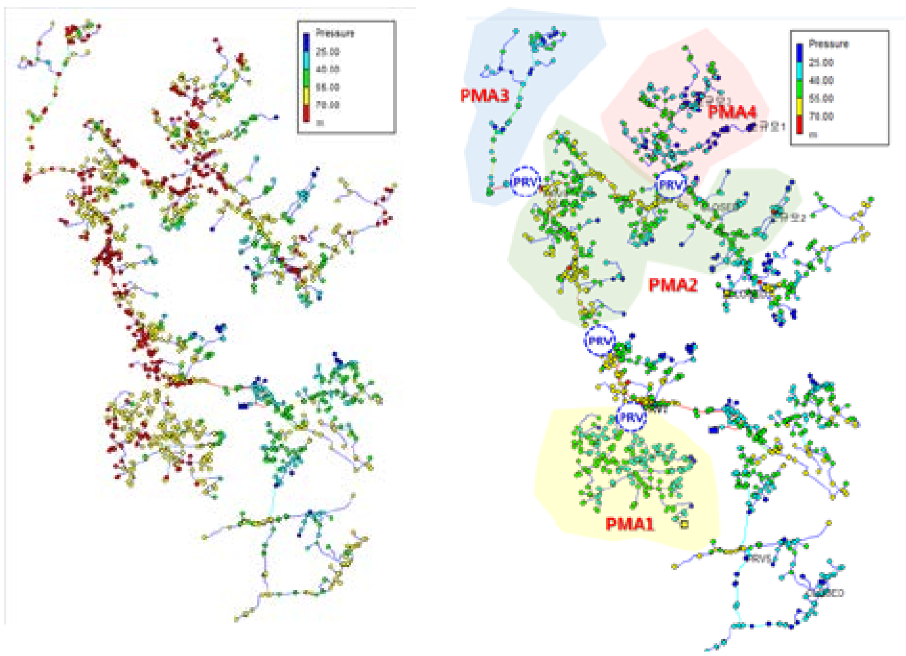


Figure 23. Comparison between before and after water pressure management
(Source: K-water)

2.2.5 Government budget support

Operation of this project was enabled by investment of Seosan city and supported by central government through their drought budget. This project cost 497 million won (approximately USD 464,600) in total, with the purchase of smart meters costing 88 million won (USD 82,000), remote monitoring center (to monitor indicators) costing 154 million won (USD 144,000), replacement and installation 129 million won (USD 120,000), Sub-DMA building 70 million won (USD 65,000) and construction control system 59 million won (USD 55,000).

3. Outputs & Outcomes

3.1 Economic outputs

3.1.1 Decrease in leakage

After applying smart metering and the SDMA system to the target area, the revenue water ratio reached 90%. This was an increase of 20% compared to the first half of 2016 and of 19% compared to that of the previous year.

Figure 24. Revenue water ratio before and after smart meter (2016)
(Source: K-water)

Leakage detection technology in three of the SDMAs found leakages in seven of the units and restored them. As a result, the revenue water ratio in the mentioned SDMAs improved from 17% to 39%.

Table 10. Revenue water ratio in SDMAs

	A1	A2	A3	A4	A5	A6
'16.7	87%	73%	92%	84%	58%	50%
'16.8	89%	86%	91%	87%	69%	78%
'16.9	95%	**90%**	88%	97%	**88%**	**89%**
		↑17%			↑30%	↑39%

Source: K-water

3.1.2 Inner leakage detection of users and restoration

Time-based use pattern analysis of the smart meter monitoring system enabled two cases of interior leakage for the user to be found and restored. As a result, each user saved 55% of water use and 70% of water cost.

Figure 25. Inner leakage detection of users and restoration
(Source: K-water)

Table 11. Economic outcome of inner leakage detection by user

	Customer A		Customer B	
	Usage (m^3/month)	Usage Fee (1000₩/month)	Usage (m^3/month)	Usage Fee (1000₩/month)
Before Restoration	60	67.2	59	65.4
After Restoration	25	18.4	28	21.0
Effect	↓35 (↓58%)	↓49.8 (↓73%)	↓31 (↓52%)	↓44.4 (↓68%)

Source: K-water

3.1.3 Find Error in inflow and outflow of distributing reservoir

In the process of revenue water analysis in each SDMA, the result comparing distributing reservoir inflow/outflow rate and distributing inflow/outflow meters found a fault that the meter indicated 430 m^3 of over supply per day (about 70%). These meters were replaced and the over-estimated 50 thousand m^3 of water which had been regarded as water purchase by multiregional water supply in the past was recaptured. As a result the revenue water ratio of Seosan city increased by 0.2% and the revenue water profit was 20 million won (approximately USD 17,400).

Table 12. Comparative measurement of distributing reservoir's inflow and outflow (measurement: m^3/hr.)

	Before replacement of metres (A)	After replacement of metres (B)	Error(C) (A-B)	Error rate (%) (C/B)
Measurement of Inflow(m^3)	391.7	363.3	28.4	7.8%

Source: K-water

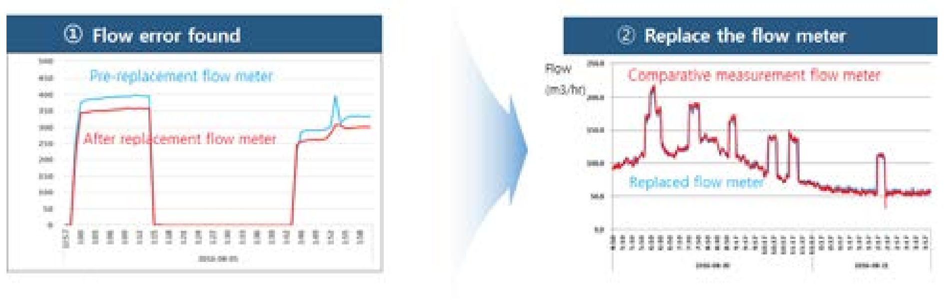


Figure 26. Calibration procedure on distributing reservoir inflow rate
Source: K-water

Figure 26 (1) shows the error in the initial meters installed. You can see this by the gap in the inflow before and after the replacement of the incorrect meters. Figure 26(2) shows that the replaced meters are measuring the data correctly by comparing the correct meters after replacement.

3.2 Social outcomes

3.2.1 Increase in customer satisfaction

By switching to using remote meters for water use and quality, customers' satisfaction has been improved as it has become possible to handle complaints promptly with surveyors responding to every customer concern and also by providing additional water quality management services such as the inspection of customers' indoor pipes.

In addition to this, as the target area for this project was based in a hillside area where the households are quite far apart it was originally too costly for the civil service to visit each traditional meter themselves to monitor the water use. This meant that customers were required to monitor the meters themselves taking them a lot of time and effort. By introducing remote metering it enabled improved monitoring of the meters by the civil service, and as a result the customer satisfaction has increased.

3.2.2 Enablers

The first success factor in enabling SWM projects is Korea's advanced ICT technology. Korea has many small and medium-sized enterprises with excellent technology, and it has a very comfortable base for constructing SWM based on Internet of Things (IoT) because it has a dense communication network in all regions.

The second factor to succeed Smart Water Management in Seosan city is enabling environment include policies, laws, plans that create an environment for integrated water management. Korea has the national and local government plan to respond disaster such as drought. Therefore, governments could allocate funds whose purpose is to adopt smart water management and address water shortage in Seosan city. Consequently, good governance make it possible to implement water solutions successfully.

3.2.3 Barriers

1. The initial investment cost is higher than the existing facility investment.
Seosan SWM project is relatively expensive in comparison to traditional meter installation practices since existing meters need to be replaced with smart meters and additional remote transmitters are required. For example, in the case of a remote transmitter, an additional 100,000 won (USD 91) is added per water service connection, and the cost of a smart meter (13 ~ 15 mm diameter) is 50,000 won (USD 46), which is 50% higher than a general meter (30,000 won (USD 27)). The higher cost is because large-scale demand or production of smart meters has yet to be achieved, and thus production costs have not decreased due to economies of scale. As such, the installation cost for smart meters will likely reduce as demand increases. In Korea, as large-scale water facility managers such as Seoul (supplying water to 2 million households) are planning to install smart meters, this problem will be resolved in the mid to long term.

In addition, 20 remote base stations were installed as part of the Seosan SWM project because the telecommunication infrastructure was not installed, and an RF communication network was used. This cost 1,000 won which is similar to the labour cost for metering ranging from 1,000 to 1,300 won per household. The smart water management business, which is currently being built, will ultimately lower the communication cost to 300 ~ 400 won / household by building the IoT (Internet of Things) network.

2. We should consider the use of existing metering staff.
With the success of the Seosan SWM project, the role of metering staff became unnecessary, but the task of reducing metering staff in a short time period of time was difficult. As a result, half of the existing metering staff had been used continuously to provide metering services including both manual and remote meter reading at the same time. Gradually, the existing metering staffs will be utilized for improving customer services.

3. Low water price in Korea
The water price in Korea is less than about 1,000 won per ton, and the installation cost of the smart meter and remote transmitter (approximately 200,000 won, USD 18] is not economical enough to rapidly expand investment.

4. Link with the Sustainable Development Goals

Seosan Smart City is linked to sustainable development goals 6 (clean water and sanitation) and 11 (sustainable cities and communities). Table 13 lists the specific targets within these SDGs that are addressed by aspects of Seosan Smart City.

Table 13. A list of the SDGs and their specific targets that relate to Seosan Smart City

Sustainable Development Goals and Targets	
SDG 1: Zero poverty **End poverty in all its forms everywhere**	
1.5	By 2030, build the resilience of the poor and those in vulnerable situations and reduce their exposure and vulnerability to climate-related extreme events and other economic, social and environmental shocks and disasters.
SDG 6: Clean water & sanitation **Ensure availability and sustainable management of water and sanitation for all**	
6.1	By 2030, achieve universal and equitable access to safe and affordable drinking water for all
6.4	By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity
6.b	Support and strengthen the participation of local communities in improving water and sanitation management
SDG 8: Promote sustainable economic growth **Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all**	
8.2	Achieve higher levels of economic productivity through diversification, technological upgrading and innovation, including through a focus on high-value added and labor-intensive sectors
SDG 11: Sustainable cities and communities **Make cities and human settlements inclusive, safe, resilient and sustainable**	
11.5	By 2030, significantly reduce the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations
SDG 12: Sustainable consumption **Ensure sustainable consumption and production patterns**	
12.2	By 2030, achieve the sustainable management and efficient use of natural resources

4.1 Goal 6 and target 6.4

Goal 6 of the United Nations (UN) Sustainable Development Goals (SDGs) ensures availability and sustainable management of water and sanitation for all. Target 6.4 of Goal 6 aims at sustainable withdrawals and supply of fresh water to solve water scarcity problems including an increase in water-use efficiency across all sectors by 2030 and a decrease in the number of people who suffer from water scarcity.

Water-use efficiency and water stress levels are indicators to measure target 6.4. Water-use efficiency shows changes in water-use efficiency over time and water stress level measures the percentage of water withdrawal in available freshwater resource. Among them, the water-use efficiency indicator is related to this case. It can be defined as a change in quantity produced in major sectors of whole water withdrawal over time. According to ISIC, the four major sectors presenting water-use efficiency are 1) Agriculture, forest and fishery, 2) manufacturing, construction, mining industry and stone-quarrying industry, 3) electric industry, 4) municipal sector. This indicator embraces agriculture, industry, energy and municipal sector and can be used as a tool for detailed analysis for national plan or decision-making.

4.1.1 Water-supply efficiency of municipal sector

Among the target 6.4, water-supply efficiency of the municipal sector is presented as efficiently providing water to domestic water users and the percentage of water withdrawal from water supply facilities (for example, water distribution efficiency, pipe loses, etc.). Measurement equation is as follows.

$$M_{we} = \frac{Mu_d}{Vm}$$

- M_{we} = Efficiency on water supply of municipal sector
- Mu_d = distribution of local water user(m^3)
- Vm = water intake of municipal sector (public water pipe and etc.)(m^3)

This indicator provides information about water resource's economic, social use efficiency (e.g. water usage in major economic parts or loss of distribution networks). This indicator measures not only the outputs of productive water use in municipal sector but also water use loss. By measuring them, it deals with the target aimed at, 'increasing major water use efficiency in every filed'.

4.2 Economic net profit occurs

The operating results from the pilot project show a 20% improvement in the revenue water ratio and 190 thousand m^3 of water per year decrease in leakage. This results in a benefit of 610 million won (about USD 590,000) for the next 8 years with the cost benefit expected to increase in net benefit (reflecting the pilot result, it is assumed 20% of improvement in revenue water ratio and 809 won/m^3 of water cost).

This result applied facility investment [500 million won (USD 455 thousand), purchase control system, smart meter and etc.], communication expenses [660 won (USD 0.6)/unit], repair and maintenance cost (2.5 million one per year) as cost, and reflected leakage reduction (water purchase), human metering cost (600 won/unit), leakage exploration cost [11 million won (USD 10,000) per year including service and etc.], meter change cost [54 thousand won (USD 49)/unit] as benefit.

5. Lessons Learned and Conclusions

5.1 Lessons Learned

1) Governance plays an important role in project enforcement

The planning and execution of the drought policy, existing laws and systems played an important role in the implementation and support of this project. In addition to this, government budget support for the project facilitated its implementation.

The *Framework Act on The Management of Disasters and Safety* encouraged the government and public institutions to plan drought measures and the *Countermeasures Against Natural Disasters Act* enforced the federal government and local governments to restrict water supply and electricity generation and to maintain drought-overcoming facilities. Without these government Acts in place, this project may not have been supported.

Also, a comprehensive statutory plan on long-term water resource management, is intended to strengthen the establishment and promotion of smart water management systems for the purpose of securing stable water resources and efficiently managing them. The

Chungcheoungnam-do water resource comprehensive plan established in 2012 to manage water demand during drought periods also assisted, as it encouraged enhancing the existing supply management. According to this plan, leakage reduction for multiregional water supply, enhanced water demand management, rationalising water cost, waste and sewage water reuse and alternative water development are all key priorities. In short, this project was enabled by drought measures and plans established by Seosan city through laws and regulation.

2) Early inputs cost occurs but profitability increases in the long term

Seosan smart water management required early facility investment and operating costs but in the long term, increase in net profit is expected. At the beginning, smart meters and repeater installations will cost a lot but in the middle and long-term, profit will be increased through a reduction in metering personnel, meter change cost and reduced leakage detection cost. This project assumes an average revenue water ratio of 87.7% for eight years and based on this, calculated input cost is 566 million won (approximately USD 492,200) and its benefit is expected as 1,179 million won (approximately USD $102,500). Therefore the Cost Benefit ratio is close to 2:1.

The investment cost for this project can be recovered in about four years. The smart meter is a battery-based technology, and economic analysis is conducted based on the 8-year replacement cycle. This means that it is possible to recover the investment cost within four years after the initial installation, and the net benefit will be generated for the remaining four years (see figure 27).

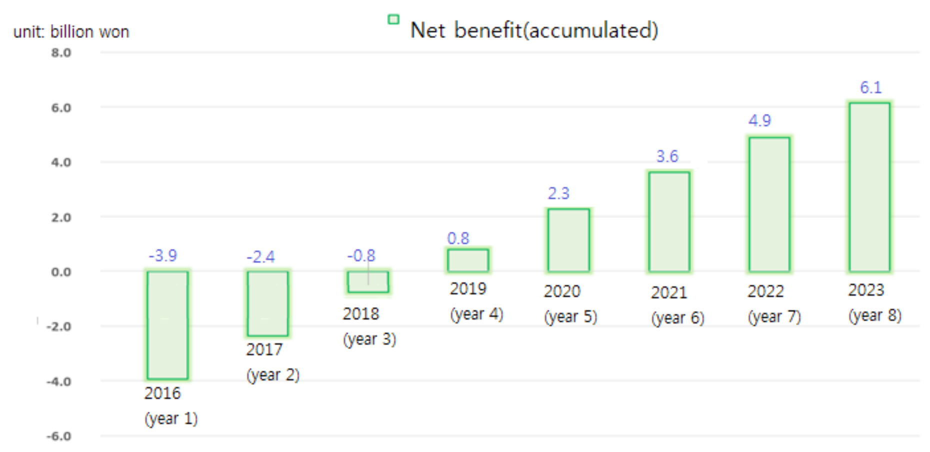


Figure 27. Net project profit by year (Source: K-water)

3) Smart metering improves sustainability in water management

Securing and operating smart water management technology by K-water was also essential. By combining the existing water management in Seosan City with smart water management tools, the efficiency was significantly improved. SDMA (Sub District Metering Area) system technology (which subdivides existing DMA systems to smaller units to improve the revenue water ratio) is one example of this. Smart metering enables a sustainable water supply by reducing water leakages and saving water and energy. In the situation where water supply is reduced or limited by drought or other challenges, new water resource development is needed to supply water stably. However this can also can be achieved by minimizing water loss through smart

water management techniques. Therefore to solve water problems such as water shortage, implementing smart water management is beneficial.

5.2 Next Steps

Korea is currently constructing a low-cost Narrowband IoT (NB-IoT)[7] communication network that is optimized for the Internet of things. It is expected that communication costs of about KRW 1,000 (USD 0.9)/ month/water supply will decline to about KRW 400 (USD 0.36) /month/ water supply. Secondly, we have analyzed the big data acquired from many smart meters (instruments) and developed and applied software that supports decision-making. This software is used for monitoring and decision making to provide information on water quantity and quality, water pressure to improve decision-making in the operation of the water facilities. Despite the low water price in Korea, as the smart water market continues to become more active with many companies competing in the market, it is expected that technology costs will decrease in the future, enabling the costs of SWM to be recovered more rapidly.

K-water has been promoting SWM business by entering overseas based on experience of SWM construction in Korea. In that case, the Asian Development Bank (ADB) is conducting an SWM TA project to build an SMW Pilot in four countries in South Asia, including Bangladesh and India, with about USD 1.25 million for four years. Dhaka is in a serious situation where the groundwater level drops by one meter per year due to the water shortage caused by many leaks and uncontrolled use of groundwater (80% of the total water supply depends on groundwater). To overcome this problem, the Bangladesh government has invested heavily in pipeline facilities through ADB's large-scale assistance, but there are still many leaks due to the lack of DMA system and measuring sensors to analyse leaks.

K-water has introduced smart meter technology to build a sustainable water management system at low cost (due to strong investment of Seosan City and supported by central government), and installed a smart meter in a deep tube well to build a real-time flow monitoring system. As a result, ADB and the local government of Bangladesh have gained considerable gains, with results measured and monitored through the use of smart meters. In addition, Bangladesh is hoping for a sustainable partnership with K-water at the completion of the pilot project, and it is expected that K-water will participate in the consulting service of the water supply facilities of Dhaka City. ADB also plans to expand K-water's SWM TA project to double its current size, initially expanding from four cities in four South Asian countries to seven cities in six countries.

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7. Narrowband IoT (NB-IoT) is a Low Power Wide Area Network (LPWAN) radio technology standard developed to enable a wide range of devices and services to be connected using cellur telecommunications bands, designed for the Internet of Things (IoT). NB-IoT focuses specifically on indoor coverage, low cost battery life, and a large number of connected devices.

Annex 1: Economic Analysis

[Condition: 20% increase in revenue water ratio (Average revenue water ratio reached 87.7%), sales price and period of project: 8 years]

- Net profit (total savings): about 610 million won/8 years (Cost 570 million won, Benefit 1.18 billion won), B/C: 2.1

		Total	1st year	2nd year	3rd year	4th year	5th year	6th year	7th year	8th year
		(million won)	2016	2017	2018	2019	2020	2021	2022	2023
1.Incremental cost (A)		**611**	**497**	**15**	**15**	**16**	**16**	**17**	**17**	**17**
Facility investment	Subtotal	497	497	-	-	-	-	-	-	-
	Purchase smart meter	88	88							
	Purchase remote indication center	154	154							
	Replacement and installation cost	129	129							
	SDMA construction	70	70							
	Monitoring center	40	40							
	Purchase S/W for monitoring system	16	16							
Communication cost	660won/unit/month	95		12.6	12.9	13.2	13.5	13.9	14.2	14.6
Repair and maintenance cost	0.5% of investment	19		2.5	2.6	2.7	2.7	2.8	2.9	2.9
1.Incremental cost(present price)(A')		**566**	**475**	**14**	**14**	**13**	**13**	**13**	**12**	**12**
Installation cost		475	475							
Communication cost		76	-	11	11	11	11	11	10	10
Repair and maintenance cost		15	-	2	2	2	2	2	2	2
2. Improvement benefit(B)		**1,456**	**86**	**186**	**192**	**211**	**201**	**192**	**191**	**196**
Revenue water profit	In sales price	1,212	78	157	159	160	162	164	165	167
Saving on metering personnel	Metering read(60% of service budget)	53		7.0	7.2	7.4	7.5	7.7	7.9	8.1
Saving on meter replacement	Existing meter replacement cost	90	2.2	9.3	13.5	29.7	17.9	6.7	4.0	6.9
Saving on leakage detection cost	Own operating cost	102	6.2	12.7	13.0	13.3	13.6	13.9	14.3	14.6
2.Improvement profit(present price)(B')		**1,179**	**82**	**170**	**168**	**176**	**160**	**146**	**139**	**137**
Revenue water profit		981	74	144	139	134	129	125	120	116
Saving on metering personnel		42	-	6.4	6.3	6.1	6.0	5.9	5.8	5.7
Saving on meter replacement cost		74	2.1	8.5	11.8	24.8	14.3	5.1	2.9	4.8
Saving on leakage detection cost		82	5.9	11.6	11.3	11.1	10.9	10.6	10.4	10.2
3.Net profit(present price)(B'-A')		**613**	**-393**	**156**	**154**	**163**	**147**	**134**	**127**	**125**

Annex 2: SWM Devices

Digital Meter

The digital meter converts measured flow data into electrical signals and transmits them on a time basis. It performs precise flow measurement by sensing 8 times per an impeller pump rotation. The outer shell of the meter made of brass mechanically wraps around the operation part and the flow chamber. This shell is resistant to external impact and low temperature during the winter season.

Rubber packing (O-ring), ultrasonic welding, and epoxy molding prevents water infiltration. Operators can easily check device conditions, flow rate, and functional overview on the liquid crystal display (LCD) panel.

Figure 0. External View of a Digital Meter

The specifications of the digital meter are as follows.

Table 0. Digital Meter Specifications

	Description	
Function	• Measuring data: accumulated flow rate, flow rate • Detection function: overload, backflow, leakage and unused • Data communication	
Advantages	• Application of Semi-conductor sensors for high precision in low flow velocity • No resistance against gear rotations of impeller • Built-in communication function enables remote meter reading • Leakage detection and warning function to reduce leakage rate • Triple waterproof design of operating parts • "Unused" function for an one elderly person household	
Technical Data	Sensor	• MR sensor type
	Battery	• 3.0V, 3,800mA (life expectancy: 8 years)
	Specifications	• Nominal temperature: 0.3 to 30 °C • Nominal pressure: 0.3 to 10 bar • Precision: Q1: ± 5 %, Q2, Q3: ± 2% • Display range: 0.0001 to 99999,9999 (m3) • Installation direction: horizontal • Housing: CAC 203 (brass casting) • Diameter: 15 to 250 mm
	Communication	• DCPLC method, pulse output

Differences between mechanical (pulse) type and digital type are summarized in Figure 1-4.

Remote Transmitter

The main characteristics of remote transmitter are as follows.

	Characteristics
	• The Remote Transmitter collects data from the meter every hour and transmits the data every 4 hours. • Direct radio path with base station by 1W high-power transmission • 19Ah capacity battery enables 8 years run-time (2Ah /yr. power consumption) • LCD display for meter reading

Table 1. Remote Transmitter Specifications

		Description
Function		• Wireless transmission of meter reading data to BS through two-way radio paging network • 24-hour operational • Minimized power consumption (battery use available)
Advantages		• Reduced operation costs, Improved transmission performance, and Improved communication reliability • Dedicated frequency by common carrier without interference
Technical Data	Wireless	• Frequency Band - Tx: 923.55Mhz to 924.4505Mhz (40 channels) - Rx: 318.1375Mhz to 319.1375Mhz (40channels) • Output power: 30dBm (1W) • Receive sensitivity: less than -115dBm
	Battery	• 3.6V/19Ah lithium primary battery
	Power	• Less than 2Ah/year
	Display	• Graphic LCD
	Exterior	• Housing: acrylonitrile-butadiene-styrene (ABS) • Weight: 390g • Dimension: 120mm * 160mm * 40mm
	Features	• Meter reading data transmission by wireless connection • Reading data display through LCD
	Installation	• Wired connection with digital meter, Wall mounting

Table 3. Remote Transmitter Specifications

		Description
Function		• Wireless transmission of meter reading data to base station through two-way radio paging network
		• 24-hour operational
		• Minimized power consumption (battery use available)
Advantage		• Reduced operation costs, Improved transmission performance, and Improved communication reliability
		• Dedicated frequency by common carrier without interference
Technical Data	Wireless	• Frequency band - Tx: 923.55Mhz to 924.4505Mhz (40 channels) - Rx: 318.1375Mhz to 319.1375Mhz (40channels)
		• Output power: 30dBm (1W)
		• Receive sensitivity: less than -115dBm
	Battery	• 3.6V/19Ah lithium primary battery
	Power consumption	• Less than 2Ah/year
	Display	• Graphic LCD
	Exterior	• Housing: ABS
		• Weight: 390g
		• Dimension: 120mm * 160mm * 40mm
	Feature	• Meter reading data transmission by wireless connection • Reading data display through LCD
	Installation	• Wired connection with digital meter, wall mounting

Base Station

Characteristics of the base station are summarized below.

	Characteristics
	• Wide area wireless transmission coverage with long distance * Transmission distance: approximately 1.5km • Low operation cost • Low power consumption, ultra-compact, easy to apply in IoT / M2M

Table 4. Base station Specifications

		Description
Function		• High power radio frequency (less then 5W) allows wide base station service coverage
		• Connects between transmitter and monitoring system through wireless paging network
Advantage		• M2M network cost competitiveness achieved thanks to inexpensive RF MODEM • Lower price service cost than any other wireless solutions
		• Extremely low battery power consumption • Micro-size and cheap IoT/M2M device application
Technical Data	Wireless specification	• Frequency band - Tx: 318.1375Mhz to 319.1375Mhz(40 channels) - Rx: 923.55Mhz to 924.4505Mhz(40 channels)
		• Output power: Max 5W
		• Receive sensitivity: less than -115dBm
	Power	• AC220±20% / DC 12V 45~65Hz
		• Power Consumption: 33.4W
	Others	• RF channel: Rx 1ch, Tx 1ch
		• Network: ethernet (10 base T, TCP/IP)
		• Dimension: 220mm * 360mm * 85mm
	Installation	• Depending on the field situation

Monitoring System

The monitoring system shows connection status and end-user meter gauge on the real-time bases. The gauge reading data can be acquired and analyzed hourly, daily, and monthly. The monitoring system calculates supplied water volume and provides information on leakage within the water supply network. As the system utilizes graphical user interface (GUI) map originated from the Google map, it is easy to use and identify operation conditions on web pages. If smart metering can be implemented in all the district metered areas (DMAs) and/or sub-DMAs (SDMAs) analytical data on non-revenue water (NRW) and minimum night flow(NMF) can be acquired daily.

Details of the monitoring system are as follows.

Table 5. Monitoring System Specifications

	Description
Function	• Metering status • hourly / daily / monthly
	• Statistics - hourly / daily / monthly - daily peak / monthly peak - over last year or month - daily average / monthly average / yearly average
	• Failure status - meter status / reading status / connection status
	• Customer management - Customer management - Local group management
	• Systems management - Admin access history - Environments configurations
Advantage	• Usage pattern Analysis - hourly / daily / monthly
	• Detection of water leakage

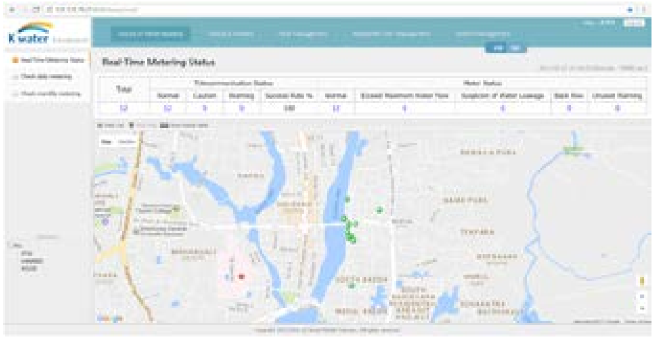


Figure 2. Current Metering Status

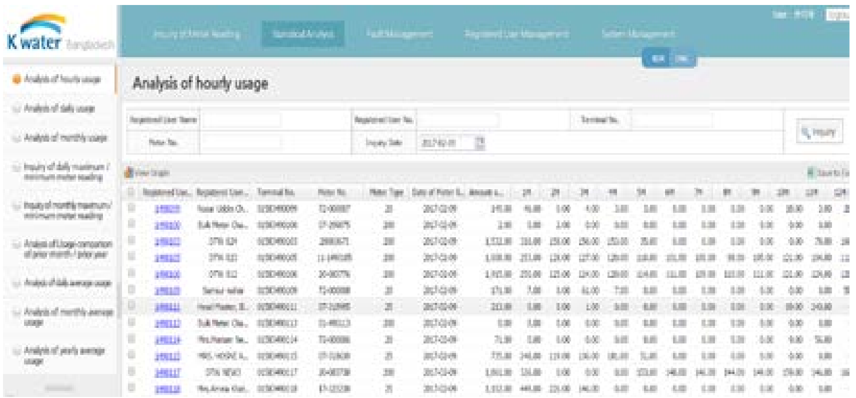


Figure 3. Hourly Usage Data

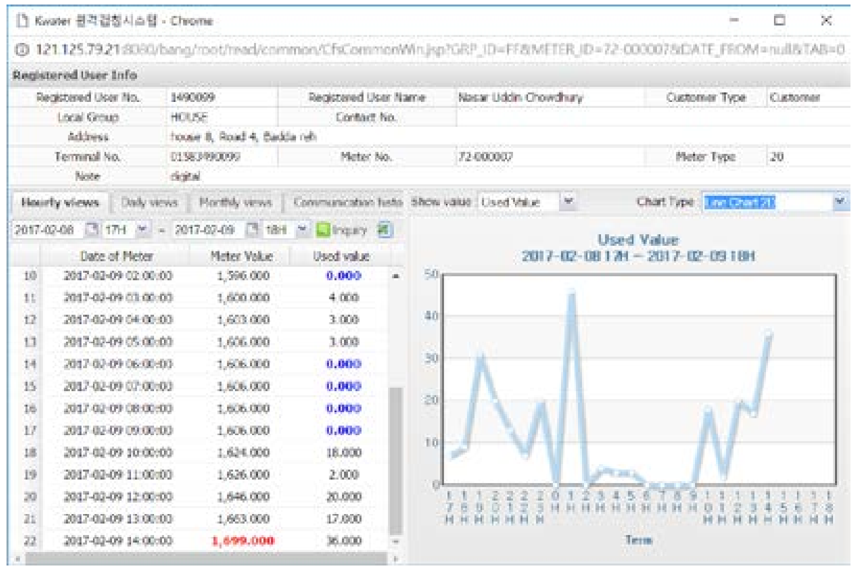


Figure 4. Customer Usage Details

The percentage of secondary industry was lower than that of Chungcheungnam-do (32.8%) and the percentage of tertiary industry was higher than that of Chungcheungnam-do (66.7%). Within tertiary industry, wholesale and retail (13%), lodging and food industry (11.1%), educational service (7%), hygienic and social welfare service industry (6.3%) took largest portions.

TEXT BOX

Smart Water Management for Denpasar City, Bali

Country: Indonesia
City/region where project is based: Denpasar City, Bali
Population (of area where the project is based): 880,600
Key organisations /stakeholders involved in the project: Stakeholders
Ministry of Public Work and Housing of Indonesia under Directorate General Water Resources (DGWR),
1. City of Denpasar
2. PDAM (local water company) Denpasar City, Partners
3. K-Water, Wareco, Hankuk Engineering

Authors: Iman Hudori - imam.hudori@smec.com
and Heungsup Shin - shin.heungsup@gmail.com
Links: pdam.denpasarkota.go.id

Water challenge

Denpasar City is one of the most famous tourist destinations on the island of Bali. Recent water balance studies show looming competition over a limited supply between tourism and other industries, agriculture, and drinking water. At the same time, there is a high level of non-revenue water (NRW), primarily due to leakage.

Project approach

The project is based on active non-revenue water (NRW) management using a zoning system, where the system as a whole is divided into a series of smaller, hydraulically isolated sub-systems, called DMAs (District Meter Areas) in which the volume of water loss can be calculated separately. DMAs are further subdivided into areas with pumping systems and those with gravity systems, and then into villages, to facilitate the effective and efficient management and control of the project. The existing potable water zones of PDAM Denpasar city use deep wells where the quality of water is excellent. Other key elements are real time monitoring using flow and pressure meters equipped with data loggers, Asset Management of existing pipe networks, and consumer communications.

Preparatory work in 2016 included carrying out a survey and data collection, assessing the existing water supply system, as well as reviewing the DMA and NRW programs. As of July 2018, the pilot project is being prepared, with plans to launch the main project in 2020, provided adequate funding is obtained.

Results and next steps

PDAM has successfully piloted a potable water zone in several neighbourhoods of Denpasar City, through establishing DMA Teras Ayung, Subita and Sarangan. Despite this success, the project has been unable to implement the DMAs properly, since the existing transmission and distribution network is connected with other zones which contain low pressure zones and old pipe networks. Future plans will be developed with consideration of water supply for the service area at high and low elevations, available pump and gravity systems, deep well availability and villages boundaries.

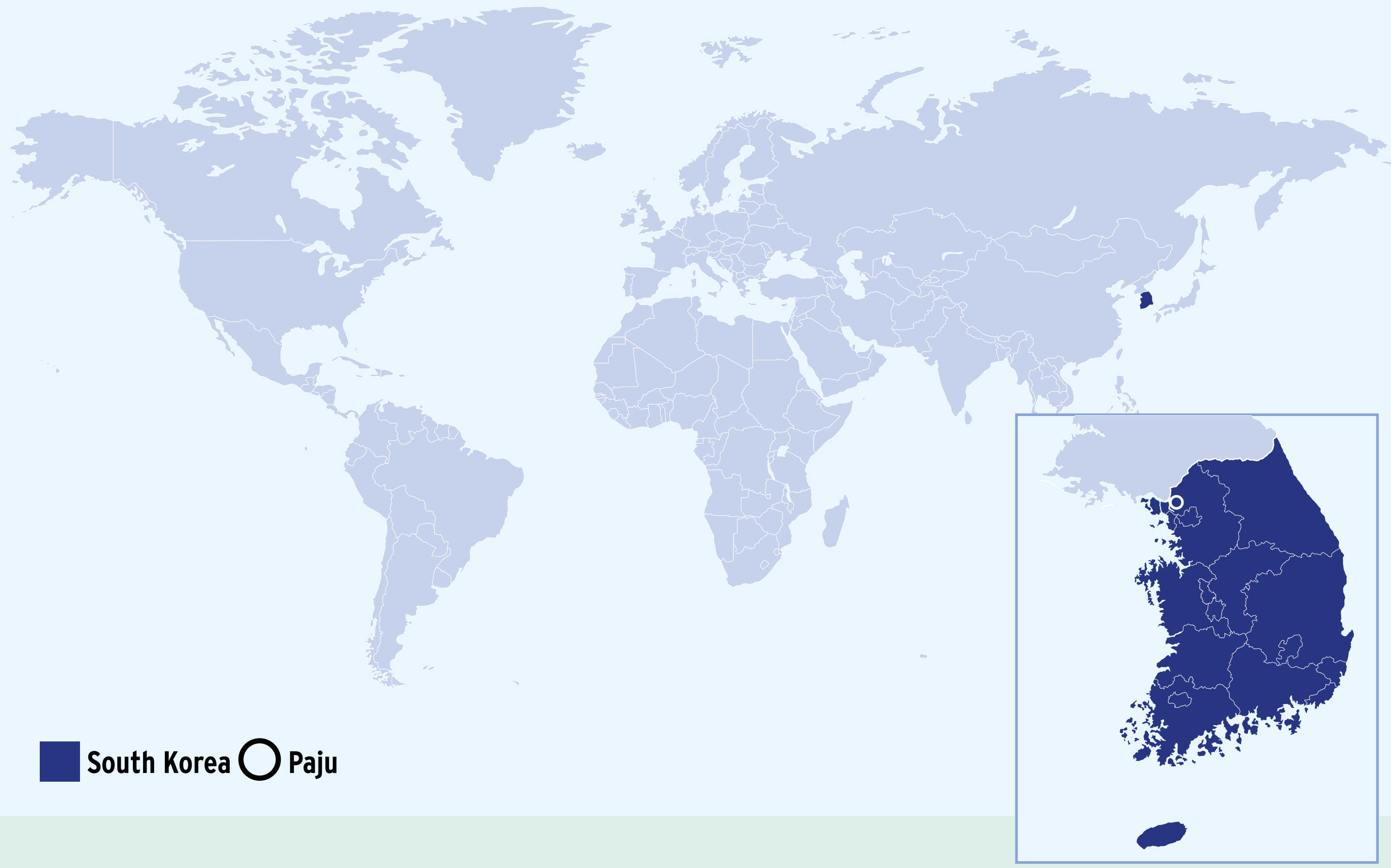
SWM: Potential and barriers

The scale of the Denpasar City SWM project is large, in terms of the investment cost required. The local government (city of Denpasar), PDAM Denpasar and even central government under Ministry of Public Work and Housing were not able to commit the required resources to support the project. Due to these fund limitations, PDAM Denpasar City has not yet fully applied Integrated Information Technology systems for monitoring existing DMAs.

However, its project managers are interested in introducing SWM tools, which they believe can help the DMA management in addressing the water shortage in Denpasar City through decreasing NRW and increasing leak detection efficiency. Establishing a series of automated DMAs not only targets NRW reduction but it also improves asset condition and customers service by improving water quality, providing adequate water pressure and maintaining asset life through pressure management, and helping to enable a continuous water supply. Specifically, the automation of DMA in Denpasar City neighbourhoods can reduce NRW from 36.5% to below 20% and generally improve the safety of water supplied.

Smart Water Management Application to Paju Smart Water City

Mr. Sukuk Yi, Dr. Munhyun Ryu, Dr. Jinsuhk Suh, Dr. Shangmoon Kim, Mr. Seokkyu Seo, Mr. Seonghan Kim, K-water (Korea Water Resources Corporation)



Summary

Despite the availability of high quality drinking water in Korea, the direct tap water drinking rate of Korea is only around 5%, which when compared with advanced countries such as the United States (56%) and Japan (52%), is extremely low. The main reason why Koreans do not drink tap water directly is distrust. More specifically, the general public has a strong distrust of tap water quality due to concerns about the aging water pipes, the smell of tap water and the taste of tap water. As a result, K-water has focused its investments on improving the water quality of existing waterworks projects and community perceptions of the water rather than on quantitative centered investments. In order to reassure people of the quality of tap water and to remove any anxieties, K-water introduced the *Smart Water City (SWC) healthy water services* with the goal to increase the direct tap water drinking rate.

A SWC integrates Information and Communication Technology (ICT) throughout the entire tap water supply process, from treatment to faucet, so that people can directly check for themselves in real-time the status of the tap water supply process and water quality. By implementing ICT into a city's water management in this way, a SWC can effectively reduce the general public's distrust in tap water thereby increasing the drinking rate of tap water.

In Paju Smart City, ICT technology including real-time sensors and on the ground staff engagement increased the tap water drinking rate substantially from 1% to 36.3% in three years. In addition to increased tap water drinking rates, community trust in water safety was also shown to increase. This shows the potential for SWCs to assist with raising community awareness of the safety of drinking water, leading to increased access to low cost safe drinking water and improved decision-making for the community interested in contributing to the efficient use of water management.

1. Introduction

1.1 Paju City Context

1.1.1 General Status

Three criteria were considered when selecting the pilot SWC project sites: 1) local governments that expressed interest in improving existing facilities and analyzing the effects of SWC; 2) areas in which advanced water treatment processes had already been or will be implemented in the near future; and 3) regions that included new cities and had relatively low densities.

Paju City was selected as the first site of the Smart Water City (SWC) pilot project. The municipality is particularly appropriate project site since K-water is already managing the local water supply system. In total, K-water operates water supply systems in 22 out of 162 municipalities in Korea through consignment agreements. Among those 22 systems, Paju City had the best conditions to carry out the SWC pilot project with advanced water treatment (activated carbon) facilities, appropriate block management; short construction period of block-building, available operation of connections between blocks with pipe networks, and optimized tap water supply facilities with dual water supply system.

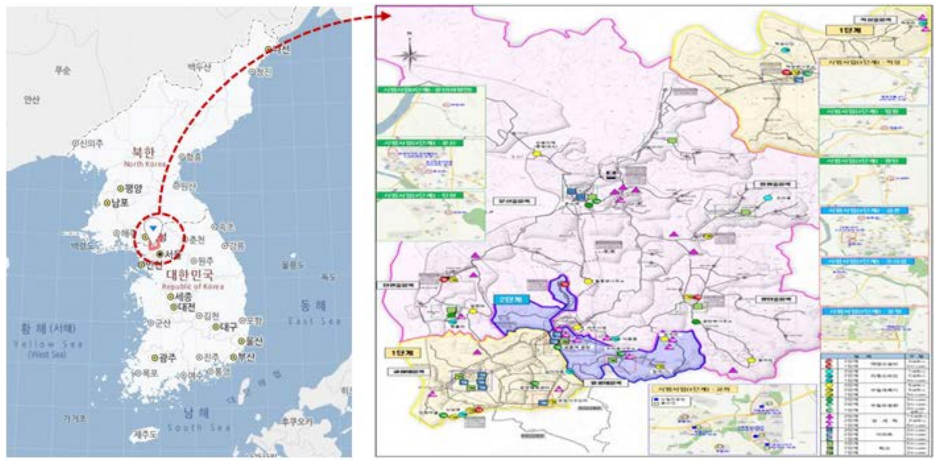


Figure 1. SWC Site (Paju City)

1.1.2 Economic Status

Gross Regional Domestic Product

Paju's Gross Regional Domestic Product (GRDP) amounted to about 9 trillion KRW (hereafter won, equivalent to 7.82 billion USD) in 2010, which accounted for 3.9% of the GRDP of 221 trillion won in Gyeonggi Province. In addition, GRDP per capita was 20.1 million (17,478 USD) won for Gyeonggi Province, while Paju City was 26.6 million won (23,130 USD).

Paju City has a great potential for regional economic growth since the growth rate of GRDP in Paju was 22.2% and GRDP per capita in 2010 was 26.6 million won (23,130 USD). The city is specialized in high-tech manufacturing and creative industries such as high-tech industrial convergence (e.g. 5G, Internet of Things, 3D printing and big data) and culture/distribution industry, these innovations will have a profound impact on industrial processes as well as create opportunities for product and service transformation, with a high possibility that it will grow into an industrial base in Northeast Asia.

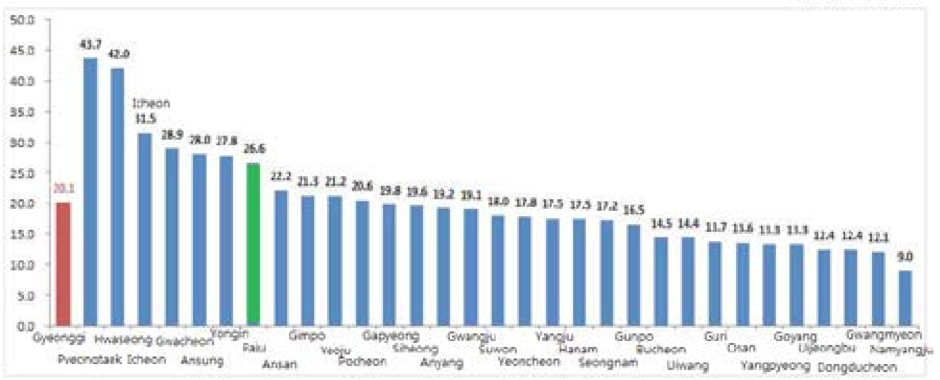


Figure 2. GRDP Increase in Paju (2010)
Source: Paju Mid-to Long-Term Development Plan, Paju City

Table 1. Gross Regional Domestic Product (GRDP) Increase in Paju (2009 to 2010)

	Paju	Gyeonggi-Province
GRDP growth rate (year-on-year ratio)	22.2%	11.6%
GRDP per capita (2010)	26,634 thousand won	20,079 thousand won

Employment Status and Conditions

The employment rate in Paju was 57.6% in 2012, which was lower than the average of 59.5% in Gyeonggi Province. However, the employment rate was 10th among the 31 cities in Gyeonggi Province. The percentage of casual workers decreased from 23.4% in 2011 to 19.9%, which was the 14th lowest among 31 cities in Gyeonggi Province. This means that the proportion of regular workers has increased and thereby the quality of jobs in the city has improved respectively.

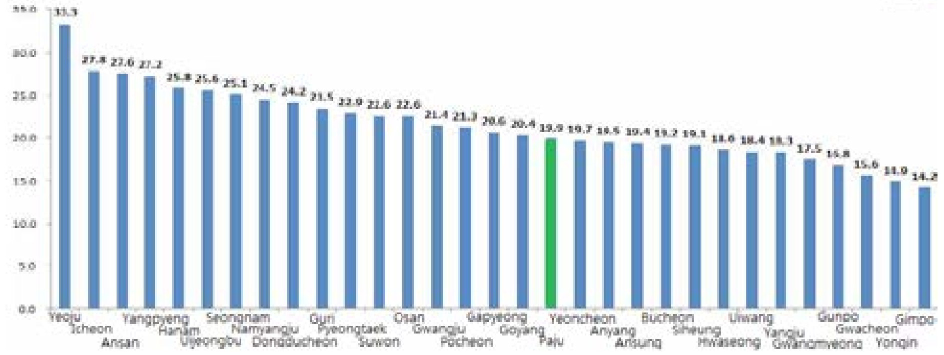


Figure 3. Percentage of Temporary Workers by City in Gyeonggi Province (2012)
Source: Employment Survey by Region, National Statistics Portal (http://kosis.kr/)
Note) Temporary and daily workers among all workers (ratio of less than one year contract period)

Figure 4. Gyeonggi Province Employment Rate by City (whole)
Source: National Statistics Portal (http://kosis.kr/)>
Note) Employment rate (%) = (Employment ÷ population over 15 years old) × 100

1.1.3 Population and Urbanization

Paju is experiencing rapidly changing market conditions through population growth due to the development of Unjeong (a new city), the revitalization of industrial complexes (such as LG Display), increase in foreign investment, and the Paju Development Project. As of 2015, the population of Paju City was 433,052 people in 171,753 households, having grown by 4.43% per annum for 10 years.

Figure 5. Paju Population Trend (2002-2013)
Source: Paju Mid-to Long-Term Development Plan, Paju City

1.1.4 Waterworks Facilities and Operation & Management Status

Prior to the SWC, Paju City commissioned K-water to operate its water management facilities. As of 2014, the total number of water users in Paju was 406,000, with a total water supply of 46,386,000 m3 / year and a household water supply rate of 96.6%. Paju sources its water from the Imjin River and Paldang Dam, which are situated to the west and southeast of Paju respectively. The water pipe network of Paju is 1,472 km, with 49 pumping stations and 44,033 service connections. The pipe network is in relatively good condition. Water supply (per capita, per day) is 361 litres (L), and sewer penetration rate is 79.5%.

Table 2. Paju Water Supply Use (as of 2015)

Year	Total Population	Served Population	Service Rate (%)	Facilities Capacity (m³/day)	Per Person Per Day Water Supply(L)
2008	319,395	272,073	85.2	225,000	370
2009	331,504	302,818	91.3	225,000	350
2010	364,223	335,254	92.0	120,297	304
2011	387,273	365,390	94.3	156,000	305
2012	402,126	382,709	95.8	100,800	297
2013	410,158	393,575	96.0	225,000	373
2014	420,526	406,145	96.6	225,000	361
2015	433,052	426,123	98.4	553,500	351

Source: Paju Statistical Yearbook (2015)

Paju City has two water treatment plants; Munsan Water Treatment Plant (96,000 m³ / day), which receives water from the Kumpa water intake plant in the Imjin River and supplies tap water (65,000 m³ / day), and the Goyang Water Treatment Plant (210,000 m³ / day), which receives water from the Paldang Water Intake Plant and supplies tap water (74,000 m³ / day). Both standard water treatment processes and advanced water treatment processes are in operation in Paju City.

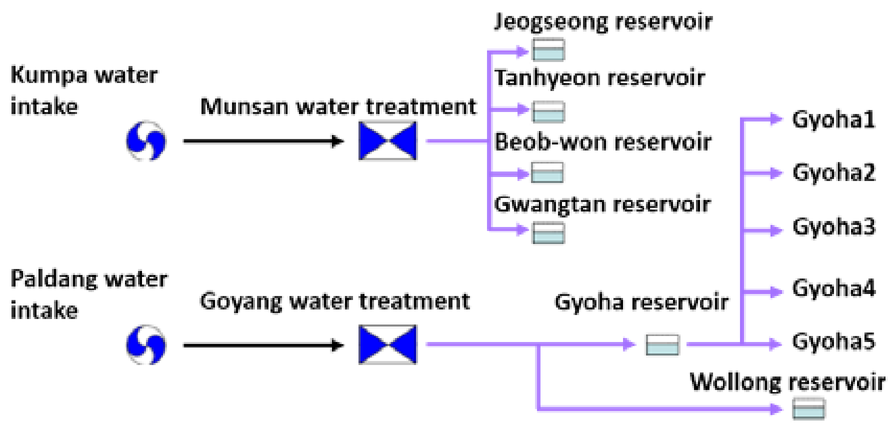


Figure 6. Paju Water Supply System

Table 3. Paju Water Supply Status (2015)

	Water Treatment Plant	Facilities Capacity (m³ / day)	Water Supply (m³ / day)	Reservoirs
Local Waterworks	Munsan Water Treatment Plant	96,000	65,000	Jeogseong, Tanhyeon, Beob-won, Gwangtan, Munsan
Multi-Regional Waterworks	Goyang Water Treatment Plant	210,000	74,000	Gyoha, Wollong

Box 1. Paju's Natural Environment

In Korea, 65% of the land is mountainous, the topsoil of the soil is thin, and the river slopes are steep, this results in reduced ability for watersheds to regenerate themselves and in floodwaters being discharged all at once. Paju City is located in the mid-western part of the Korean peninsula and in the northwest part of Gyeonggi Province. The area of the city is about 30km in length east-west and 36km in length north-south. Paju has a unique terrain, not found in other parts of Korea. The topography of Paju is a rectangular obsidian form, and the eastern part is composed of mountain areas connected to Mt. Gamak, Mt. Papyyeong, and Mt. Goryeong. It is also composed of flat land formed along the lava site of the Imjin River basin, where vertical cliffs formed by river erosion have created a canyon filled landscape.

1.2 Water Status in Paju City

1.2.1 Water Resources Status

The average annual precipitation in Paju is 1,223mm (Korea's annual mean precipitation is 1,227mm), and the precipitation in July and August accounts for 47.1% of the annual total. Fluctuation in runoff is consequently high, with peak flows in summer.

In addition, Paju has an abundance of water resources including four national rivers, 30 regional rivers and 76 small rivers. Among them, the main rivers of Paju are the Han River, which is facing the west, and the Imjin River, which flows into the Han River through the south. Imjin River (51%) and Han River (49%) are used as water sources, and agricultural irrigation canals are used in the Paju and Kyongha Plains, respectively. Other small streams, such as

Gwacheon, Gobyeon River, Nulchon, and Tanpongchun, along with the Imjin River, Munsan River, and Gongneung River, are continuously improving river flood prevention.

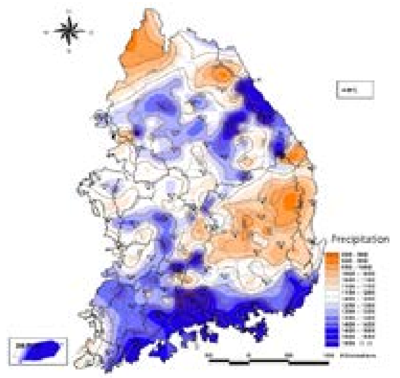


Figure 7. Annual average precipitation distribution by region (Source: Long-term comprehensive plan for water resources (2011 - 2020), Ministry of Land, Transport and Maritime Affairs)

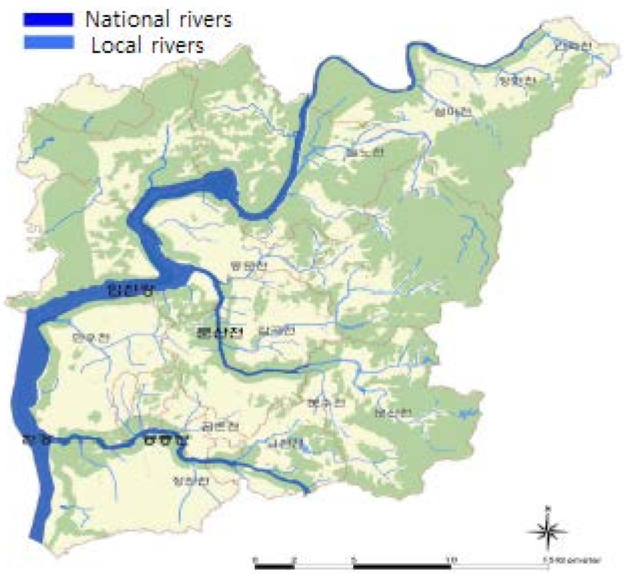


Figure 8. Paju River Status Map (Source: Paju Mid- to Long-term Development Plan, Paju City)

1.2.2 Water Quality Status

Paju lies downstream of the Han River. The Biochemical Oxygen Demand (BOD) pollution level of Paju declined over a five year period from 2008 to 2012. Since 2011, the annual average water pollution rate has decreased. The water quality targets of the central branch station of the lower stream of the Han River in 2012 were achieved with BOD 3.6mg / L and T-P 0.33mg / L. The water quality of Paju was rated grade III [1]at BOD 3.0mg /L in 2012, compared to 5.2mg / L in 2008. In addition, Chemical Oxygen Demand (COD), and Total Phosphorous (T-P) for 2012 improved compared to 2008, and the COD / BOD ratio increased to 2.3 from 1.8 in 2008.

1. The Ministry of Environment in Korea has set seven criteria (Table 4) for the river water quality based on BOD, COD, T-P, SS (Suspended Solid), etc. as provided by the Enforcement Decree of the Framework Act on Environment Policy)

Looking at the trends of water quality change from 2008 to 2012, the BOD standard is in the range of 3.0 to 5.5 mg / L ("normal to slightly better"), but the improvement trend is in the range of 6.7 to 9.1 mg / ("slightly worse" rating), but has been steadily decreasing since 2008. T-P has been increasing and decreasing in the range of 0.211 to 0.467 mg / L ("slightly worse"), however since 2009 has been decreasing.

Table 4. River Water Quality Standard

Grade	Biochemical Oxygen Demand (BOD, mg/L)	Chemical Oxygen Demand (COD, mg/L)	Total Phosphorous (T-P, mg/L)
Ia	1 ≤	2 ≤	0.02 ≤
Ib	2 ≤	4 ≤	0.04 ≤
II	3 ≤	5 ≤	0.1 ≤
III	5 ≤	7 ≤	0.2 ≤
IV	8 ≤	9 ≤	0.3 ≤
V	10 ≤	11 ≤	0.5 ≤
VI	10 >	11 >	0.5 >

Source: http://www.wamis.go.kr/WKE/wke_wqbase_1st.aspx

Table 5. Lower Part of the Han River <Middle Branch Station (Paju) Water Quality

Substances	2008	2009	2010	2011	2012
BOD(mg/L)	5.2	5.5	4.1	3.0	3.0
COD((mg/L)	9.1	8.1	6.9	6.7	6.9
T-P(mg/L)	0.361	0.467	0.298	0.326	0.211
COD/BOD ratio	1.8	1.5	1.7	2.2	2.3

Source: "Han River Submerged Land Water Environment Management Plan", Han River Basin Environment Agency

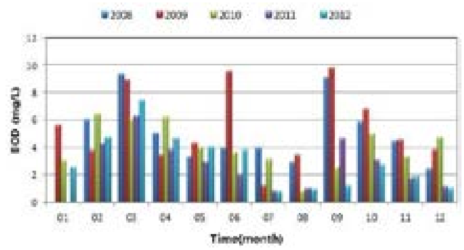


Figure 9. Changes in Monthly BOD According to the Central Branch Station Representative Year

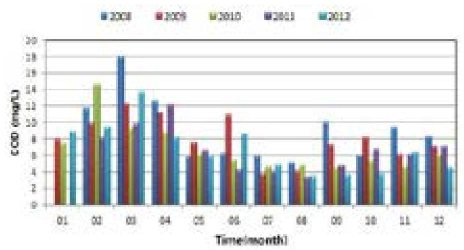


Figure 10. Change of Monthly COD According to the Middle Branch Station Representative Year

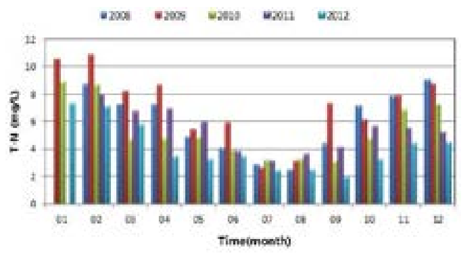


Figure 11. Change of Monthly T-N According to the Central Branch Station Representative Year

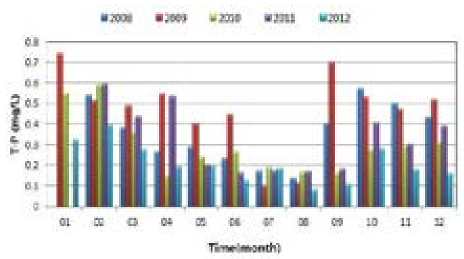


Figure 12. Change of Monthly T-P According to the Chubu Branch Station Year

Source: "Han River Submerged Land Water Environment Management Plan", Han River Basin Environment Agency

On the other hand, monthly water quality changes show that the best water quality is in summer (July-August) and lowest water quality in is winter (February to March). It is considered that this is due to both the self-purification effect that occurs with the increase of microbial activity due to the rise of the water temperature and also due to the dilution effect by the increase of the flow, which results from the summer flood.

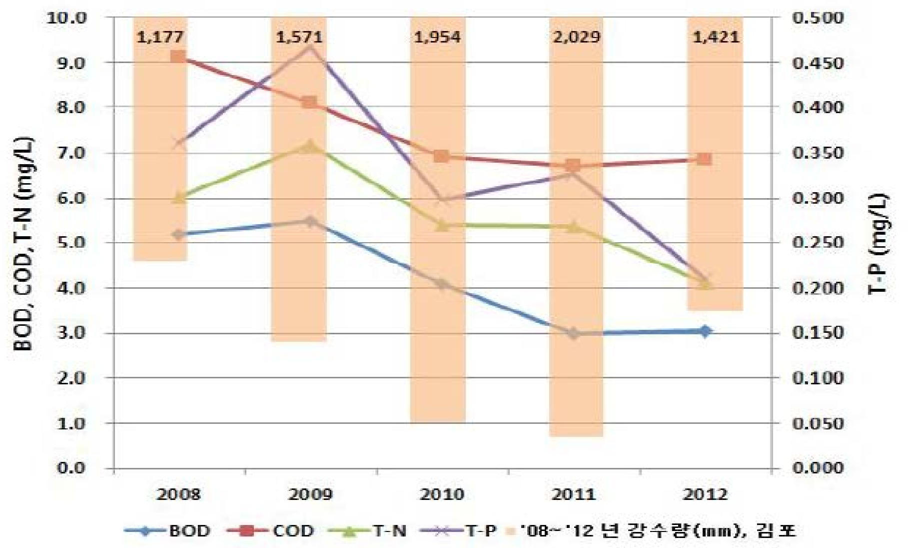


Figure 13. Annual Changes in Water Quality and Precipitation Downstream of the Han River in Paju
Source: "Han River Sub-regional Water Environment Management Plan", Han River Basin Environment Agency

In the case of the Imjin River in Paju, the BOD changes in the river according to the year between 2006 and 2011 showed that the average BOD of 2.2 mg / L in 2011 was slightly better than the river water quality gradeII and that the water quality was found to be good. In detail, the river water quality grade of Munsan Stream maintains the III grade (average) over a period of 6 years with an average BOD of 3.05mg / L, BOD (mg / L) of Gongreung Stream and Munsan Stream is slightly lowered, BOD (mg / L) remained similar to the past.

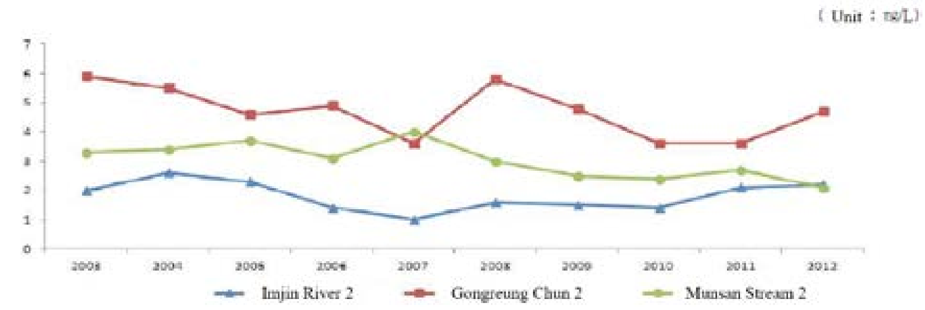


Figure 14. Change of Water Quality in the Imjin River in Paju (BOD)
Source: Water Environment Information System Homepage (http://water.nier.go.kr/)
Imjin River 2: Paju City, Gyeonggi Province
Gongreung Chun 2: Cho Ri-eup in Paju City, Gyeonggi-Province(do)
Munsan Stream 2: Bongam-ri, Paju-eup, Paju-si, Gyeonggi-Province(do)

1.3 Water Challenges in Paju City

1.3.1 Low Tap Water Drinking Rate

Despite Korea being recognized worldwide as having excellent quality tap water[2], only 5% of the community drink tap water due to a distrust in and anxiety about the tap water quality, taste and smell, and in Paju it is as little as 1%. In particular, 30.8% of respondents surveyed by K-water in 2014 were concerned about the water quality from water tanks and pipes, and 28.1% were concerned about water pollution (see Figure 15). The reasons for low tap water drinking are mainly due to the negative images and concerns about tap water. This drinking water rate is extremely low compared with advanced countries such as the US (56%) and Japan (52%).

As a result of this low drinking rate, K-water is making efforts to continuously increase investment and operation to improve the quality of tap water, such as introducing advanced water treatment technology and strengthening water quality standards, thereby contributing to improving public health and living standards.

As part of these efforts, K-water required a sustainable water management plan to address the social and environmental aspects of water quality and to eliminate any anxieties about tap water. The plan also aims to maximize water use efficiency through systematic management of water quality and water quantity, and to improve the tap water drinking rate through smart water management using cutting-edge ICT (information and communicationi technology).

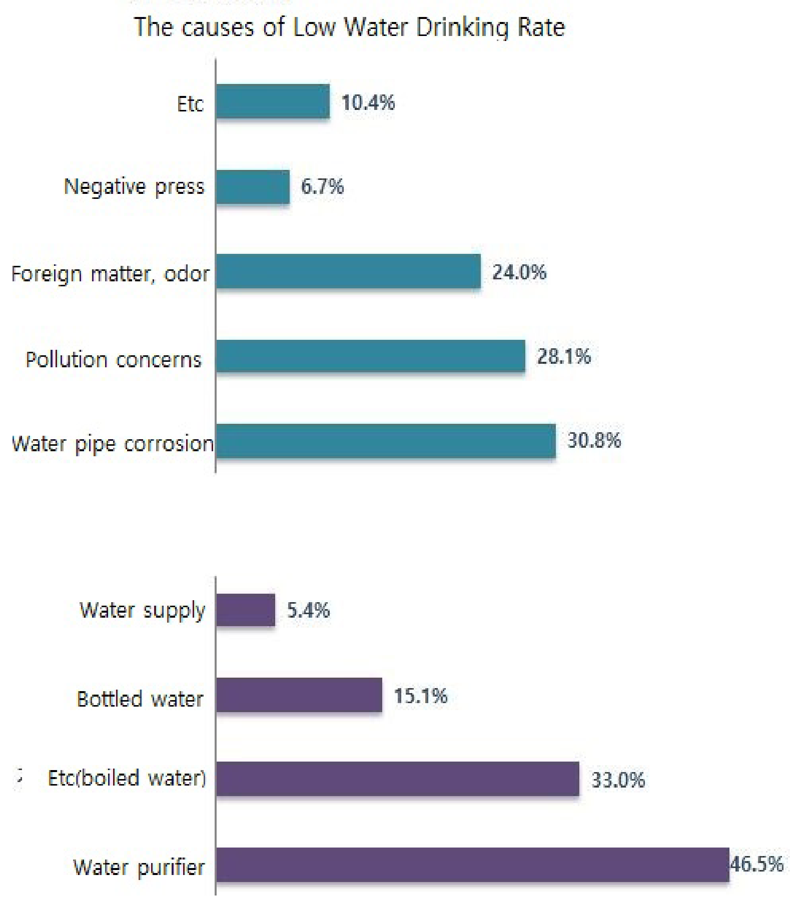


Figure 15. Drinking Water Status
Source: K-water, 2014

2. According to the UN's national water quality index, Korea ranked 8th out of 122 countries and ranked 7th at the 22nd World Water Tasting Tournament held in 2012, competing with 32 advanced countries.

As shown Figure 15, 79.5% of those surveyed said they did not drink tap water without further treatment in their homes, with 46.5% using a water purifier and 33% boiling the water to improve the taste and quality of the water, while only 5.4% of people drink tap water without any treatment.

2. Economic, Environmental, Policy and Technical Factors in Paju Smart City

2.1 SWC Investment in Paju

The budgets of the major sectors in Paju have been gradually increasing since 2014. In addition, the change in the budget scale for major sectors related to the technology business shows that it has increased year-on-year in most technology development sectors. The growth rate in the urban development sector was in the order of urban development (98.8%), public development projects (42.4%), infrastructure (29.0%) and sewerage (19.2%). The budget of the waterworks and sewerage is about 43 billion won (37.4 million USD) and 50 billion won (43.5 million USD) respectively, indicating that technology budgets are concentrated in connection with water supply and sewage systems.

Table 6. Paju City Technology-Related Budget (Unit: KRW 1,000 won)

	2014	2015	Variation	%
Public Development	778,690	1,109,127	△330,437	△42.4
Urban Development	89,484	1,110	△88,374	△98.8
Infrastructure	119,586	154,300	△34,714	△29.0
Waterworks	43,789,771	43,971,431	△181,660	△0.4
Sewers	62,843,862	50,750,799	▽12,093,063	▽19.2

Source: Paju City (www.paju.go.kr)

In addition, the size of research and development (R&D) investment for the establishment and development of smart water management (SWM) technology in Korea is steadily increasing from 5.4 billion won (4.7 million USD) in 2013, 7.5 billion won (6.5 million USD) in 2014 and 7.9 billion won (6.9 million USD) in 2016. The government is planning to increase to 10 billion won (8.7 million USD) by 2020 (MOLIT 2016).

In accordance with this trend, Paju invested 2 billion won (1.7 million USD) into the Paju Smart City project (as a pilot project for healthy tap water supply) over three years (from Phase 1 in 2014 to Phase 3 in 2016) and 5.8 billion won (5 million USD) for K-water during this time. The project was based on the agreement on improvement of the water supply network and stability of tap water supply and on water quality management and water quality information using ICT.

Table 7. Overview of the SWC Project in Paju

	Total	Phase 1	Phase 2	Phase 3
Period	'14.4 ~'16.12	'14.4 ~'15.3	'15.4 ~'16.3	'16.4 ~'16.12
Area	All Paju Areas	Gyoha·Jeogseong (Water supply population: 37,000)	Phase 1 + Wolong Area (Water supply population 223,000)	All Paju Areas (Water supply population 406,000)
Expense	7.8 billion won	2.9 billion won	1.8 billion won	3.1 billion won

Source: K-water

2.2 Environmental Factors

2.2.1 Water Quality in Paju City

As a result of examining the water quality of Munsan water treatment plant in Paju City, microorganisms such as coliform bacteria and other general bacteria[3] were found to be below the reference value or not detected, and the amount of oil and inorganic substances having harmful effects on health was measured to be significantly below the standard values. In addition, all of the aesthetic substances such as taste, odor, color, zinc and iron were much lower than the standard values. Moreover, the disinfectant and disinfection by-products were lower than the standard values. So, it is clear that the water quality in Paju City is safe overall, however to improve perceptions of the water quality within the community it was still deemed appropriate to improve the water quality to the highest possible standard.

Table 8. Results of Microorganism Testing at Paju Water Treatment Plant

	General bacteria (CFU / mL)	Total coliforms (MPN)
Standard	100	-
Measures	0	Non-detection

Source: National Waterworks Information System

Table 9. Results of Testing for Organic and Inorganic Substances that are Harmful to Health at Paju Water Treatment Plant

	Carbon tetrachloride(mg/L)	Phenol(mg/L)	Lead(mg/L)	Fluorine(mg/L)
Standard	0.002	0.005	0.01	1.5
Measures	0	0	0	0

Source: National Waterworks Information System

Table 10. Results of Aesthetic Impact Substance Testing at Paju Water Treatment Plant

	flavor	smell	Chromaticity (degrees)	Zinc (mg/L)	Iron (mg/L)	Manganese (mg/L)	Turbidity (NTU)
Standard	No flavor	Odorless	5	3	0.5	0.05	0.5
Measures	None	None	0	0.004	0	0	0.04

Source: National Waterworks Information System

2.2.2 Quality of Tap Water at Paju Water Treatment Plant

Tap water quality was assessed in September 2016 on three old water faucets in Paju. The results showed that no E. coli was detected, ammonia nitrogen was '0', the pH level was adequate, and appropriate amounts of zinc and chlorine ion were detected and did not affect water quality.

2.3 Policy Factors

2.3.1 Government Water Management Policy

In 2010, the Korean national government launched research and development (R&D) into smart water management and related technologies as part of a new growth engine strategy. According to the government's SWM roadmap, the focus is on mid- to long- term technology development and budgeting, and in the short-term commercialization that supports the activation of private investment. By 2030, the government plans to promote the management of a demonstration complex with the aim of building a nation-wide SWM system and to establish a base city for each of the 7 major metropolitan areas[4]. As a result,

3. It refers to various bacteria other than pathogens in water and is generically called aerobic bacteria and anaerobic bacteria.
4. Seoul, Busan, Daegu, Incheon, Kwangju, Daejeon, and Ulsan.

efforts have been made to improve water management by ICT in the water sector. Since 1999, the government has established a detailed plan to build a comprehensive information system for national water resources management, and is constantly promoting the water management information system.

Box 2. SWM Research Trends and Cases in Korea

Korea has been interested in smart water management since 2010 and has developed various related technologies. The Ministry of Land, Infrastructure and Transport formed and supported a research group to develop and implement practical water service technologies for five years from 2012. This SWG Research Group pursued three projects; (1) Water resources and distribution management (2) Water supply and demand assessment, Integrated water management, and (3) ICT based water resources management. The goal of the first project was to develop intelligent water resources operations technology, to improve the water independence rate[1] (reducing the reliance on external water sources) by 30% and reduce energy costs used in water resources operations by 10%. The second project aimed at developing an intelligent watershed management platform for regional water shortage risk assessment, real-time water supply management, and intelligent water supply and demand integrated information management. The third project aimed to develop a two-way remote meter reading system and water information service using ICT.

The Smart Water Grid Research Group was comprised of three cooperative organisations under the supervision of Incheon National University, 10 consultants, 8 consigners and 44 participating companies (Incheon National University and 54 others).

Source : Lee Sang-ho (2015), Global Competition, Smart Water Service, Journal of Water Policy and Economy, April 2015 Vol.24

Moreover, in accordance with the shift in focus from obtaining a "safe water supply" in the 1990s to moving towards a "tastier and healthier water supply," since 2000, the government and K-water are implementing the ‘*Healthy water for the human body’ program.* This healthy water supply program goes beyond traditional methods to supply safe water by providing minerals in the tap water through the management of water quantity and water quality from source to faucet. The program includes the use of SWM, providing relevant, real-time information about tap water that can be trusted by the community at anytime and location.

As part of this SWM approach K-water is pursuing five major objectives: 1) intake source water management; 2) water treatment system optimization; 3) intelligent distribution network management; 4) customized industrial water supply and; 5) wastewater treatment operating efficiency.

Figure 16. Concept of the Healthy Water Supply Program of K-water
(Source: K-water)

Table 11. K-water's Healthy Water Supply Project

	Details
Water Quality Management of Water Resources	• Developing a prediction system that can monitor the occurrence of algae odor substances in advance to establish a preventive water quality safety management system • Establishing preemptive response measures for water quality such as algae through the operation of real-time algae odor measurement system and an on-line toxin on-line measurement system
Water Treatment System Optimisation	• Operating water safety management techniques and water treatment process diagnosis programs to strengthen healthy tap water production system that everyone trusts • Introducing of a cutting-edge water supply system including the location of water purification facilities near consumers using new concepts based on vertical water treatment technology
Intelligent Network Operation	• Collecting operational data for the entire water supply process from water source to faucet and building a remote real-time monitoring control operating system based on ICT • Analysing the collected data to realise healthy water supply through the intelligent network operation system that can manage quantity, water quality and energy, such as supply of uninterrupted water and improvement of reasonable facilities
Efficient Sewage Treatment Operation	• Constructing and operating sewerage upstream of the dam to improve the living environment, including improvement of river water quality and of public sanitation • Establishing a clean and stable water circulation system through participation in large-scale sewage projects by private investment

Within the *‘Healthy Water Supply Program’* the Smart Water City (SWC) project acts as a consumer-oriented SWM system that adopts the paradigm of "healthy water supply to the human body." The purpose of the Paju SWC project is to improve the reliability of tap water by providing scientific information on water quality and ICT based water quality management, strengthening water supply stability and efficiency, and providing water quality information to the people. In addition, by integrating ICT throughout the supply process from water source to tap, water quantity and water quality is scientifically managed to create a city where consumers can trust and drink the water from the tap.

2.3.2 Water Management Policy of Paju City and Consignment and Operation Management of Water Supply Facilities

Paju is making plans in the fields of natural ecology, soil and ground water, air, water quality, water and sewage, noise and vibration, water resources, energy and waste for environmental management. In water management, it is necessary to expand water quality monitoring capabilities, enhance sewage treatment plants (increasing the treatment area, the population and improving the sewage treatment rate), manage pollution sources at the level of total pollution management and promote public participation.

Paju City is expanding the water supply and water purification systems in rural areas to meet citizens' demand for high quality of water supply and sewage treatment. In 2014, Paju City increased sewage treatment facilities in major areas and is planning additional expansion of sewage treatment facilities and sewer maintenance plans in preparation for rapid population growth.

2.4 Technical Factors

Business Overview (Innovative Smart Water Management Technology Solution Proposed)

The Paju SWC project provides a total solution for tap water operation and management including GIS and real-time measurement data, water supply, water quality crisis management and demand forecasting. Included in this SWC project is water-NET, a system developed by K-water to monitor and analyze the entire process of tap water supply using real-time ICT. The main SWM solutions provided in this project are shown below in Figure 17.

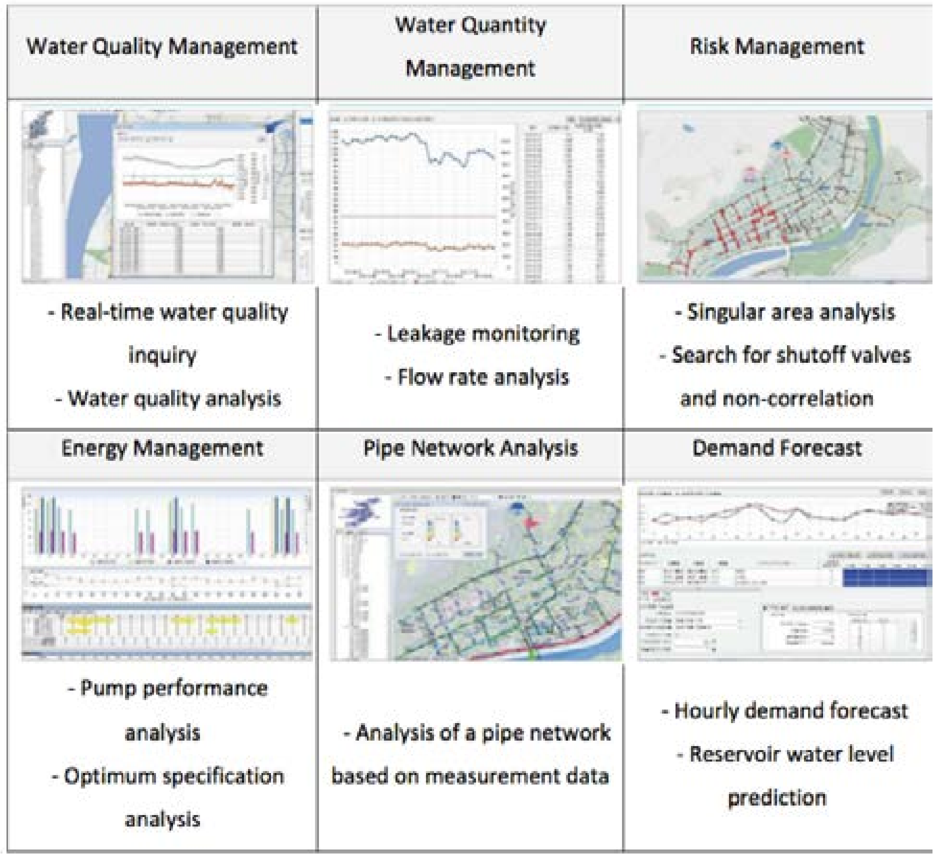


Figure 17. Main Functions of Regular Water Supply Management System Applied to the Paju Smart Water City Pilot Project
(Source: K-water)

Developed by K-water, water-NET consists mainly of two programs: Dr.Pipe and Net.Operation. Dr.Pipe is a water pipe diagnostics program, which uses performance evaluation and diagnostic software to promote technological realization of the *'Preliminary Diagnosis Post Improvement'* policy, proposed to perform maintenance and improvement of the water pipe network more efficiently and reasonably. It supports the establishment of an optimal network improvement plan based on the diagnosis and evaluation of pipeline information, repairs, water quality and facilities.

Net.Operation is a water network operation management program which is comprised of modules including real-time pipe network analysis, water quantity, water quality, crisis and energy management based on GIS and real time data, water pressure, and real-time leakage monitoring and leakage estimation.

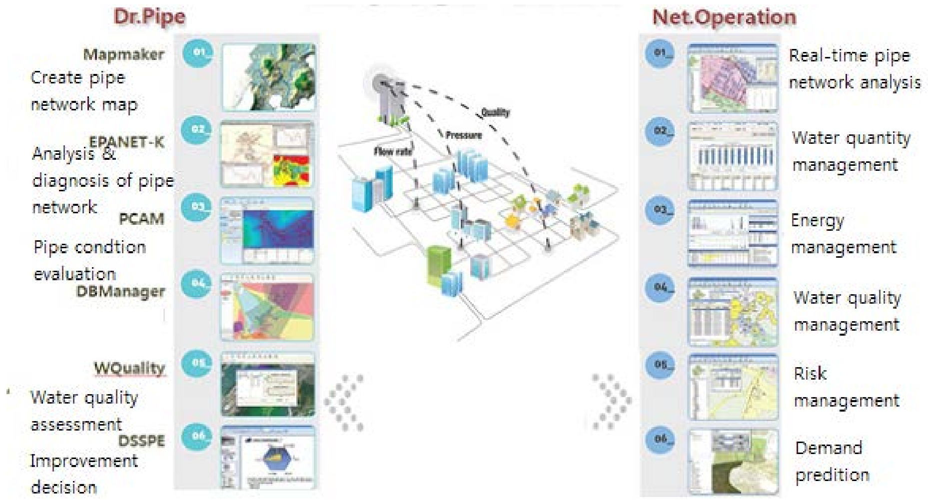
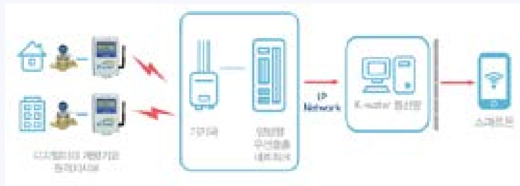


Figure 18. Water-NET system diagram applied to the Paju Smart Water City Pilot Project

Table 12. Major Technologies applied to the Paju SWC Pilot Project

Residual chlorine equalisation	Technology to improve water quality, safety and chlorine taste and smell by dispersing injection of disinfectant (chlorine) into the reservoir and pipeline to prevent propagation of pathogenic microorganisms		
Automatic drainage system	The technology to clean the pipes at all times through the automatic discharge of excess pollution and the length of time the water remains in the pipe through real-time water quality measurements of the tap water supply pipes		
Tube cleaning	The tube cleaning technique includes an air bubble injection method in which compressed air is injected into a tube to discharge foreign matter through contraction and expansion and a sponge- Injection method	 1) Air bubble injection method	 2) Sponge injection system

Exploration with continued water supply	As a technology to check the internal state of the pipe without stopping the supply of tap water, long-distance unmanned aerial surveying equipment (Sahara) is able to survey D300mm or more, water pressure under 14kgf / cm2, maximum 1.8km, -15) is more than D 150mm · Water pressure is less than 7.5kgf / cm2 · It is possible to survey up to 1.8km	
Remote leak monitoring	A technology that detects leakage sounds from a buried pipe and detects frequency and amplitude to determine leakage and predict leakage points	
Smart metering	Technology that provides usage and charge information through a smartphone app by analysing usage amount, abnormal flow rate, leakage, etc. based on time data acquired through digital meters	

3. Outputs and Outcomes of the Paju SWM Pilot Project

3.1 Water Quality Improvement

The Paju SWC Pilot Project contributed to the improvement of water quality at the Paju City water treatment plant. The residual chlorine leveling operation resulted in the equalization of residual chlorine in the supply process as well as supplying healthier water based on the effects of the improvement of water quality in the Munsan and Goyang areas due to the reduction of byproducts generated during disinfection. The effect of reducing the residual chlorine concentration differed in the Munsan and Goyang areas by 29.2% and 17.2%, respectively. In the case of the Munsan water treatment plant, the amount of disinfectant (chlorine) injection required was reduced by 8.9%, and the disinfection by-products (THMs) in the entire supply period decreased by an average of 22.9% (0.0498 → 0.0384mg / L).

In the water treatment process, chlorine acts as a disinfectant, but it also causes tap water to have a distinctive odor and taste. Residual chlorine makes the taste of tap water bitter and when an excessive amount of chlorine is added to tap water, it can cause problems to the human body such as lowered immunity and increases in harmful active oxygen. In some cases, trihalomethanes (THMs) form when organics (humus) and chlorine, which is injected during the tap water chlorine disinfection process, are combined. According to the US Environmental Protection Agency (EPA) standards, trihalomethanes are classified as a carcinogen and should not exceed 0.1 mg per liter of tap water.

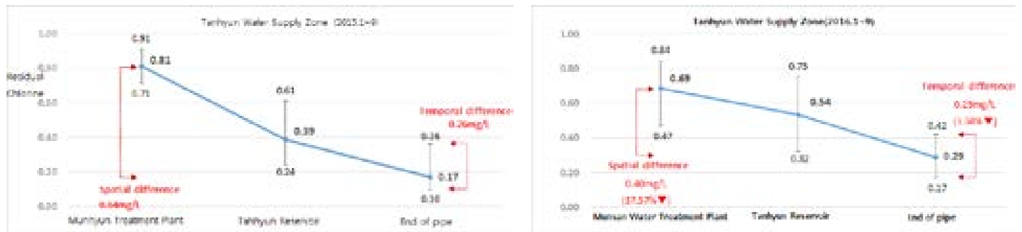
Therefore, in order to maintain the disinfection ability yet avoid undesirable taste and odor of tap water, residual chlorine should be kept constantly below a certain level.

In order to solve the problem of excess residual chlorine in the potable water system, a disinfectant dispersion injection system was developed. In a conventional tap water supply system, the system injects the disinfectant once only until the tap water is delivered to the consumer. Therefore, the water company was forced to inject the disinfectant based on the average time from the water treatment plant to the faucet, which caused a difference in the concentration of the disinfectant depending on the location of the consumer. Due to differences in the concentration of the disinfectant, the taste, odor, and water quality of the tap water could not be guaranteed. Nonetheless, the concentration of disinfectant in the demonstration area can be maintained at the same level by dispersing the disinfectant in relation to the time difference between when the tap water was used in each region.

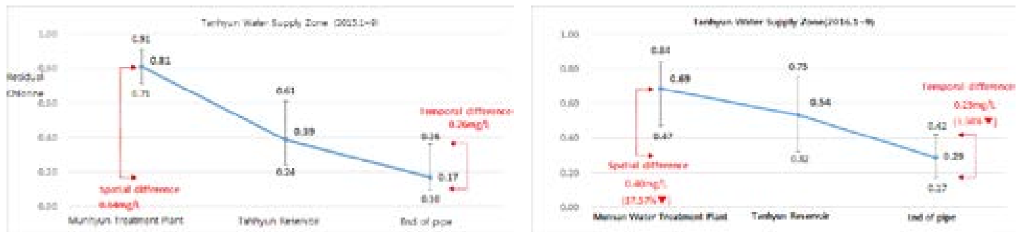
Table 13. Status of Residual Chlorine Equalisation

Water purification plant	Water supply area	Spatial distribution			Temporal distribution		
		2015 (Δmg/ℓ)	2016 (Δmg/ℓ)	% Change	2015 (Δmg/ℓ)	2016 (Δmg/ℓ)	% Change
Average change rate		-	-	↓17.24	-	-	↓29.20
Munsan	Jeogseong	0.50	0.43	↓14.00	0.42	0.13	↓69.05
	Gwangtan	0.45	0.37	↓17.78	0.34	0.31	↓8.82
	Tanhyeon	0.64	0.40	↓37.50	0.26	0.25	↓3.85
	Beob-won	0.46	0.38	↓17.39	0.20	0.15	↓25.00
	Munsan	0.39	0.37	↓5.13	0.35	0.22	↓37.14
Goyang	Gyoha	0.35	0.21	↓40.00	0.36	0.30	↓16.67
	Wollong	0.18	0.20	↑11.11	0.41	0.23	↓43.90

* (Spatial distribution) Residual chlorine concentration difference from water purification plant to tiller / (temporal distribution) Residual chlorine concentration difference



Reduction of Spatial and Temporary Residual Chlorine Concentration Difference Between Before and After Operation of Tan-Hyeun Drainage Area Re-chlorinisation Facility



Residual chlorine titration before / after disinfectant injection amount
Disinfectant injection volume reduction rate

Figure 19. Monthly disinfectant injection volume change at Munsan water purification plant
(Source: K-water)

Table 14. Change in all-process disinfection by-products (THMs) reduction unit: mg/ℓ

	Average	Jeogseong		Tanhyeon		Gwangtan		Beob-won		Munsan
		Reservoir	End of pipe	Reservoir	End of pipe	Reservoir	End of pipe	Reservoir	End of pipe	end of pipe
‘15. 9	0.0498	0.048	0.050	0.047	0.053	0.045	0.053	0.048	0.050	0.054
‘16. 9	0.0384	0.038	0.040	0.034	0.038	0.036	0.041	0.036	0.042	0.041
Reduction rate(%)	22.9	20.8	20.0	27.7	28.3	20.0	22.6	25.0	16.0	24.1

Source: K-water
* Water quality standard of drinking water THMs (total trucholymethane) 0.1 mg / ℓ or less
(chart above -Munsan has no “reservoir” column- double check it is not a mistake)

In addition, the quality of the drainage pipes were improved, especially indoors and in poor quality areas. The analysis of 14 out of 15 areas of the drainage pipe resulted in a decrease of 27 - 89% in the concentration of sediments in the pipes. In addition, water quality analysis of 168 samples across 660 indoor water pipe cleaning points showed the improvement of domestic water quality (11.8% of residual chlorine standard) as well as positive effects in terms of turbidity, iron and copper.

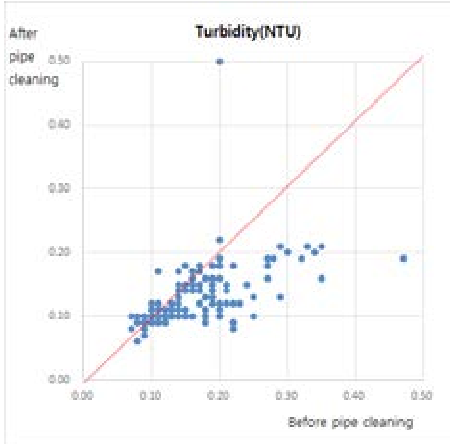
Float particle concentration before and after cleaning	Reduction rate of suspended particle concentration

Figure 20. Change in the Concentration of Suspended Particles During Pipe Cleaning
(Source: K-water)

Table 15. Water Quality Analysis Results Before and After Indoor Pipe Cleaning

	Residual chlorine(mg/L)	Turbidity (NTU)	Iron (mg/L)	Copper (mg/L)
Water quality	0.1~4.0	0.5 or less	0.3 or less	1.0 or less
Before cleaning	0.204	0.165	0.017	0.023
After Cleaning	0.228	0.127	0.006	0.016
Variation	↑0.024	↓0.038	↓0.011	↓0.007
Rate of change(%)	↑11.76	↓23.03	↓64.71	↓30.43

Source: K-water



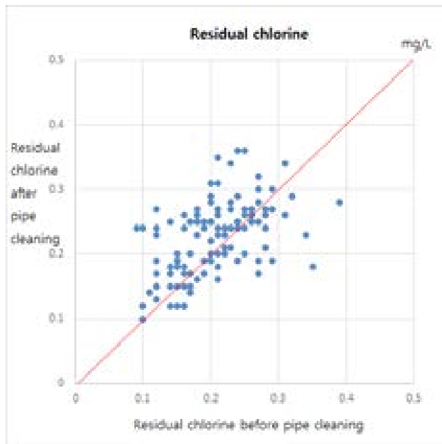


Figure 21. Turbidity before and after pipe cleaning
Figure 22. Residual chlorine before and after pipe cleaning

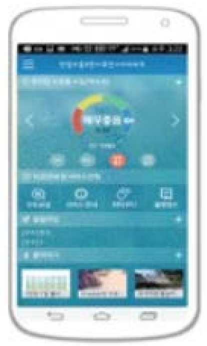
3.2 Social Performance

3.2.1 Establishment of a Real-Time Information Exchange System

In 2014, the first phase of the Paju SWC Pilot Project commenced to supply 37,000 people in two regions in the Paju area. By 2016 (the third phase) the total area of Paju was included, with supply provided for 444,000 people. As part of the project, each household in Paju can install leak detection sensors and automated water quality meters in their water pipes to measure leakage and water quality in real-time, with measurement results provided by way of outdoor water quality signboards and a smartphone application. In addition, an automatic drain that discharges water pollutants can prevent water quality accidents in advance. As the revenue water rate of Paju was 86.6% in 2014, which was higher than other local water management facilities, leak detection monitors were not considered a priority for the project. However, as leaks tend to occur after a certain period of time without careful management, K-water included leak detection tools to ensure the revenue water continued at a high rate in the future.

By installing and operating water quality measuring instruments at major points in the supply process such as water treatment plants, pipelines, reservoirs, and apartment water tanks, real time water quality information measured during the entire tap water supply process can be directly confirmed through electric signboards and a smartphone app. Also, a variety of convenient functions are offered such as water quality and billing information, application for customized water services, and customer satisfaction reports through the smartphone application.

(1) Water quality signboard service in front of an apartment



(2) Smartphone Application Service

Figure 23. Real-Time Water Quality Information Services
(Source: K-water)

In addition to the monitors and real-time updates, many drinking fountains have been installed in apartment buildings, and indoors and outdoors in elementary schools, with water quality information analyzed and disseminated in real time to manage and inform customers of water quality at all times. These drinking fountains contribute to creating a new tap water drinking culture by improving transparency and trust within the community. Real-time information provides citizens with the opportunity to get acquainted with clean and healthy tap water.

(1) Tap water station at an elementary school

(2) Tap water fountains at an apartment

Figure 24. Tap Water Fountains in Paju
(Source: K-water)

3.2.2 Customized Customer Service Implementation

In order to improve the general public's trust in tap water, residents of Paju can also request a 'Water Codi[5]' to check the water quality of each home and a 'water doctor' service is provided to check the condition of indoor water pipes and to wash the pipes when needed. As part of this service a 'Water Codi' operator, equipped with water quality measurement devices, visits and measures the water quality of the tap water, and inspects the sanitary condition by inserting endoscopic equipment in the water pipe. 'Water Codi" actions are divided into two steps. First, a test is conducted to assess five parameters including turbidity, hydrogen ion concentration (pH), residual chlorine, iron and copper. Then, in a second test, the drinking water quality inspection agency conducts a test to check the reference level. At this time, the first item is inspected again, and the bacteria, total coliform, coliform, zinc, manganese, and ammonia nitrogen are further inspected. The pilot project was conducted for the purpose of guaranteeing the quality of tap water through 'Tap water safety assurance' so as to drink tap water comfortably, and to conduct various water tap water quality inspection services.

Figure 25. 'Water Codi' Services

5. "Water Codi" is a contract worker employed by K-water specifically for the purpose of improving customer satisfaction by proactively performing customer management services such as water quality inspections and management of local waterworks and households.

Table 16. Tap Water Relief Assurance Service

Type	Services
Water pollution inspection	• Water quality inspection or water quality inspection
Self-inspection	• Conducts water quality inspections (circulation in the same area) • Daily inspections area selected for inspection only
Booth type group inspection	• Inspection of tap water from customers who visit a water quality inspection booth • Examination of large complexes such as apartments

3.3 Improvement of Revenue Water Rate

After 500 leak detecting sensors were installed in three small blocks with high non-revenue water (water which is lost to leakages) in Paju, the water network's managers were able to detect the location of the leakage points, enabling them to repair leaks quickly. The quick repair of leaking areas resulted in a reduced average leakage of 1,521m3/ day, which means that the revenue water rate improved by an average of 13.38% over the course of the project. As a result, the economic efficiency of 515 million won (447,826 USD) was achieved.

Table 17. Leakage Recovery and Non-revenue Water Rate

Location	Leak quantity (estimation) (m^3/day)	Revenue water (%)		
		Before application	After application	Improvement effect
Total (Average)	1,520.6	74.32	88.52	13.38%p↑
GH 1-3	355.7	71.91 (Jan~May, 2016)	88.08 (Jun~Oct, 2016)	16.17%p↑
BW 1-1	397.0	76.73 (Jan~Aug, 2016)	94.05 (Sep~Oct, 2016)	17.32%p↑
JS 1-1	767.9	76.77 (Jan~Sep, 2016)	83.43 (Oct, 2016)	6.66%p↑

3.4 Technical Performance

3.4.1 Homogenization rate of residual chlorine

The SWC pilot project was a challenging project that solved many of the existing tap water problems that were previously mentioned in this report. In relation to the challenges associated with too much chlorine in the water supply, the chlorine injection step was applied not only to the water purification plant process but also to the faucet. By choosing a system, which can inject the disinfectant locally, the homogenization[6] rate of residual chlorine in tap water was improved to a range of 24.3 - 36.4%. That is, the increase in the homogenization rate of the residual chlorine eventually weakens the odor of tap water, thereby reducing the discomfort of water users.

3.4.2 Reduced contamination in tap water

The indoor pipe cleaning, which was included as part of the SWC pilot, reduced pollution caused by contaminated tap water in the water treatment plant. As a result, in the SWC business district, the average number of civil complaints on tap water quality was reduced from 4.5 per month to 1.3 per month (a decrease of 71.1%).

6. Homogenization is to disperse each component of a heterogeneous mixture into particles or molecules phases to homogenize the whole.

4. Social, Environmental and Economic Impacts of the Paju SWM pilot project

4.1 Links with Sustainable Development Goals

The SWC project aimed to improve the drinking rate of tap water and increase water utilization by reducing water leakage. The reduction of water usage by minimizing water leakages can also reduce the amount of water intake from sources such as rivers and streams, thereby improving water efficiency and lowering the water stress index.

SDG 6 was created to ensure availability and sustainable management of water and sanitation for all. More specifically, target 6.4 aims to reduce water use efficiency across all sectors and ensure sustainable withdrawals and to supply water to and reduce the number of people suffering from water scarcity. This is also demonstrated in target 12.2, which looks to achieve sustainable and efficient management in water resources.

By increasing the availability of clean, affordable drinking water for communities, the Paju Project also significantly improves access to safe and affordable drinking water for the community (target 6.1). It is anticipated that as the project continues, the percentage of community members drinking tap water will continue to increase towards the rates of other developed countries.

By empowering the community with real-time information on water quality and use, they become considerably more involved in decision-making for their local water use and management. This project has also increased the trust in the community towards their water supplier, showing the potential for SWM to support water agencies in engagement and raising the awareness of communities.

By introducing SWM into Paju, job creation and training also increased (target 4.4), increasing local capacity and opportunities for the community.

Table 18. A list of the SDGs and their specific targets that relate to Paju SWM Project

Sustainable Development Goals and Targets	
SDG 4: Increase opportunities and job creation **Ensure inclusive and equitable education and promote lifelong learning opportunities for all**	
4.4	By 2030, substantially increase the number of youth and adults who have relevant skills, including technical and vocational skills, for employment, decent jobs and entrepreneurship
SDG 6: Clean water and sanitation **Ensure availability and sustainable management of water and sanitation for all**	
6.1	By 2030, achieve universal and equitable access to safe and affordable drinking water for all
6.4	By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity
6.b	Support and strengthen the participation of local communities in improving water and sanitation management
SDG 12: Sustainable consumption **Ensure sustainable consumption and production patterns**	
12.2	By 2030, achieve the sustainable management and efficient use of natural resources

4.2 Expansion of Smart Water Management Policy

To support the aim to become a Smart Water City, Paju is actively developing water related policies such as revising the *Paju City Water Supply Ordinance* and the *Paju City Urban Planning Ordinance* to provide clean and healthy water to the residents of Paju. In addition, Paju has introduced a smart water technology (system) developed by water-related specialist organisations, such as the water-NET monitoring and analysis system for water supply in all processes to promote more efficient and sustainable water management policies.

4.3 Economic Income and Job Creation

As a result of the SWC Pilot Project, the value of water leakage reduction is estimated to be 515 million won (448 thousand USD) per year in consideration of the reduction of 1,521 m³ / day, and the revenue water rate has improved by 13.38% on average. In relation to quantitative water balance analyses, the water leakage reduction effect is also 1,111 m³ / day. The costs are expected to be reduced to 376 million won per year. The SWC project contributes to the regional economy as well as job creation. Since the implementation of the SWC Pilot Project, Paju City has established a 'Clean Water Environment Project Team' that includes waterworks, sewerage, environmental facilities, and cityscapes, and has deployed a total of 98 civil servants. Considering that the number of civil servants in Paju is 1,291, it can be seen that a large number of public officials have been deployed in the water related field due to this project. Paju City has selected construction companies as a local social enterprise by promoting the SWC project with K-water, which has resulted in a large number of local community jobs, including 238 jobs in water related fields for the duration of the project.

Table 19. Estimation of Leakage by Block and Cost Saving Effects

	Leak recovery location	Leak quantity (m³/day)	Saved Cost (million won/year)
Total		1520.6	515
GH 1-3	3 places	355.7	120
BW 1-1	3 places	397.0	134
JS 1-1	C9	767.9	260

Note: Applied the total cost of water supply in Paju in 2014 (927.03 won / m³)
Source: K-water internal document

Table 20. Quantitative Water Balance Analysis and Cost Saving Effects Unit : m³/day

		GH 1-3	BW 1-1	JS 1-1
• Before leak repair				
Supply quantity(a)		2,601	2,741	2,500
Effective quantity	Revenue quantity(b)	1,870	2,103	1,919
	Uncounted quantity by meter(c)	78	82	75
Leak quantity(d=a-b-c)		653	556	506
• After leak repair				
Supply quantity(a’)		2,439	2,511	2,293
Effective quantity	Revenue quantity(b’)	2,148	2,361	1,913
	Uncounted quantity by meter(c’)	73	75	69
Leak quantity(d’=a’-b’-c’)		218	75	311
Leak reduction quantity(d-d’)		435	481	195
Cost Reduction		147 million won/year	163 million won/year	66 million won/year

Source: K-water internal document

4.4 Improving Water Environments

Based on the results of the semi-permanent antimicrobial effect maintenance (an anti-microbial injection which suppresses bacterial propagation per tube, in a pipe by itself), the reduction of disinfection by-products (THMs), and the decrease in the average turbidity by 27.2%, the SWC project is expected to have had a positive impact on water environment and ecosystem health.

The major water quality influences of the water pollutant clusters in the SWC business area (throughout the 1st - 3rd stage) were mainly caused by the drainage of sediments inside the pipes such as the reverse osmosis system and fine rust particles. It is expected that the sediments affecting the water quality will be removed and the decontamination system with weak adhesive force, which will affect the water quality, will be removed at the same time, thereby contributing to the elimination of water quality complaints due to long-term sediment discharge. As a result, from the viewpoint of water quality, turbid particles are removed from the pipe surface (27.0 - 88.7%) by pipe cleaning, and the turbidity inducing component in water is greatly reduced, resulting in a reduction of turbidity of 6.7% - 92.3%

4.5 Increasing Social Satisfaction

The major accomplishments of the Paju SWC Pilot Project include relieving distrust of tap water and improving the reliability of tap water through smart water management services and customized customer services. Although the direct drinking rate of tap water in Paju City was only 1% before the project was implemented, it was confirmed that the rate of direct drinking water rose to 36.3% after applying the SWC project. When you consider that the average drinking tap water rate of the people in Korea is only about 5%, this results show that the perception of tap water by Paju citizens has been significantly improved through the SWC pilot.

In addition to improved drinking tap water rates, after applying the Paju SWC Pilot Project, overall satisfaction of tap water improved from 60.0% in 2014 to 86.0% in 2016, and the satisfaction rate of healthy water service also improved from 80.7% in 2014 to 93.8% in 2016. Through this project, the more than 400,000 people in Paju will be able to drink tap water with confidence, and household economic and social costs related to the purchasing of bottled water and water purifiers will be significantly reduced.

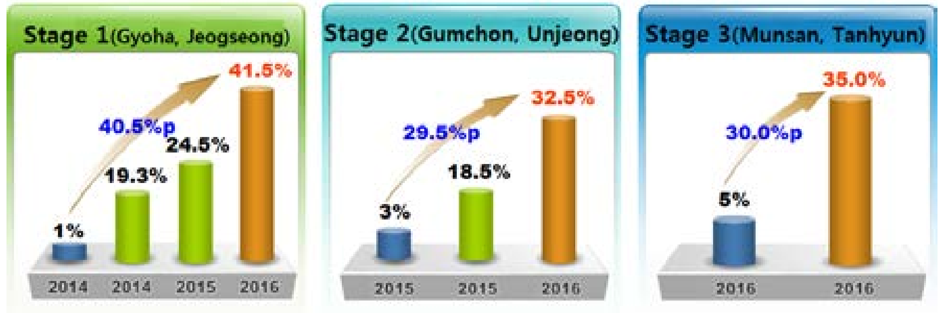


Figure 25. Paju city's direct drinking water rate change

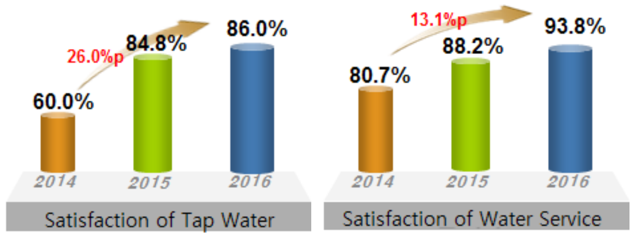


Figure 26. Change of satisfaction of tap water and water service in Paju.

5. Enablers, Barriers and Lessons Learned

5.1 Enablers

5.1.1 Government investment

While the United States and Europe rely on the private sector the development and distribution of smart water management technologies, Korea was able to carry out projects led by the state or public entities to benefit from the initial investments that required relatively large capital. As a result of this the financial cost of disseminating SWM is also an important matter as investment in SWM was mainly covered by public funding, which may not be possible if replicating the project elsewhere.

5.1.2 High technological capacity and industry already present in Korea

Another enabler that supported the project is the information and communication technology and infrastructure construction status in Korea, which is currently the highest in the world. This was certainly an advantageous environment for developing and introducing water management technology based on ICT.

5.2 Barriers

5.2.1 Challenges in scaling up and replicating the successful pilot project

Relatively low water management technologies and water rates below cost (see Table 21) are obstacles to overcome. Compared with information and communication technology, Korea's water management and water technologies have not yet reached the highest level in the world. While there is a strong interest in Korea to both scale up and replicate the technologies used as part of the Paju Smart City pilot, K-water recognizes that low water rates and lack of related budgets may make it difficult to apply newly developed technologies to the field. Tariffs for tap water barely cover operation and maintenance (O&M) costs and only a small portion of the capital charges. Therefore, policy support and related technologies should be continuously developed to overcome these problems.

Table 21. Cost recovery ratio of tap water in Korea

	2012	2013	2014	2015
Multi-regional water supply	82.6%	84.5%	84.8%	83.8%
Local water supply	79.7%	77.8%	76.1%	77.5%

Source : K-water (2017), Local Waterworks Total Management Performance Evaluation Report

5.3 Lessons Learned

1) At the beginning of the project, investments by national or public institutions are essential.

Public investments such as state and local governments and public institutions essential at the beginning stages of the project. While there was an initial financial deficit in the first stage of the project, the public sector, governments and public entities were willing to invest in SWM due to the public benefits it achieves, such as improved quality of life, as shown in Paju City. The government realized that it was more important to have indirect benefits such as a reduction in the cost of water purifiers and bottled water and an increase in citizen satisfaction (shown through improved direct drinking rate) than to have short-term direct benefits such as the reduction of production costs through leakage reduction. The cost of the initial investments will be recovered financially through direct benefits from the SWM such as reduced costs and increased efficiency in the mid- to long-term; however, in the short-term it may be necessary to recover some costs through a gradual increase in water prices. Despite this, the overall benefits for the community will far outweigh any future cost recovery.

2) It is important to generate confidence in water quality improvement by providing visible information to consumers and diverse services
Community engagement and information sharing played a major role in increasing the tap water drinking rates in Paju. The three key factors which enabled us to increase the tap water drinking rates were**:** 1) involving the community in the public activities of the project, 2) the community's belief in the visible results shown during the project, such as the visiting service of Water Cordi, and 3) the open access to real-time updates on the tap water quality with the electric signboard. Likewise, through gaining community confidence in tap water quality, Paju has created a situation where safe tap water is more highly consumed.

3) Stakeholder participation and coordination mechanisms are key to the success of the project.
Community-based organization involvement is necessary in order to reflect various needs at the local level. Such involvement is particularly important to develop the appropriate strategy for a smart urban water scheme, which varies depending on the local context, as there is no "one size fits all" solution. This project could be successfully carried out in other cities by working with a local and diverse stakeholder engagement group to ensure appropriate solutions are developed with local circumstances in mind.

6. Conclusion and Next Steps

6.1 Conclusion

This study shows how SWM systems can be implemented to improve water services and by doing so can increase the trust of drinking tap water rate. Through this study, we have investigated how SWM was applied in the field of water management in Paju City and how the project manifested in the performance and effect through the Paju SWC project. Even though the SWC project has been applied to Paju for a period of only three years, the results and effects on Paju City residents are significant. These results have included 1) improved awareness of tap water, 2) improved quality of tap water through the cleaning of household pipes, 3) positive changes in the rate of direct drinking of tap water and 4) increased trust in tap water. In addition, this study highlights that government support (through policy and investment) and research and development within the technology fields are needed to support the global agenda setting of SWM. In particular, in the technical field, as mentioned above, we can say that a systematic concept integrating unit technologies plays a major role in the improvement of both water quality and quantity, along with improved community trust. Through these policies and technologies, real economic, environmental, and social performance and effects can be manifested. These effects can result in efforts and results to implement SDGs aimed at sustainable development.

CASE STUDIES
SMART WATER MANAGEMENT APPLICATION TO PAJU SMART WATER CITY

6.2 Next Steps

At present, K-water is pushing for the expansion of SWC to local waterworks. As of 2018, K-water is in the process of introducing Smart Water City to six municipalities (Yangju, Dongducheon, Jeongeup, Goryeong, Naju) including Sejong City, the new administrative capital. In addition, K-water aims to introduce SWC to four municipalities in 2018, five municipalities in 2019, and five municipalities in 2020. The Korean government will invest 12 billion KRW (10.4 million USD) from 2017 to 2020 in the Sejong SWC project. This project will aim to improve the tap water supply system and to enhance water quality and water quantity management with the overall project goal set to improve the direct drinking water rate in Korea to 20%.

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TEXT BOX

Promoting commercial aquaponics farming among smallholder households/farms for water-use efficiency, food security and livelihood improvements

Country: Uganda
City/region where project is based: Kampala, Kamuli, Adjumani, Hoima, Wakiso and Kamwenge Districts
Population (of area where the project is based): 5,551,052 nationals and 429,337 refugees (Uganda is hosting more than 1.5million refugees)
Key organisations /stakeholders involved in the project: USAID, Sweden (SIDA); Netherlands and South African Governments; District Local Governments; Care & Assistance for Forced Migrants (CAFOMI) and Navigators of Development Association (NAVODA); Kampala Capital City Authority (KCCA) and Water Governance Institute (WGI)
Authors: Bazira Henry Mugisha

Water challenge

The dwindling fish stocks in natural water bodies due to overfishing to meet market demands is making fish very scarce in Uganda. Also, horticultural crop produce, essential to balance human diets, is currently in short supply in the country, making such products unaffordable. Furthermore, the impression to local residents and businesses that water is abundant is resulting in its wastage.

Project approach

Integrated fish and crop farming (Aquaponics) closes the water recycling/ reuse loop between farming enterprises, resulting in increased efficiency. Water is first introduced (manually or automatically) into the fish-tank from where it is drawn-out as fish-waste-water and irrigated onto a crop in grow-beds or gardens. The grow-beds are comprised of a sand-gravel-aggregate layered medium on which the crop is grown and through which the fish-waste-water is filtered and returned (manually or automatically) to the fish tank. This process removes the ammonia (fish faeces), thus cleaning the water and making it re-useable multiple times. Alternatively, the fish-waste-water is reused once as irrigation in gardens. While the systems are currently operated manually, there is potential to automate them using water pumps, pH monitors/ sensors and oxygenators based on grid/ generator electricity or solar energy, depending on farmers' preference, affordability and access to the energy options. The limited coverage of grid electricity and the expensive generator/ solar energy options makes manual systems more common. Three Aquaponics design options that are being commercialized for urban, per-urban and rural households/farms settings – these include a one cubic meter unit (option 1); a 9.2 cubic meter unit (option 2); and 75 cubic meter unit (option 3) with 200; 1200 and 7500 maximum fish stock and 10 -15 horticultural plants per square metre capacity, respectively. This plant stocking is 3-5 times higher compared to traditional agriculture, which is aimed at increasing the surface area for ammonia extraction from the fish-waste-water.

Results

The results include:

- 100 local small-scale farmers have adopted the innovation.
- 11.2tons of produce (8.5tons fish & 2.7tons of a variety of horticultural crops) from 1.3ha of land over a 2½ year period, demonstrating increased productivity per unit area. Part of the produce was consumed domestically and the surplus sold.

- Total monetary value of produce was US$16,600 fish and US$3,450 crops.
- Volume of water recycled that was also saved for other food value-chain processes was 7,300,000litres.
- The 3 Aquaponics design options cited above have been set-up in urban (27), per-urban (26) and rural (47) households/farms settings. Option 3 has only been set-up in peri-urban and rural settings, totalling to 6 units.
- 40 additional adoptees need to be realised to hit the 2019 adoption target.

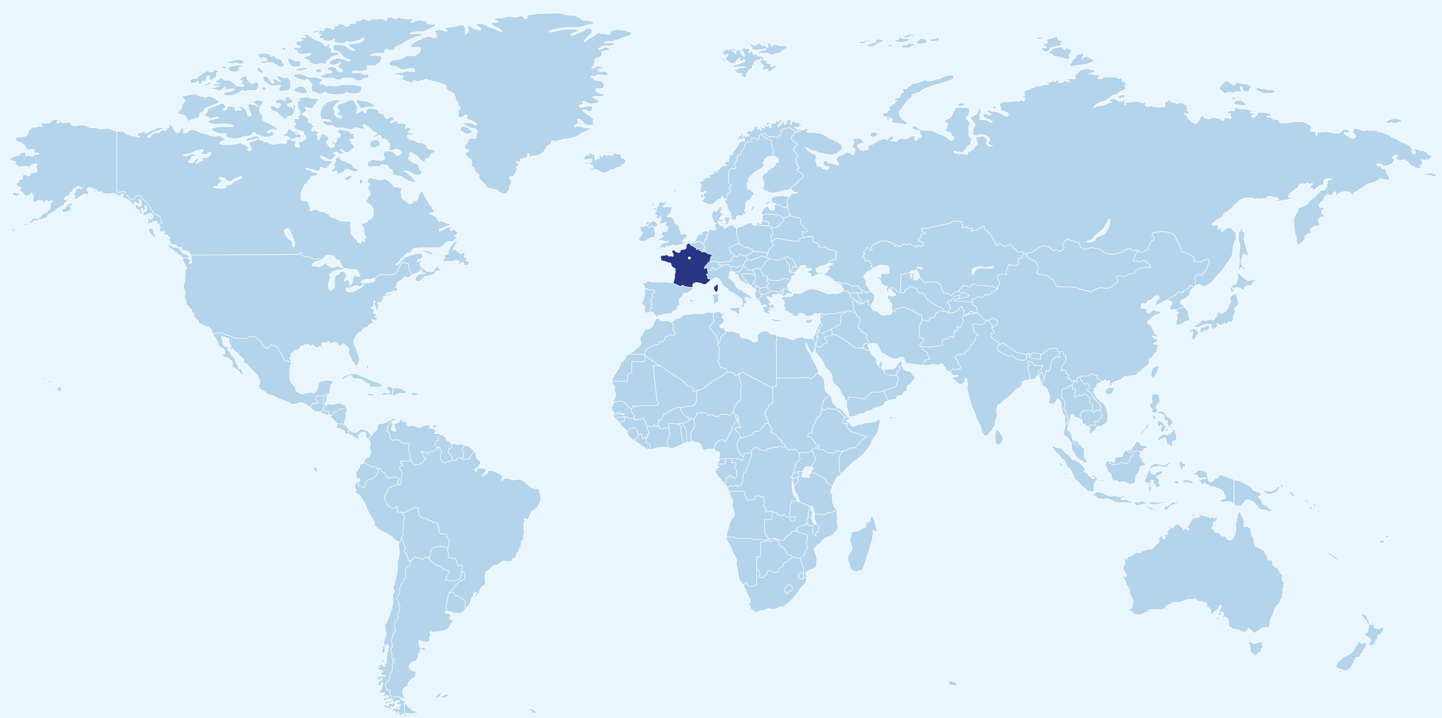
SWM: Potential and barriers

We are interested in improving our project through adding SWM applications, particularly real-time data. This would reduce the amount of work farmers must do to ensure good water quality and its supply/ circulation in the systems, since sensors can control water supply and flows. Real-time data would also improve crop yields and water-use efficiency, food security and livelihood improvements. It will require introducing solar energy, since existing energy options are not reliable. The potential barriers of adding real-time data technology include:

- Limited availability and resources to cover the cost of required technology for automation;
- Difficulty in establishing linkages with suitable technology sources;
- Lack of financial support for demonstration and training of farmers in smart agriculture and water-use efficiency;
- Difficulty in securing a dependable and affordable source of good quality fish feeds and fish fingerlings.

Integrated Smart Water Management of Sanitation System in the Greater Paris Region

Jean-Pierre Tabuchi, SIAAP, Territorial Strategy Direction, Technical Advisor
Béatrice Blanchet, SIAAP, Sanitation System and Sewer Direction, Deputy Director
Vincent Rocher, SIAAP, Innovation and Environment Direction, Chief of Expertise and Prospective Service



Paris, France

Summary

The greatest challenge that the sanitation system of the greater Paris region had to face in the final decades of the twentieth century was the quality recovery of the Seine and Marne rivers. The pollution of the receiving water was caused by a lack of treatment capacity and technical performance as well as by combined sewer overflows during rain events.

After decades of investments, huge improvements in the water quality of receiving waters were obtained and the objectives of the European Water Framework Directive (WFD) are close to being achieved thanks to the development of wastewater treatment plants and a sewage transport system. At the same time Syndicat Interdépartemental pour l'Assainissement de l'Agglomération Parisienne (SIAAP), the public utility in charge of the transport and treatment of wastewater for the Greater Paris region, has also invested in a real-time control following a 1997 sanitation masterplan study that recommended the implementation of real-time control for better control of stormwater pollution caused by combined sewer overflows, allowing a reduced need for storage facilities.

Building upon existing systems and the experience acquired since the mid-1980s at SIAAP as well as each of the its constitutive *départements*: Paris, Hauts-de-Seine, Seine-Saint-Denis and Val-de-Marne, this real-time control system called MAGES (*Modèle d'Aide à la Gestion des Emissaires du SIAAP)* began operation in 2008. The new system (as described in section 3.2) integrates all the data from each *département* system, and is powered by a hydraulic deterministic model fed in real-time by 2000 sensors. It provides flow forecasts for a trend scenario in each part of SIAAP's networks and at each treatment plant on different time scales depending on the weather conditions. This trend scenario is used by the operators to adjust the management of the system.

This smart system takes advantage of the capacity within the coverage area to transfer sewage from one wastewater treatment plant (WWTP) to another. Such transfers enhance system wide security in case of shutdown due to any reason such as planned works or incidents.
MAGES has been the driver of several changes in the way to see and operate the sanitation system. First, each operating site has the knowledge in real-time of what has happened elsewhere on the sanitation system, resulting in a shared and global view of the system. At the same time, the SIAAP department that operates MAGES has a global overview of the hydraulic running condition of the whole system.

Ten years after the commissioning of MAGES, it is still difficult to assess its benefits in terms of savings either on investment or operation costs. Nonetheless, smart management is here to stay. Projected constraints on the operation of Paris's regional sanitation system from tighter regulations, population growth and effects of climate change on the Seine hydrology are impelling SIAAP to develop smarter tools aimed at reducing pollutant loads discharged into the rivers without entailing excessive costs.

This case study details the development of a real-time control system (MAGES) in the Paris region designed to better control stormwater pollution caused by combined sewer overflows and to optimize the need for additional storage or treatment facilities. The case study is structured to outline the challenges facing the Greater Paris region water and sanitation networks, and the solutions provided by SIAAP, the public utility in charge of the treatment and transport of wastewater, over the past 20 years After a brief overview of the geographical characteristics of the region of concern, it introduces SIAAP and the challenges facing it in ensuring improved quality of the Seine. This is followed by a description of the evolution and features of the MAGES system, links to the Sustainable Development Goals, and challenges and opportunities that lie ahead.

1. Background

To enable better understanding of the general context in which the project takes place, the following section describes the role of SIAAP as an institutional organization, and the geographical situation, climate conditions and demography of the Greater Paris region.

Box 1. Water resources in the Greater Paris region and SIAAP's collection area

Catchment:

Name: Seine basin
Area within Seine basin: 77,000 km^2
Area within Greater Paris region: 2845 km^2
Area within SIAAP's collection area: 1800 km^2
Principle sources of water used: 15-20 % groundwater, 80-85 % from surface water in which 60% from Seine, 30% from Marne, 10% from Oise.

Climate:

Temperate with oceanic influence
Annual Rainfall: 640 mm

Demographics:

Population: Greater Paris region: **10.5 million inhabitants (**SIAAP's collection area: **9 Million inhabitants)**
Population density: Greater Paris region**: 3690 inhabitants/km^2** (SIAAP's collection area: **5000 inhabitants/km^2)**

1.1 Geography, climate and hydrology of the Greater Paris Region

1.1.1 Political geography: Territory of the megacity of Paris and the SIAAP

1.1.1.1 The megacity of Paris

The Île-de-France region is divided into eight *départements* (see Figure 1):

- Paris both a city and a *département*;
- Hauts-de-Seine;
- Seine-Saint-Denis;
- Val-de-Marne.

which form the *Petite-Couronne* (Paris and its surrounding *départements*). Beyond this is the *Grande-Couronne* (outer suburbs) with:

- Seine-et-Marne;
- Yvelines;
- Essonne;
- Val-d'Oise.

This territory, divided into 1,280 municipalities (*communes*), covers a surface area of 12,000km^2 and has 12 million inhabitants (Tabuchi et. al. 2016).

The megacity of Paris has no formal administrative existence making it hard to describe. The Ile-de France region consists of a group of municipalities forming a continuous built area[1] referred to as the Paris urban unit (*unité urbaine de Paris*). This definition has been adopted herein for the **megacity of Paris**; it consists of 412 municipalities with a population of 10.7 (2015) million inhabitants and a surface area of 2,845 km^2 (see Figure 2). The new administrative structure of the Greater Paris Metropolis (*Métropole du Grand Paris - MGP*) (Act of 25 January 2014) only covers part of the megacity, which equates to a quarter of its surface area and half of its population. It corresponds approximately to the *Petite-Couronne* or inner suburbs.

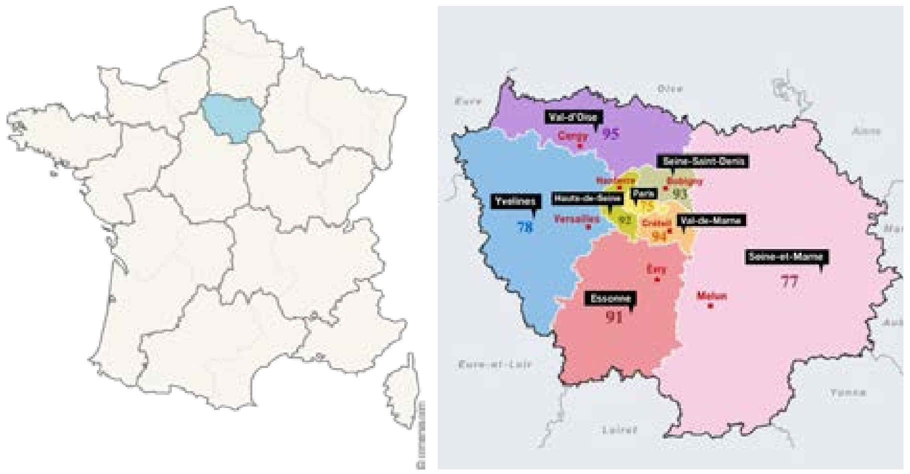


Figure 1. The Île-de-France region in France (left) and its eight départements (right)

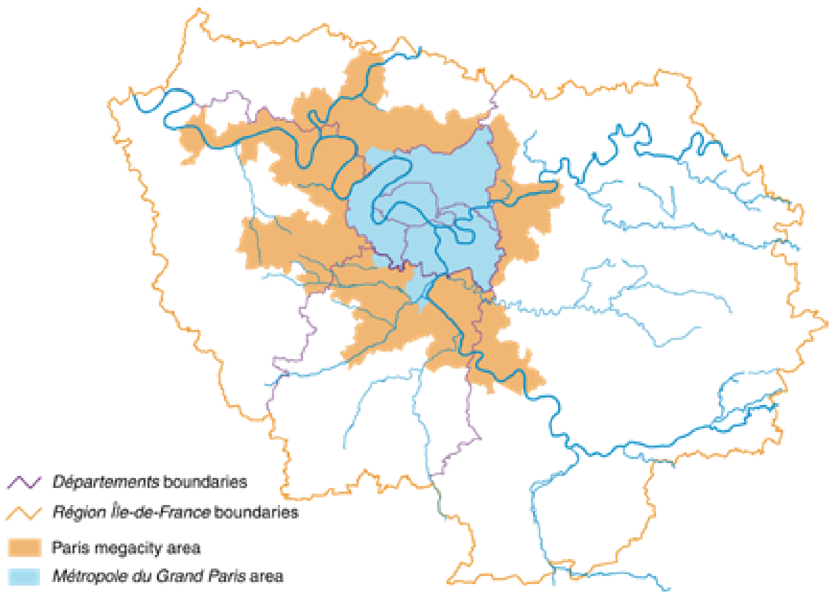


Figure 2. The boundaries of the Greater Paris metropolis and the megacity of Paris
(SIAAP - Source: INSEE, MGP)

Therefore, no consolidated data, including water management data, exist at the scale of the territory covered by the megacity of Paris. In addition, the data presented in this report relate to entities which are relevant to a particular activity: waste water treatment and drinking water, or to an administrative division: Ile de France region, *départements* and groups of municipalities.

1. The French National Institute of Statistics and Economic Studies (INSEE) defines an *urban unit* as a continuous, uninterrupted built area of more than 200 meters between two constructions.

1.1.1.2 The SIAAP institution

The SIAAP is responsible for sewage treatment for a territory that covers only a part of megacity of Paris. It is administered by the Petite-Couronne's *départements*, however its collection area also overlaps with the outer suburbs. This territory, with a total surface area of 1,800 km² consists of a total of 284 municipalities, which are home to 9 million inhabitants.

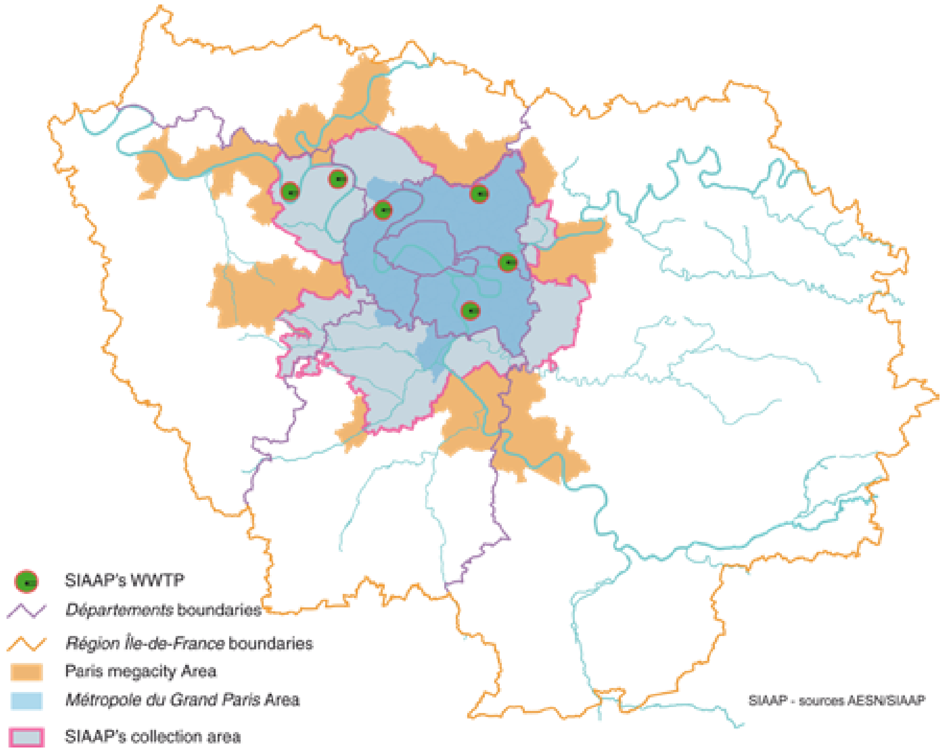


Figure 3. Map of the boundaries of the Greater Paris metropolis and the megacity of Paris
(SIAAP - Source: INSEE, MGP)

1.1.2 Climate and hydrology

1.1.2.1 Climate

The climate of the Paris region is temperate with an oceanic influence. The rainfall distribution is relatively consistent throughout the year and the temperatures are mild, in both summer and winter (see Table 1 and Figure 4).

Table 1. Annual precipitation levels at Paris-Montsouris

Year type	Precipitation level
Normally wet year (value exceeded one year in five)	738.9 mm
Average year	641.6 mm
Normally dry year (value not exceeded one year in five)	530.7 mm

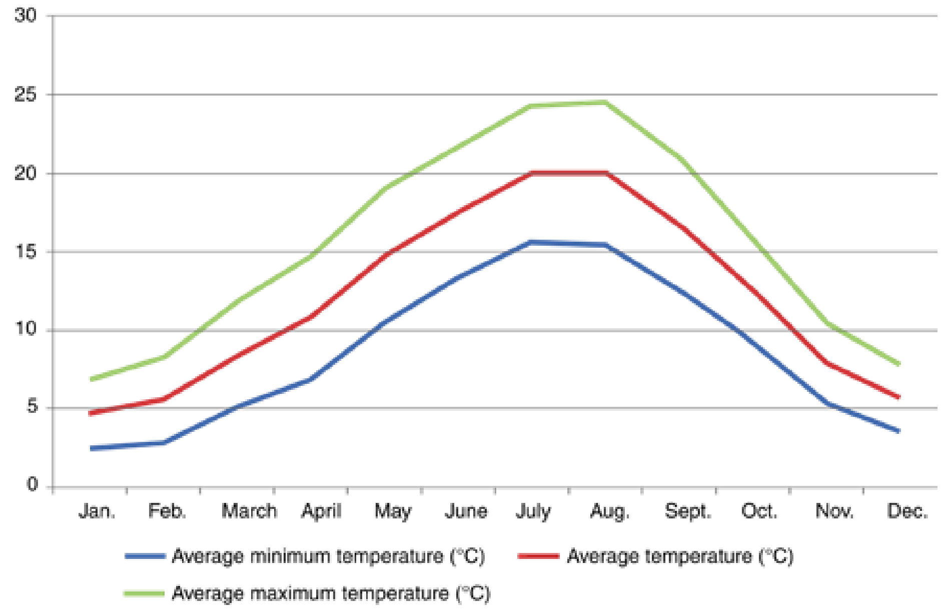


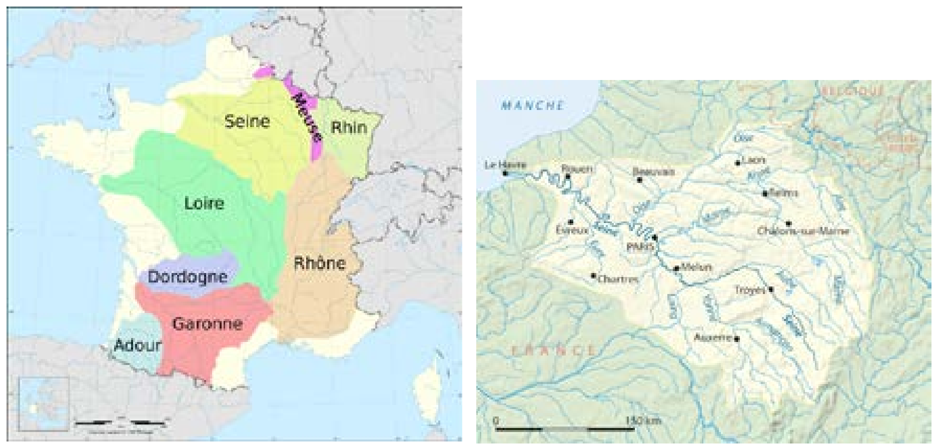
Figure 4. Average temperatures – 1970 – 2000

1.1.3 Hydrology

1.1.3.1 The hydrographical network

The megacity of Paris is situated in the Seine basin - one of the eight major French drainage basins (see Figure 5). It covers an area of 77,000 km². The major drainage axis is the Seine and its two main tributaries: the Marne and the Oise.

The main waterways, the rivers Seine, Oise, and Marne, are canalised and navigable. They play a major role in the supply of goods and also for the disposal of excavated soils and wastes from construction sites in Paris. These three waterways comprise the main water resources for the megacity of Paris.



A **B**

Figure 5. The major drainage basins in France (A) and the Seine basin (B)

1.1.3.2 Flow rate of the Seine

The median flow rate of the Seine in Paris, and the five-year and ten-year wet and dry flow rates, are low compared to other French rivers (Figure 6). The Seine and Marne have an oceanic regime[2] characterised by a low-flow period during the summer until the start of autumn and a flood period in February (due to low evaporation and high rainfall). The flow rates in these two rivers are controlled, for both high flow and low flow, by storage dams situated upstream of the basin area, thus limiting the impacts of natural flooding hazards.

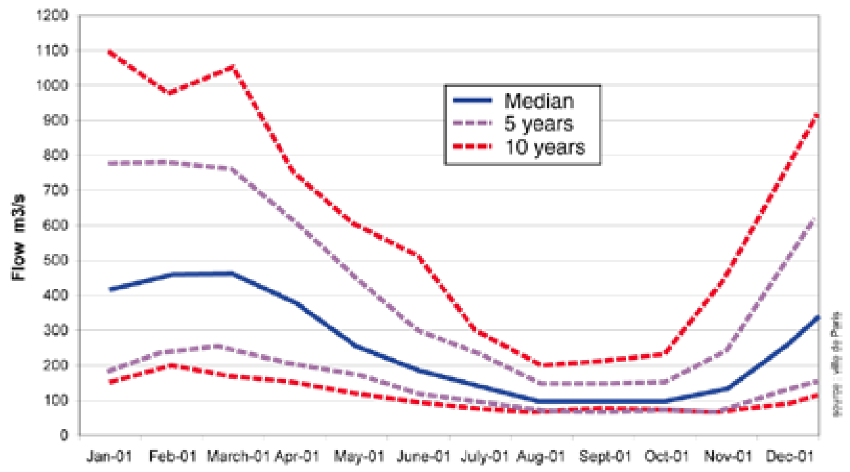


Figure 6. Five-year and ten-year flow rates of the Seine in Paris (source: Ville de Paris/AESN)

The main characteristic values of the Seine flow rate in Paris, and the Marne where it enters the megacity of Paris, are compiled in Table 2.

Table 2. Characteristic flow rates of the Seine in Paris and the Marne upstream of Paris

	Average	Low water (5-year) Average monthly flow rate	Low water (5-year) Daily flow rate over 10 days	High water (5-year) Average daily flow rate	High water (10-year) Average daily flow rate
Seine in Paris Austerlitz bridge	310 m³/s	82 m³/s	71 m³/s	1400 m³/s	1600 m³/s
Marne in Noisiel	109 m³/s	32 m³/s	27 m³/s	440 m³/s	500 m³/s

1.1.3.3 Flow control on the Marne and the Seine

As for any hydrological system, the Seine and the Marne are subject to high and low flow periods, but the extent of the development of the Paris conurbation has made it particularly vulnerable to these natural phenomena, and to flooding in particular. The floods of 1910 and 1924, but also the drought of 1921, prompted the French government and the local political authorities to adapt the Seine catchment in response to these hazards. The final works were completed in 1990.

The *Seine Grands Lacs*[3] public institution currently manages 850 Mm³ of storage capacity designed to mitigate flooding, provide alleviation of low flow and help to meet the water use needs of the megacity of Paris as well as the cooling needs of the nuclear power station at Nogent-sur-Seine. As an illustration of the alleviation of low flow provided by the reservoirs, 40% of the minimum annual flow of approximately 85 m³/s for the Seine in Paris comes from storage dams.

2. Oceanic regimes are a characteristic of western European climate: under the influence of Gulf Stream in Atlantic Ocean, the climate is cool with high rainfall in winter. Low evaporation added to rainfall means more runoff and a higher flood hazard.
3. The *Seine Grands Lacs* regional public corporation is administered by the *départements* of Hauts-de-Seine, Seine-Saint-Denis, Val-de-Marne and Paris, which own the large lakes upstream of the Paris region

1.1.3.4 A megacity on a small river

The Seine, which drains the pollution generated by 14 million inhabitants in the Paris region has a very low discharge dilution capacity, especially during its seasonal low flow period in summer and autumn (Figure 6) which is significantly below that of other river basins in France (Table 3).

Table 3. Comparison of minimum water flows and dilution capacity of different French rivers

	Five-year minimum water flow m³/s	Conurbation	Population Millions of inhabitants	Impacts Dilution capacity
Rhine	520	Strasbourg	0.7	65 m³/d/inhabitant
Rhône	380	Lyon	1.8	18 m³/d/inhabitant
Seine (at Poissy)	170	Paris urban unit	10.5	1.4 m³/d/inhabitant

Box 2. Greater Paris Region demography and territory

Demographic data

The urban growth of the megacity naturally began in the city of Paris (until 1930). It continued in the inner suburbs and then into the outer suburbs (*Grande Couronne*) from the 1960s onwards.
Due to its density, the city of Paris corresponds to a 'dense city' model, whose consequences include very high use rates of all networked infrastructure systems, including drinking water, sanitation, and public transport, with a peak during the daytime as the resident population of 2.2 million inhabitants of the City of Paris expands to nearly 3 million including commuters (see Table 4).

TABLE 4. Demographic data on the Île-de-France region (2012) and average sizes of households

Département	Surface area (km²)	Population (2012)	Density (inhabitants/km²)	Average size of households
Paris	105	2,240,621	21,300	1.9
Hauts-de-Seine	176	1,586,434	9,010	2.3
Seine-Saint-Denis	236	1,538,726	6,520	2.6
Val-de-Marne	245	1,341,831	5,480	2.4
Paris & inner suburbs	657	6,707,612	6,800	
Essonne	1,804	1,237,507	690	2.6
Val-d'Oise	1,246	1,187,081	950	2.7
Yvelines	2,285	1,412,356	620	2.6
Seine-et-Marne	5,915	1,353,946	230	2.6
Outer suburbs	11,250	5,190,890	460	
Megacity of Paris	2,845	10,550,350	3,710	
Île-de-France	12,012	11,898,502	990	2.4

Source: (https://www.insee.fr/fr/statistiques)

Occupation of space

- 20% of the Île-de-France region is occupied by urbanised areas (roads and buildings);
- 13% by built areas (housing and buildings);
- 53% crops;
- 23% woodland (23%).

On the other hand, for Paris and the inner suburbs, urban space occupies 84% of the territory and built areas occupy 60%. Rural space is very limited (16%).

Economic data

The Île-de-France region is ranked highly in the global economy. In 2012, its GDP of €612 billion made it the sixth-ranked metropolitan area after Tokyo, Greater New York, Los Angeles, Osaka and London.
With over 5.9 million jobs, 85.5% of which are in the tertiary sector, Île-de-France stands out due to its dominant position in the national economy and the size of the tertiary sector, although it remains highly diversified in relation to other cities of a similar size. Despite a high level of de-industrialisation, it remains France's leading industrial region. Its agriculture—mainly devoted to cereal crops—is amongst the most productive in France and tourism is a major industry (33 million hotel nights in 2013).

1.2 SIAAP and the sanitation at the heart of the megacity of Paris

The SIAAP, created in 1970, is the public utility in charge of the transport and treatment of wastewater for the Greater Paris region. SIAAP is the operator located downstream of a large sewage collection and transport system for a drainage area of 1800 km^2 and serving 9 million inhabitants. The SIAAP plays a key role as it treats the sewage produced by 9 million inhabitants. As operator of the main sanitation system on the Seine catchment, it is also responsible for the impact of the sanitation system on the natural environment. Furthermore, the SIAAP is, as are many other sanitation utilities around the world, playing an increasing role in a carbon-free and a circular economy.

The sanitation scheme for the conurbation has evolved over time. In 1929, the principle was to concentrate all of the wastewater at a single plant downstream of the conurbation. In 1968, this single-plant concept was abandoned, at a time that coincided with the emergence of the first institutional decentralisation measure for the conurbation (see Figure 7).

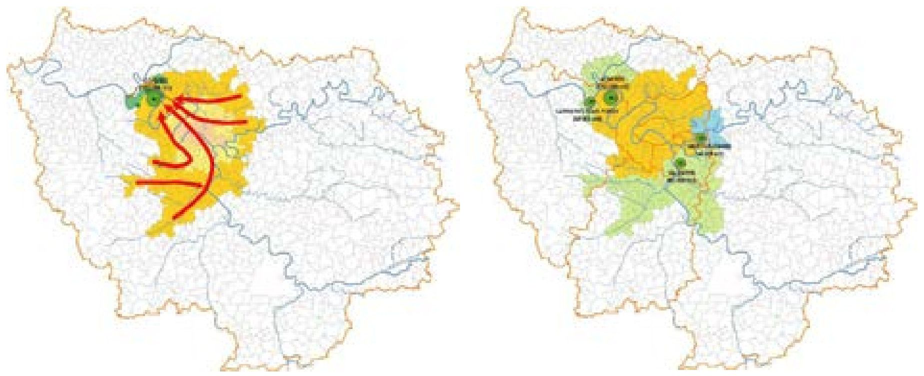


Figure 7. Greater Paris region sanitation program in 1929 (left) and 1968 (right)
(Source: SIAAP)

CASE STUDIES
INTEGRATED SMART WATER MANAGEMENT OF SANITATION SYSTEM IN THE GREATER PARIS REGION

A modern master plan was adopted in 1997. It established the broad directions of the sanitation policy currently in force in the central area of the megacity. The plan was the subject of an agreement between the SIAAP, the Île-de-France region and the Water Agency. The main goal was to limit the volume treated at the *Achères – Seine-Aval* downstream wastewater treatment plant. The reason for this downsizing of treatment capacity was because of local complaints related to odor nuisances caused by the WWTP. A new sharing of the treatment capacity between six WWTP was then decided. The creation of stormwater storage/release basins was also recommended in order to reduce pollution during rainy weather.

Since then, the master plan was revised in 2007 with a consultation extended to the SIAAP's constituent *départements* and to the inter-municipal regulatory authorities linked to the SIAAP. A new revision has been approved in 2017. It places particular emphasis on controlling pollution in wet weather, which is the main cause of failing to achieve the targets of the European Water Framework Directive (WFD). It takes account for the population increasing from 8.8 million inhabitants in 2009 to 9.6 million in 2030, water consumption declining from 59 m^3/inhabitant/year to 52 m^3/inhabitant/year and, above all, the run-off surface area connected to the sanitation system (see 1.2.2.2) stabilising at the current value of 252 km^2.

1.2.1 A multi-operator system

Within the region covered by the SIAAP, the collection, conveyance and treatment of wastewater are divided among several operators (Figure 8):

1. Collection: the municipalities or consortia thereof, are responsible for the basic collection of urban wastewater as well as stormwater throughout a 15,000 km system. This is an essential level because it determines the quality of the wastewater collection and the control of stormwater;
2. Conveyance: the *départements* of Paris, Hauts-de-Seine, Seine-Saint-Denis, Val-de-Marne and, in the outer suburbs, the inter-municipal sanitation authorities (*syndicats intercommunaux d'assainissement*), are responsible for the intermediate conveyance between the authorities responsible for the basic collection and the transfer sewers leading to the wastewater treatment plants;
3. Treatment: the SIAAP is responsible for the final conveyance to its wastewater treatment sites. Some of SIAAP's main sewers are operated by the four *départements* mentioned above.

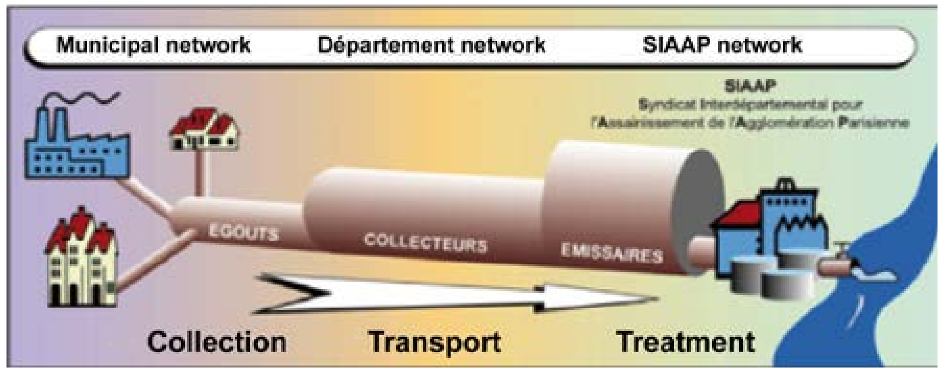


Figure 8. Flowchart showing the waste water collection and treatment in the megacity of Paris.
Source: https://www.seine-saint-denis.fr/IMG/jpg/reseaudea72-2.jpg

1.2.2 Sanitation infrastructure

1.2.2.1 Wastewater treatment plants

The SIAAP has completed the construction of the 6 wastewater treatment plants planned in 1997 (see Figure 9). In 2006 the SIAAP had reached sufficient treatment capacity to handle all the sewage produced (see Table 5). Nevertheless, the modernisation of the oldest plant *Seine-Aval* is still underway. These works should constitute the last stage in ensuring the good physico-chemical status of the Seine, a requirement of France's European commitments for 2021.

Seine-Aval plays a key role in the system. This due to its historical position in the system: this WWTP was the focus point of the sewer system. For this reason, most of the sewage flows to it. The second point is related to its capacity, as it is SIAAP's largest WWTP. This means that *Seine-Aval* plays the role of an 'expansion tank'.

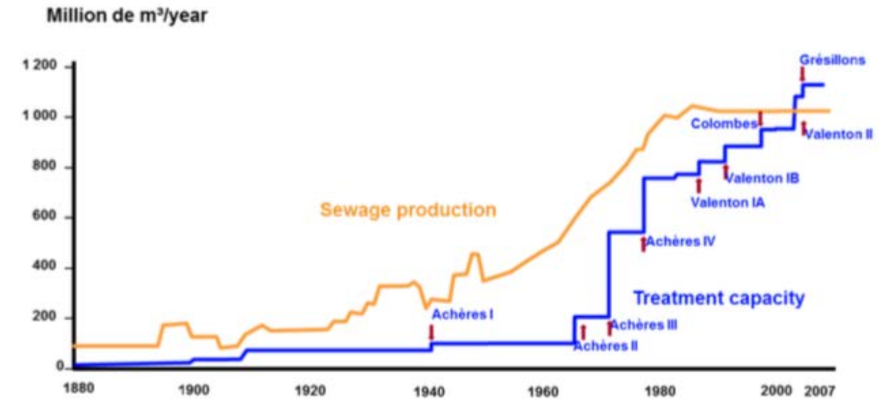


Figure 9. Long-term evolution of sewage production and WWTP capacity in Greater Paris

Table 5. Capacities of the SIAAP plants in person equivalents

Treatment Plant	Person Equivalent (PE) capacity	
	Optimum capacity	Biological treatment capacity in rainy weather
Seine-Aval at Saint-Germain-en-Laye (Yvelines)	4,182,000 PE	8,218,000 PE
Seine-Amont at Valenton (Val-de-Marne)	2,618,000 PE	4,000,000 PE
Seine-Centre at Colombes (Hauts-de-Seine)	982,000 PE	982,000 PE
Seine-Grésillons at Triel-sur-Seine (Yvelines)	1,149,000 PE	1,322,000 PE
Marne-Aval at Noisy-le-Grand (Seine-Saint-Denis)	500,000 PE	605,000 PE
Seine-Morée at Blanc Mesnil (Seine-Saint-Denis)	300,000 PE	351,000 PE
Total	9,731,000 PE	15,478,000 PE

CASE STUDIES
INTEGRATED SMART WATER MANAGEMENT OF SANITATION SYSTEM IN THE GREATER PARIS REGION

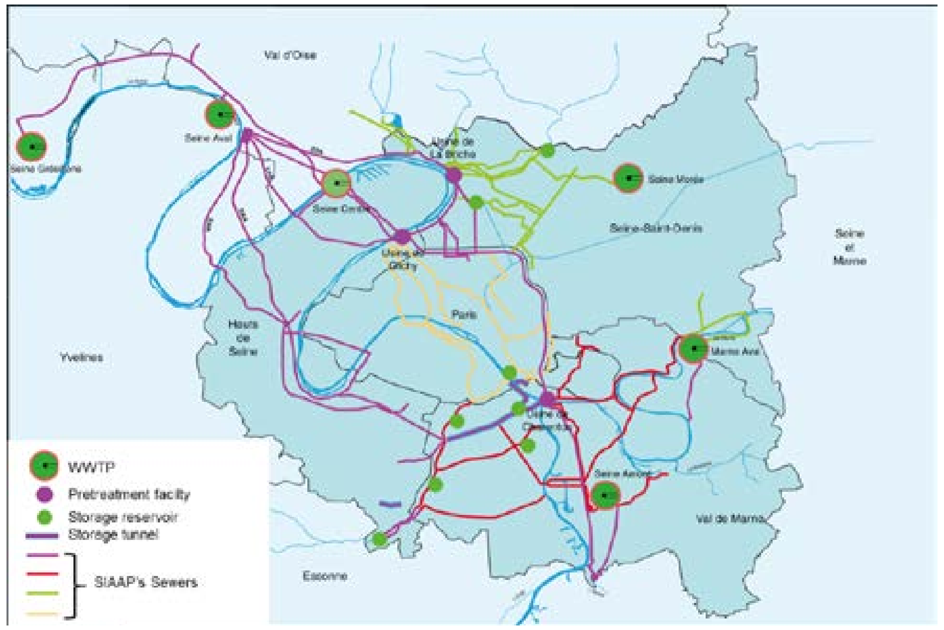


Figure 10. Location of the SIAAP's major facilities (violet: Sewers operated by SIAAP, Sewers orange: operated by Paris, green: Sewers operated by Seine-Saint-Denis and red: Sewers operated by Val-de-Marne)

1.2.2.2 Sewage collection and transport systems at the heart of the megacity of Paris

A vast collection and conveyance system, with an estimated length of 15,000 km, has been created over time in line with the growing urbanisation of this region.

In many cases, the Paris region sanitation is based on a combined sewer system in its center part and on a separate system in its outskirts, which was developed more widely after the Second World War (see Figure 11).

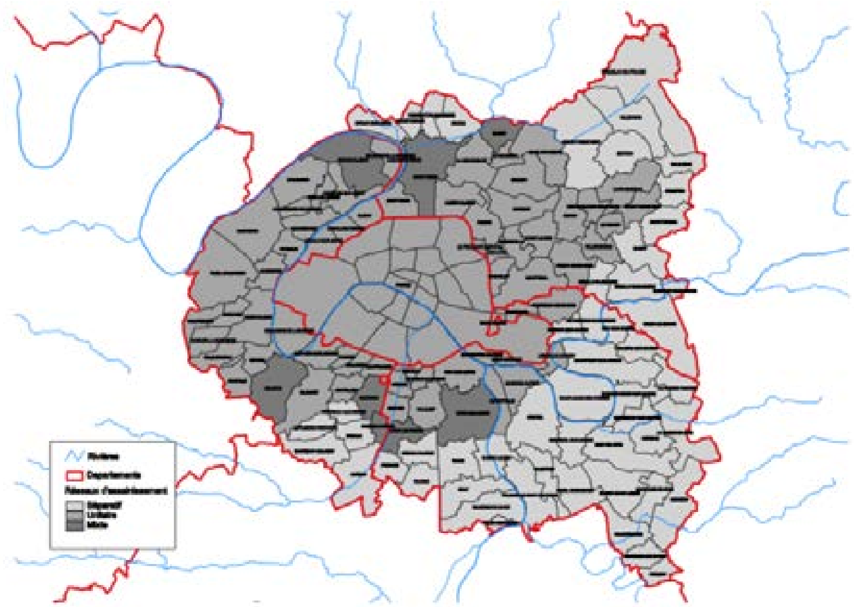


Figure 11. Typology of sewage collection inside SIAAP's administrative boundaries: Light grey: separate system, medium grey: combined system and dark grey for mixed system

Table 6. Breakdown of the linear length of the main sewers owned by the départements

	Paris	Hauts de Seine	Seine-Saint-Denis	Val-de-Marne
Combined sewers	2,100 km	384 km	356 km	195 km
Stormwater		74 km	190 km	377 km
Wastewater sewers		72 km	124 km	261 km
Total	2,100 km	530 km	670 km	833 km

In addition to the treatment plants belonging to the SIAAP and the main networks stated above, the Greater Paris region sanitation system consists of:

- stormwater storage facilities with a total capacity of 2.5 million cubic meters;
- 200 combined sewer overflows (CSOs), with 10 of them which are representing over half of the discharged volume;
- numerous electromechanical pumping stations and stormwater outlets;
- highly sophisticated real-time wastewater and stormwater management systems (see sections 1.2.2.5 and 3 below).

1.2.2.3 Sewage composition

Sewage treated by the SIAAP is composed of various sources of water, with wastewater contributing around 60% of the total annual volume arriving in SIAAP's treatment plants (see Figure 12). Infiltration water contributes approximately 25%, stormwater approximately 5% and specific to Paris region: the non-potable water used in Paris city for street cleaning and for sewer flushing to remove solid deposits and 10% of stormwater mainly related to combined sewers.

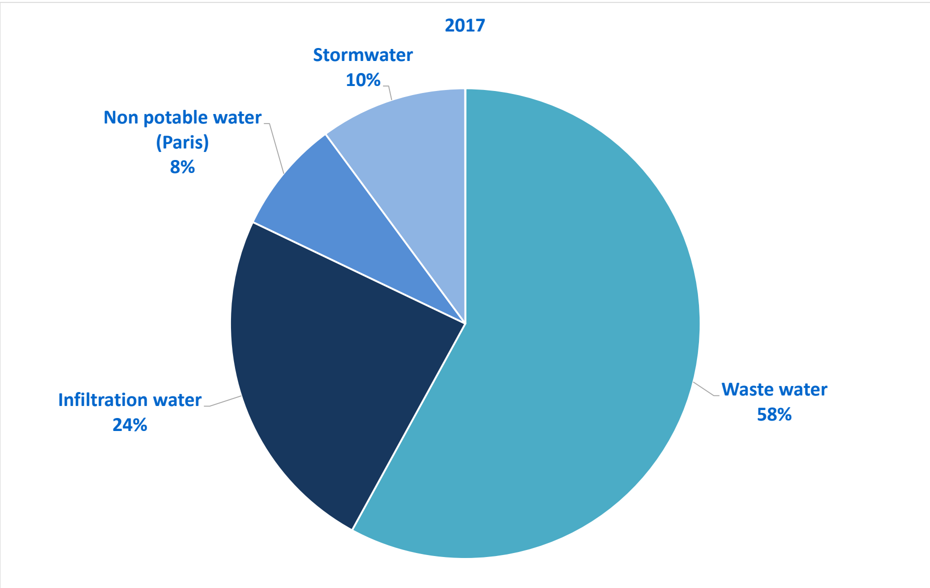


Figure 12. SIAAP's sewage composition – 2017

The percentage of the different kinds of water depends on the annual amount of rain (see Figure 13).

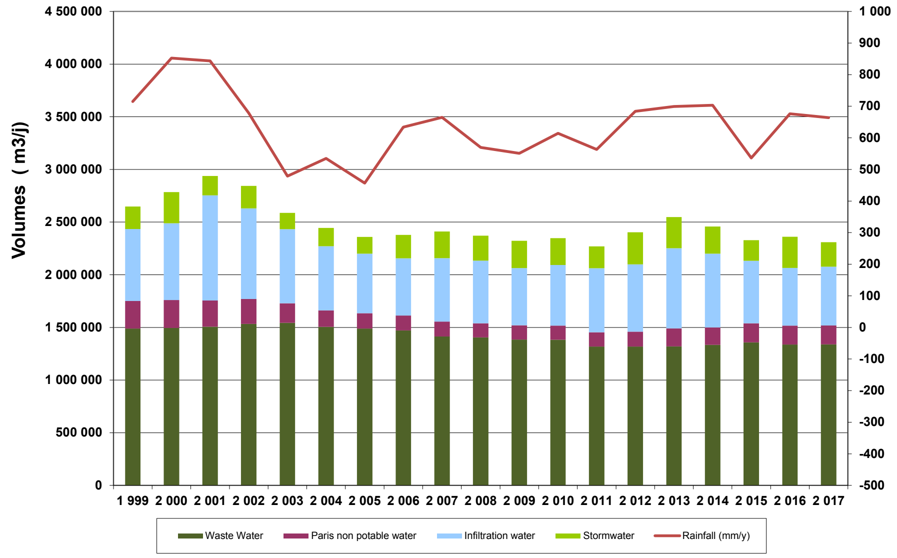


Figure 13. Annual variation in different kinds of waters entering in sewage composition

1.2.2.4 Stormwater storage facilities

SIAAP has a stormwater storage capacity of 955,000 m^3, of which 270,000 are in the form of reservoir tunnels. SIAAP and its départements have a total storage capacity of 2.5 Mm^3. These assets consists of underground or open air storage tanks but also reservoirs tunnels.

These storage facilities are multipurpose works with aims to handle sewer overflow caused by cloudburst and to reduce stormwater pollution during small to average rain events. Some facilities are located on a separate stormwater network but most of them are connected to combined sewers. The polluted part of the stored water is diverted to one of SIAAP's treatment plants.

1.2.2.5 Real-time Control system (RTC) (see section 3)

Historically, stormwater management systems have been implemented primarily by the départements to manage flows in rainy weather, particularly in order to counteract the risks of flooding due to the overflowing of systems. This drove them to started investing in real- time management at a very early stage, in the late 1970s. Seine-Saint-Denis, the pioneer, started to implement its first local RTC station in 1974 for the management on a stormwater storage facility. Ten years after they had a complete remote control system: NIAGARA (*Nouvelle Interface Applicative de Gestion Automatisée du Réseau d'Assainissement*). Seine- Saint-Denis was followed by Hauts-de-Seine with GAIA (*Gestion Assistée par l'Informatique de l'Assainissement*), Val-de-Marne with VALERIE (*Val-de-Marne régulation informatisée des effluents*), Paris with GAAPSAR (Gestion Automatisée de l'Assainissement Parisien) and SIAAP with SCORE (*Système de contrôle et de régulation des émissaires*). Today, each operator possesses a system adapted to its specific constraints, with the dual aim of combating flooding and protecting the receiving water. These real-time control systems are now interconnected and the different operators communicate with each other.

One of the unique characteristics of SIAAP's system is the existing interconnection capacities among the wastewater treatment plants. This ability to transfer flows among treatment plants is a rare enough occurrence worldwide to be worthy of mention here. The management of this system is made with MAGES or SIAAP sewage Management Assistance Model. The full description of this Smart Water Management (SWM) system is developed in the following section 3.

2. Water Challenges

2.1 Recovery of water quality in the Seine

The Seine is not a large river when compared to the population settled in its catchment: around 14 million inhabitants rely on a flow as low as 95 m^3/s on average of every 5 years. During the last five decades, the challenge was the recovery of water quality within the Seine through and downstream of Paris, and to reach the good status stated in the European WFD (2000/60/EC of 23th October 2000). This means that one of the key water challenges is maintaining the quality of the receiving water.

The WFD and its incorporation into French law (especially the Order of 25th July 2015) currently set the targets to be achieved in addition to the procedures and criteria for assessing water quality (see Table 8).

Urban development led to deterioration in the quality of the Seine's water, from early observations in the 1870s until the 1970s. During the last 35 years, the physico-chemical quality of the water in the Marne and Seine has improved very significantly both upstream and downstream of the conurbation (Figure 14, figure 15 and Figure 16). The figures represent ammonia evolution through fifteen years with a first step of improvement in 2007 and a second step in 2012 due to works on *Seine-Aval* Waste Water Treatment Plant. They compare the changes between 1971-1972, 1985-1986 and 2012-2013 with regard to four parameters (dissolved O_2, BOD_5, NH_4+ and PO_4^{3-}).

These improvements are largely due to the general policy of developing sewage treatment plants. However, downstream of the megacity of Paris, the nitrogen and phosphorous concentrations still do not meet the WFD good status targets. Works are being carried out on the *Seine-Aval* wastewater treatment plant situated downstream of Paris megacity (see 1.2.2.1), so that it can make a decisive contribution to achieving good water status in the Seine pursuant to the targets set by the Water Framework Directive.

Table 8. French physico-chemical criteria for the receiving water quality

QUALITY PARAMETERS	QUALITY LIMITS				
	VERY GOOD	GOOD	MEDIUM	POOR	BAD
OXYGEN BALANCE					
Dissolved oxygen (mgO_2/l)		8	6	4	3
Dissolved oxygen saturation rate (%)		90	70	50	30
BOD_5 (mgO_2/l)		3	6	10	25
Dissolved Organic Carbon (mgC/l)		5	7	10	15
TEMPERATURE					
Salmon stream		20	21,5	25	28
Cyprinid stream		24	25,5	27	28
NUTRIENTS					
PO_4^{3-} (mg $PO_4^{3-}.l^{-1}$)		0,1	0,5	1	2
Total Phosphorus mg P/l		0,05	0,2	0,5	1
NH_4^+ (mg $NH_4^+.l^{-1}$)		0,1	0,5	2	5
NO_2^- (mg $NO_2^-.l^{-1}$)		0,1	0,3	0,5	1
NO_3^- (mg $NO_3^-.l^{-1}$)		10	50	*	*
ACIDIFICATION					
pH minimum		6,5	6,0	5,5	4,5
pH maximum		8,2	9	*	*

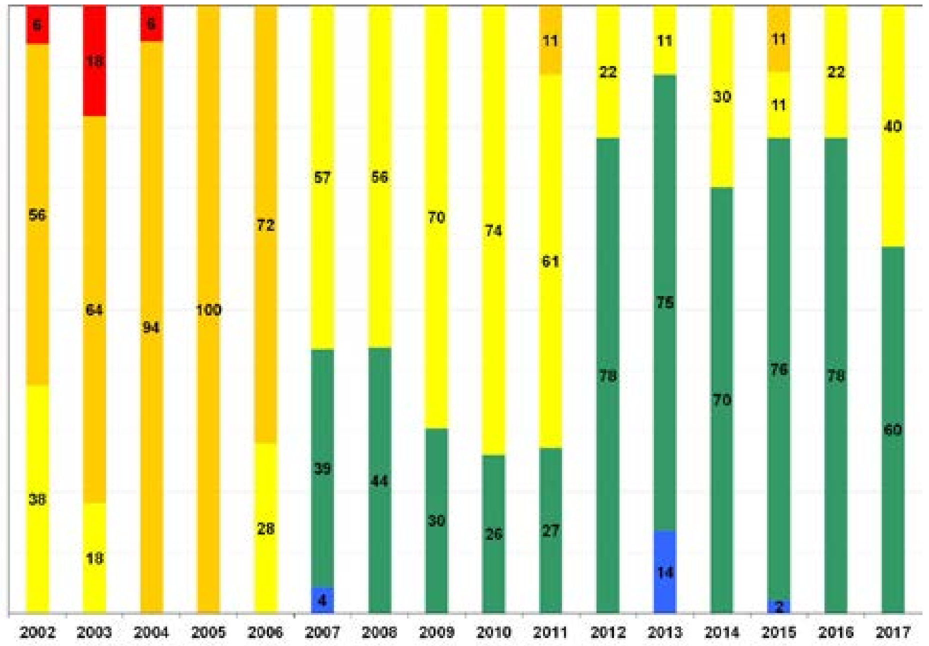


Figure 14. Evolution of the Seine dowstream of Paris (Poissy monitoring station) region for ammonia – Percentage of time in compliance with French environmental standards (SIAAP)

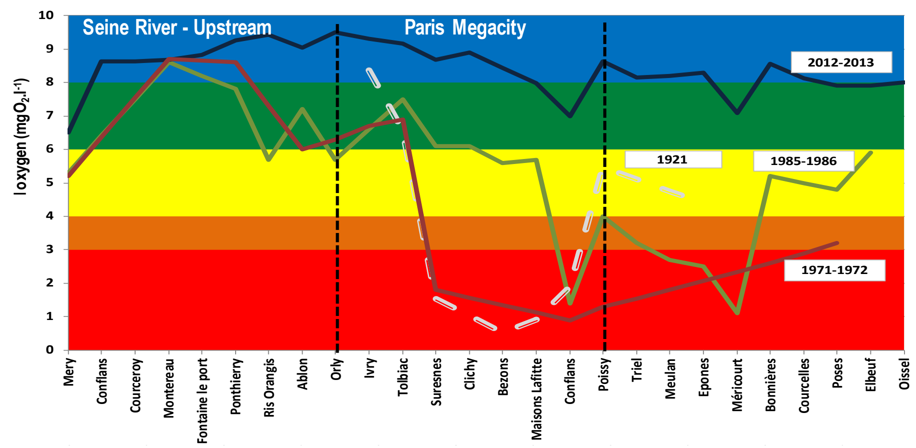


Figure 15. Changes in dissolved oxygen concentrations in the Seine in 1971-1972, 1985-1986 and 2012-2013 (Rocher and Azimi 2017)

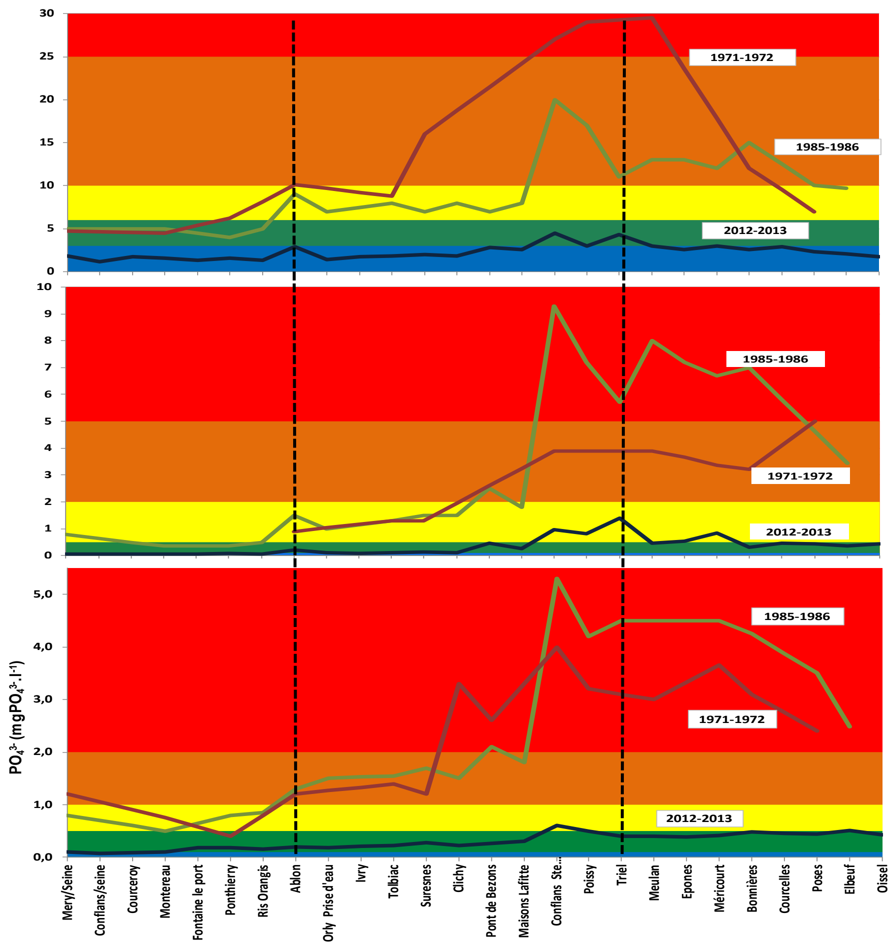


Figure 16. Changes in concentrations of carbonaceous (BOD5), nitrogenous (ammonium) and phosphatic (ortho-phosphates) pollution in the Seine in 1971-1972, 1985-1986 and 2012-2013 (Rocher and Azimi 2017)

With regard to micro-pollutants, the 2013 status review as part of the WFD reveals a less satisfactory situation, especially due to the presence of polycyclic aromatic hydrocarbons (PAH).

The monitoring of fish stocks carried out since 1990 by the SIAAP, however, provides an overview of the significant improvement in stocks in the Seine over the last 25 years. In this time, the number of species counted during electro-fishing operations rose from 12-14 to more than 20, with an accumulated total of 32 species counted during the operations[4] (see Figure 17). We can now observe the presence of species considered to be sensitive to pollution like salmon.

4. Bleak, eel, common barbell, Amur bitterling, white bream, common bream, pike, crucian carp, common carp, sculpin, chub, sticklebacks, common roach, gudgeon, ruffe, nase, ide, perch, pumpkinseed, catfish, common rudd, zander, wels catfish, tench, and dace.

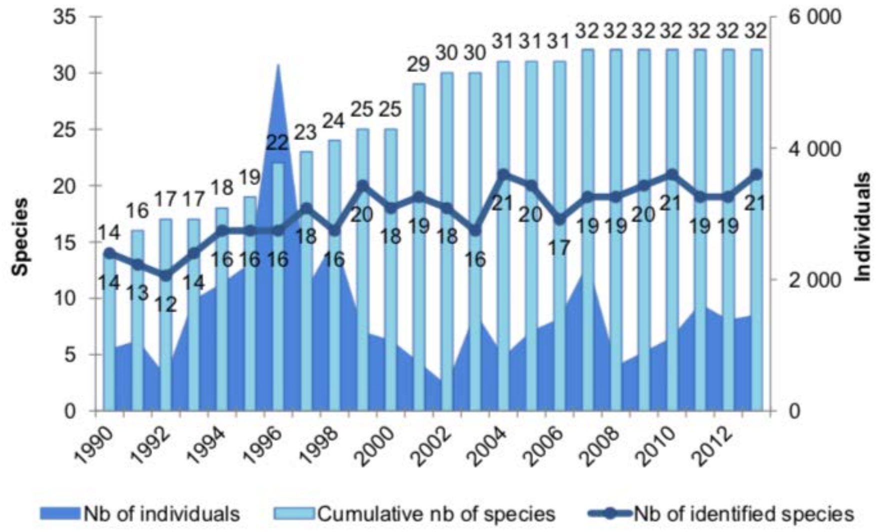


Figure 17. The number of species and individual specimens counted in the Seine per fishing year and the accumulated total over the period of study (1990-2013) (Azimi and Rocher 2016)

2.2 Growing population in the Paris megacity

Throughout the SIAAP's administrative territory, a 9%[5] increase in the population is anticipated over the 2012 – 2030 period, which amounts to practically 1 million inhabitants whose arrival may have a significant impact on water management: water supply, wastewater collection and management of the impervious surfaces of new development areas.

2.3 The effects of climate change

The effects of climate change on the hydrology of the Seine have been examined primarily in the framework of several research projects[6], in partnership with operational stakeholders. All of these projects will result in major changes to the hydrology of the Seine basin area from 2050 onwards: water resources may no longer be abundant. At the same time, there are no clear statistical signals concerning a change in the flood hazard.

The main conclusions are as follows:

- An increase in air temperatures of 2.3°C for the annual average temperature and as much as 3°C in summer;
- A downward trend for summer rainfall with strong uncertainties about the rainfall characteristics but of lesser importance than the increase in the evaporation rate;
- The rising air temperature will significantly increase the potential evapotranspiration demand. At the scale of the Seine catchment, this will strongly reduce aquifer recharge and lower the flow rates of rivers;
- The low flow rates of the Seine, with very similar rules for low flow support by storage dams to those in force today, will drop significantly from 2050 onwards. A drop of between -10 and -50% in the mean annual flow rate of the Seine in Paris is anticipated, depending on the models used. The drop in the five-year low flow rate could be as much

5. Hypothesis adopted by the SIAAP for the 2015 revision of its sanitation plan in agreement with government authorities.
6. 'RexHySS', carried out by a multidisciplinary team from 2007 to 2009, allows for the estimation of the consequences of climate change on the hydrological regime of the Seine by 2050 and 2100
'Climaware', for which some of the research concerned the Seine basin and the role of storage dams seeks to propose adaptation strategies for water management in response to the impacts of climate change on surface waters.
'Explore 2070' program simulates a horizon of 2045 – 2065 based on the A1B climate change scenario of the Intergovernmental Panel on Climate Change (IPCC).

as 60%. This decrease is simulated on the basis of the current abstractions and land uses. The changes concerning ten-year return period floods are less consistent and are generally statistically less significant;
- In aquifers, the groundwater table will lower by 1 to 5 meters compared to today's level, impacting the main supply sources for rivers.

The results obtained show that by 2050, the highest probabilities concern the drought hazard. Therefore, more studies and research need to be carried out in this field, specifically concerning the impacts of changing agricultural practices on water requirements, changes in the management of these structures and in their characteristics, and the changes in drinking water consumption for domestic uses. The main issue relating to climate change concerns the risks of a deterioration in water quality as a result of the drop in the low flow rates of rivers. Overall, the pollution loads discharged by the urban wastewater treatment plants situated in the upstream basin areas of the Seine are likely to remain stable, as the population will not increase as much as in the Paris region[7]. Any drop in the rate of flow should thus lead to higher concentrations in the water. The megacity of Paris will thus face a twofold problem, with a reduction of the dilution capacity for these discharges due simply to the drop in flow rates, which will be magnified by the highly likely increase in concentrations in the Seine, Marne and Oise. At the same time, the rise in the population of the megacity will increase the pressure on treatment systems. In this context, if one assumes that sustainable development is based on keeping water quality in a good condition for the next generation, maintaining the water quality within the Seine becomes a very important issue.

An analysis undertaken by government agencies and all stakeholders has allowed for the performance of a shared diagnosis concerning the sustainability of the Paris conurbation, especially—but not exclusively—in the water sector. The findings can be summarised in the following manner:
- With regard to drinking water, the report concludes that 'Modifications to the hydrogeological regime in response to climate change could significantly modify the current fragile balance, with a reduction in the flow rates of the major rivers in summer, a seasonal increase in agricultural needs in particular, a rise in temperatures and in evapotranspiration, new requirements relating to adaptation to climate change, etc. Groundwater resources, which supply many local authorities in the outer suburbs, are dependent on how surface soils are used, and are damaged by the increased concentrations of pesticides and nitrates associated with agricultural practices. Changing these practices has emerged as a general challenge: a model that uses inputs and water more sparingly must be sought;
- Regarding sanitation: the report stresses that 'the consequences of climate change for the dilution capacity of wastewater will be an essential factor in maintaining the good status of surface water bodies. At the Ile-de-France level, the discharges and abstractions will certainly increase the pressure exerted by the Paris conurbation on aquatic environments and the already vulnerable water resources, in a context of heightened tensions due to climate change'.

2.4 Flood protection

The first type of floods caused by rivers like the Seine or Marne are not in the SIAAP mandate, however, the operation of the sanitation system can be severely affected by Seine or Marne flooding. In those conditions, the SIAAP has to ensure good conditions for the sanitation of Paris Region: the SIAAP then operates the system in close cooperation with all its other partners in order to provide stormwater drainage and to avoid sewer overflow floods or any shutdown of the sanitation system.

7. Waste Water Treatment Plans (WWTPs) are based on traditional activated sludge with high-level performance, in particular in relation to the major parameters such as Biochemical Oxygen Demand (BOD) and ammonia. Concerning nitrate, the current regulation obliges domestic WWTP to remove 70% of the total nitrogen. Today the main nitrate contributor is agriculture.

The second type of flooding, which is of concern, are those caused by heavy rainstorms that overload the sewer system. These floods are more strongly related to SIAAP's sanitation tasks and even though the SIAAP is not formally in charge of the management of stormwater, it has to pay attention to this issue particularly in some parts of the Paris region. This was the starting point of Real-Time Control development in Paris region (see section 3.2.2).

Box 3. How the Seine quality recovery challenge been addressed in the past

The result in the Seine quality improvement is the consequence of a long-term policy started in the mid-1960s. To address the poor water quality of the French rivers, a Water Act was voted in 1964. This first Water Act was original in several points, with the key points as follows:
- Integrated water management based on the main French rivers basins and not on the administrative limits;
- A new governance with a basin committee where the water management policy is defined by the water users: cities, industries, farmers, environmental associations, fishing professionals and State authorities;
- Water agencies per basin were created. These agencies are in charge of the financial part of the water management policy by collecting fees based on the pollutant emissions and by encouraging works and actions by providing subsidies.

This is the base of the water management policy in France. Thanks to this policy and these tools, the SIAAP has launched a continuous program of works in order to improve its WWTP capacity and performance. This program became more ambitious during the last two decades.

Figure 18 below shows the history of sanitation in Paris region. Its only since the end of 1990's the treatment capacity is sufficient enough to treat all the collected sewage.

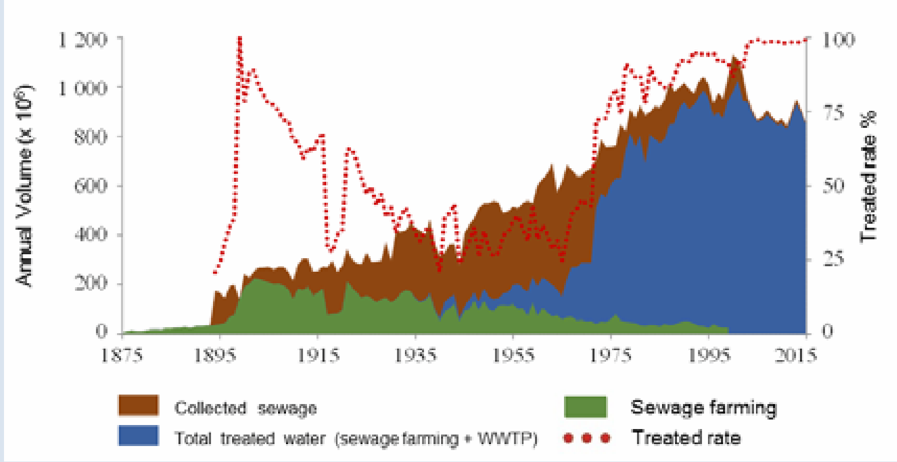


FIGURE 18. Volume evolution for collected and treated wastewater by sewage farming and centralized treatment in conventional treatment plants from 1875 to today
(Rocher and Azimi 2017)

3. Smart Water Management Solution

3.1 MAGES presentation, how does it address the Paris region water challenge?

The development and implementation of the smart water management systems in Paris region is the result of a long process originally related to local floods during cloudburst events. Since that time, the sanitation system has gone through major changes in its structure and in its regulatory frame (Blanchet et. al. 2008; Tabuchi and Blanchet 2016).

As stated above, today sanitation of Paris region relies on a multi-stakeholders management organization, a vast sewer system to collect and transport the 2.4 Mm^3/d produced by 9 million inhabitants, on 6 interconnected WWTP and all the system is of a high impact risk for the receiving waters. After the time of development and implementation of local real time control system, then came the time for a comprehensive vision of sanitation system operation. This appeared to be increasingly necessary to efficiently manage this interactive and complex system on which rely the Seine quality recovery to comply with WFD objectives.

In 2001 the SIAAP decided to build a new real time control system on the base of the existing systems. This new RTC had to allow in real time, data and information exchanges between the different system, to provide a comprehensive overview of the status of the system and to produce operation scenario. This system, described herein after is based on hydraulic and hydrologic numeric models fed by continuous monitoring of the sewage network and weather forecast-based radar images. After a presentation of MAGES context and origins, the following paragraphs provide a comprehensive description of the developed solution and the main results obtained thanks to the implementation of this decision support system in SIAAP's sanitation system.

3.2 MAGES context and origins

3.2.1 The technical context

The network under SIAAP's control consists of large collectors and main sewers, built at depths varying from 3m to 100m, depending on the topography, and whose diameter varies between 2.5m and 6m. Its total length is about 400 km. Numerous system interconnections have been created to guide flows according to the available capacity of downstream main sewers, storage and treatment works and also to allow by-pass without spillage of untreated water to receiving water during maintenance operation. One of the very special characteristics of the Paris agglomeration is its high water transfer capacity between WWTPs. Although it is common in large cities to find several wastewater treatment plants, it is rare that they have the possibility of transferring water between them through an interconnected sewer network. This feature is the fruit of the history of the agglomeration. This is mainly due to the fact that originally the system was designed with a WWTP downstream of Paris region. In 1968, a sanitation master plan was adopted with the idea of splitting the collection zone and with a new distribution of treatment facilities around the agglomeration. This treatment facility's new distribution was strengthened the 1997's sanitation master plan which main conclusion was the decision to downsize *Seine-Aval* WWTP from initial capacity of 2.7 Mm^3/d to 1.3 Mm^3/d. This evolution from a single treatment site to a multi-site approach implanted on a main transport network has been a favorable factor and it has been taken advantage of to reinforce this link between the treatment plants. The flow management system takes great advantage of this feature.

Concerning *Seine-Aval* downsize, regarding to the original design of the sewers, the consequence is a decrease of water velocity which, added low slopes, drives to a high sensitivity of the sewage transport network to solid deposits. This is a problem when a strong rain event occurs after a long dry weather period: the consequence is a very high suspended solids concentration.

The other important aspect is the water management in rainy weather. In order to reduce the combined sewer overflow (CSO) frequency, volumes and their impact on the receiving environment, 955 000 m^3 of storage tanks and reservoir tunnels were built to ensure the storage of the polluted water and their released to the treatment plants.

Approximately 150 local management stations with remote-controlled regulating and pumping equipment have been deployed in the SIAAP's area of competence and allow the implementation of a real-time control of the works.

At last, among the important technological developments, the treatment processes implemented at SIAAP rely heavily on biofiltration, which is distinguished by the short residence time of the effluents, less than 2 hours. This means that the treatment systems are very responsive with very little buffer time. This is an advantage for example for adapting the wastewater treatment to the requirements of the receiving water protection, it's also sometimes a disadvantage: the operation of such a system can be difficult due to its reactivity.

3.2.2 The road taken from SCORE to MAGES

In the late 1980s, SIAAP developed a real-time control system, called SCORE to address the significant shortage of effluent treatment capabilities. At that time, only 3 WWTP were operational, the capacity deficit was around 500 000 m^3/d and they only concerned the 'Western system[8]' related to the *Seine-Aval* plant whose project was then to increase its capacity from 2.1Mm^3/d to 2.7 Mm^3/d. In an interim stage, the idea was to take advantage of the sewer pipes' ability, in dry weather, to store the daily peak of the effluents and to treat the sewage during the night, when the flow is lower. However, one had to be sure not to take risks in the face of floods during rain events. The two graphs below (Figure 19 and Figure 20) show the results of flow control in order to smooth the hydrograph between night and day. The first one illustrates the regulation obtained with SCORE at its beginning. At that time the average flow rate capacity of *Seine-Aval* WWTP was around 25m^3/s. The table also shows the improvement of flow control from year to year.

SCORE was based on the system of five main sewers supplying Seine-Aval which were equipped with regulating valves. Each main sewer was divided in several trunks used for sewage storage. Given the hydraulic risks associated with the rains, this system already included a rain forecast. The remote management system was the precursor of the current system and was began operation in 1992. It was independent from those implemented by each *département* (see section 1.2.2.5).

8. The 'Western system' is the downstream part of SIAAP's sanitation system. It is based *Seine-Aval*, *Seine-Centre* and *Seine-Grésillons* treatment plants which are interconnected and located in the West side of Paris region.

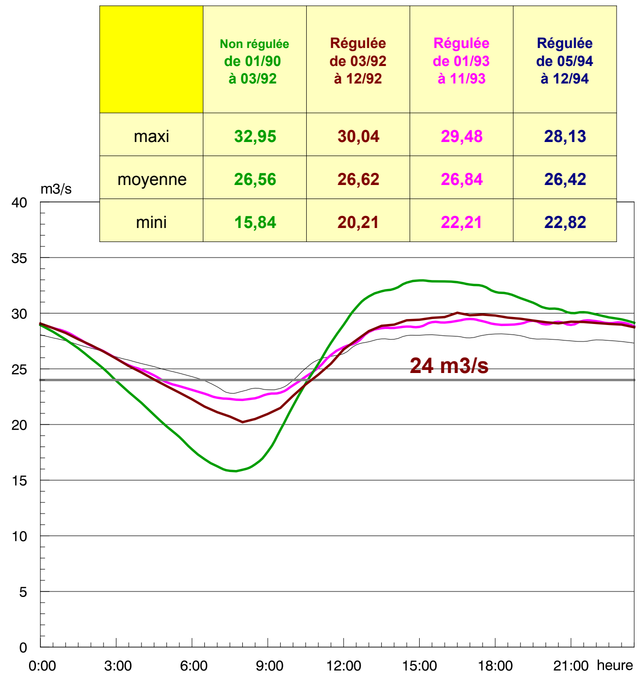


Figure 19. Illustration of the flow control at the inlet of Seine-Aval WWTP with the SCORE system. The curves represent the average daily flow variation without control (green curve), and the improvement of the regulation obtained between 1992 and 1994 (other curves)

The curve below (Figure 20) shows the current flow control with MAGES in dry conditions. The steady flow is required by the operator of Seine-Aval WWTP.

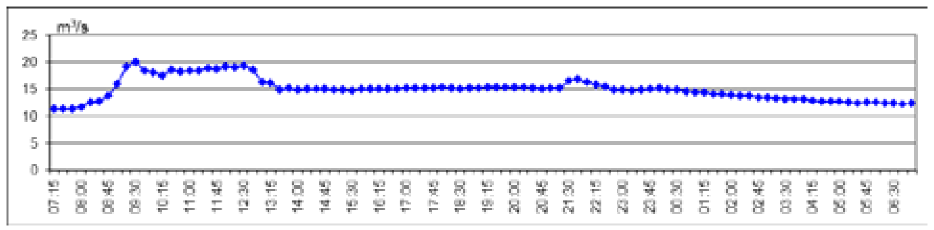


Figure 20. Example of flow remote control obtained at Seine-Aval inlet with MAGES in dry weather condition – (02/07/2018)

In 1989, following local protests, it was decided not to increase the capacity of Seine-Aval as was originally planned. This decision led to the development of a new sanitation master plan that was approved in 1997. This scheme introduced three important evolutions:

1. Downsizing Seine-Aval capacity to 1.5 Mm^3/d instead of 2.7 Mm^3/d as was originally planned. This led to a new distribution of sewage treatment capacities on SIAAP's territory.
2. Stormwater pollution control due to combined sewer overflows. The master plan was designed with the objective to avoid untreated CSOs spillage for a return period of less than 6 months. With this in view, the construction of a total stormwater storage capacity of 1,693,000 m^3 was planned.
3. Implementation of a real-time control system of SIAAP effluents. The studies of the time showed that a real-time control system would allow the reduction of 500 000 m^3 in discharges from sanitation system during heavy rains.

3.3 MAGES's objectives

In this context, in 2001, the SIAAP launched with the active collaboration of all its partners (*départements*, treatment plant operators and Water Agency) the construction of a dynamic management support tool of its sanitation system, called MAGES. This system aims to meet three main objectives:

1. Global and shared knowledge of the sanitation system. To satisfy this objective, the operators have pooled the data they use for the management of their works through a data exchange system: the EDEN system (Environmental Data Exchange). EDEN allows the exchange and centralization of the measurements and the current state of the works.
2. The prediction of the operation of the sanitation system in a stable configuration. The aim is to provide each operator with a forecast of flow capacity of the sewage transport (collection) system and storage works and flow arriving at each WWTP, with a forecasting horizon of 24 hours in dry weather and 6 hours in rainy weather.
3. Assistance for the management of the sanitation system to optimize the use of the structures during the rainy episodes.

3.4 The development process

On this basis, but also thanks to the experience of SCORE and the other *départements* of the Paris region, SIAAP launched SCORE's evolution project towards a system integrating all the SIAAP networks by opening and extending it to equivalent systems of its partners.

It began with studies and *interdépartemental* working groups (SIAAP, *départements* and Water Agency) aimed at pooling knowledge about the structure and operation of the network. This stage was the occasion for establishing in-depth and intense exchanges between the stakeholders. The studies were followed by developments of the existing SCORE system. This system allowed the supervision of the flow condition (water level and speed) on the entire SIAAP network as well as the remote control of the control devices. In addition, the EDEN (Environmental Data Exchange) system has been developed to enable network supervision centers in the core zone and SIAAP to share data in real-time. At this stage, SIAAP had knowledge of the real-time structure and operation of its network and upstream departmental networks. It had tools for control and control of the network devices Flow management could therefore be implemented operationally from remote management centers. However, given the complexity of the network, a management support system seemed to be essential to optimize the use of the means implemented.

Given the very innovative nature of the management assistance tool to be put in place with the uncertainties on the results and taking into account the obligation of result, the second step was to launch a kind of contest. According to the French Public Procurement Code, two '*marché de définition*' or definition studies with two consultant consortia were selected in January 2004.

The study contracts were divided into three phases:

1. Modeling
   The objective of the first phase of the study, known as modeling, was to develop a software model to reproduce and then predict, using measurement data (hydraulic, rainfall) and various information (positions of moving parts, availability of works, etc.), the evolution of various variables that can be used for the management of structures.
2. Decision Support Tool
   The second phase involved the study of a decision support tool. It had to rely on the modeling effort of the first phase and the methods proposed by the candidate. The main result of this phase was a software model which, fed by the same type of data as the first model, was to provide management instructions that could be used by the different operators of *départemental* and *interdépartemental* sanitation works.

3. Tender Document
   The final phase was the drafting of the tender document[9]: especially the detailed requirements specification for the creation and full implementation of the MAGES forecasting and decision support tool, and the drafting of an offer to this tender document.

These definition studies began on April 1, 2004 and ended in October 2005 with the submission by each incumbent of the products from Phase 3; the tender document and the technical and financial offer for the development of the tool. Two approaches were proposed by the candidates: one proposed a solution based on a stochastic modeling approach while the other was based on a deterministic modeling of all the processes from runoff to hydraulic transport. The solution based on a deterministic model was chosen because it was considered more understandable and manageable in its adaptations and evolutions by the operating teams. The realization of this project was led by the consortium constituted by the companies *Eau et Force* (a SUEZ subsidiary) and *SATELEC*.

This led to the launch of the MAGES project, which is the core of the real-time control system. The aim was to put a forecast model of the network states and a management aid system at the disposal of the operators of SIAAP and the departments of the near suburbs of Paris. This system proposes orders on the control devices in order to reduce spills in the Seine and Marne, and to optimize treatments.

The contract, started in April 2006, consisted in the extension and the implementation for the operation of the software model realised in the definition study. This included:
- the design, production, installation, commissioning of operating tools (hardware, software) on all operating sites for real-time uses (management scenario proposals) and deferred time (simulation of past situations, integration of new system documentations, training, testing of different scenarios);
- setting up these tools in accordance with the current situation of the territory managed by the SIAAP and partners, and with the specific needs of each operator;
- the development of the central control station: SAPHYR PC;
- the training of future MAGES users.

3.5 The technical solution

3.5.1 General principles

MAGES relies on real-time deterministic modeling of transport and storage structures with 23,000 calculation points coupled with an optimization process for searching the management scenario. This modeling takes into account the following inputs based on an intensive data sharing network (see Figure 21, Figure 22):
- dry weather sewage flow inputs;
- measured and forecast rainfall inputs;
- field measures data with a set of more than 2,000 sensors;
- physical changes to the sanitation system. These could be related to maintenance works or incidents inherent in the operation of any sanitation system.

9. In French : dossier de consultation des entreprises

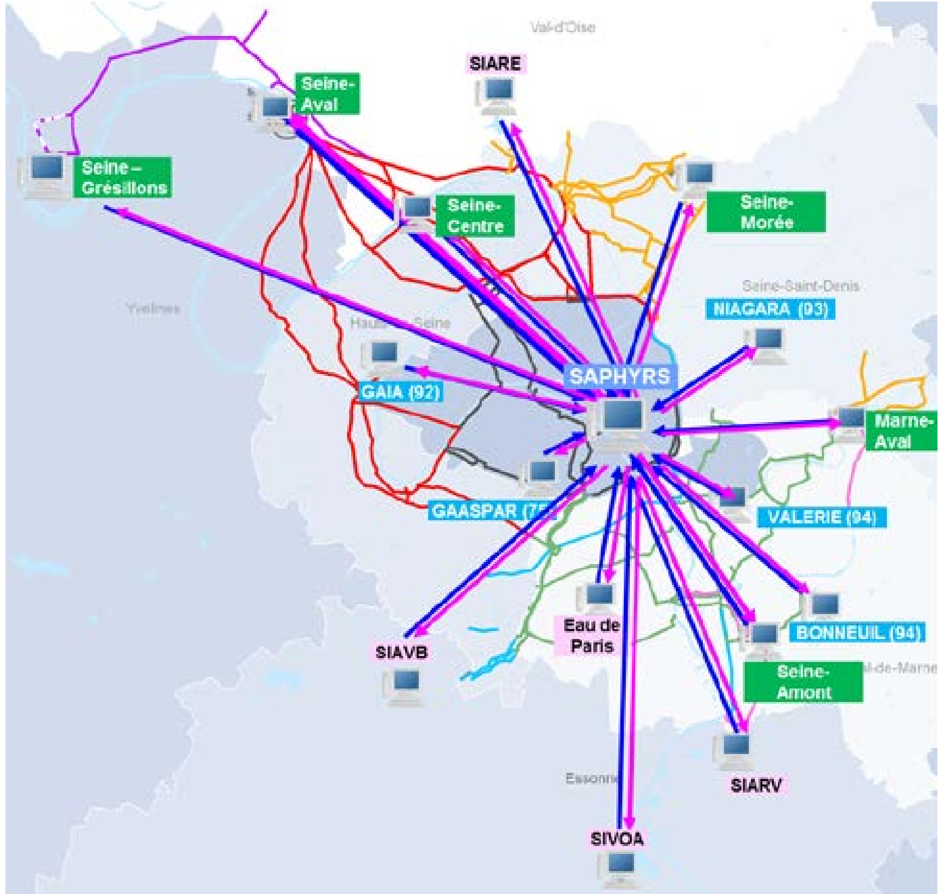


Figure 21. Main data transfers between SAPHYR control room and MAGES with WWTPs (green) SIAAP operator members (blue) and outside operators (pink)

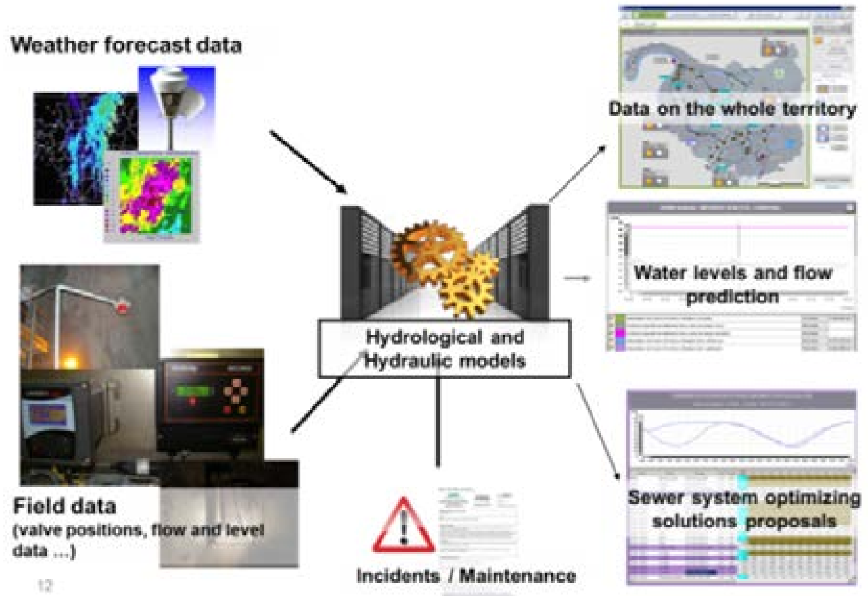


Figure 22. Schematic of data and MAGES output processing operations

A MAGES treatment cycle updates every five minutes to show:

- Identification of the current state of the system:
    - the measurements collected in real-time, after following a validation process,
    - these measurements are also used to update the models (position of regulators, filling of basins, etc.),
    - the simulation of the state of the network carried out with the detailed hydraulic model. This simulation provides a consistent state of the system by completing the valid measurements with the results from the modeling. Thus, each operator has at the same time a synthetic, comprehensive and complete vision configuration and hydraulic status of the sewerage network, e.g. heights, flow rates, discharged flows, volumes stored, volumes treated, etc.

- Prediction of future trends.
  The MAGES system provides the expected state of the system by integrating the effect of the rain forecasts. It is based on the detailed hydraulic model: flow rates and water levels are estimated assuming that the network configuration (valve position, pumping rates) is unchanged over the prediction horizon, except for works which have a local regulation, which is taken into account in the forecast. The hydraulic status (flows and heights) is then displayed for around 400 key points along the network, with a horizon of 24 hours in dry weather, and 6 hours in rainy weather.

- Determination of the optimized management scenario.
  A linear model based on simplified hydraulic and hydrological equations calculates a large number of simulations in a few minutes, the results of which contribute to the creation of an optimization problem. This optimization problem is subject to a solver that minimizes the cost of an 'objective' function. It is the parameters of this objective function that set the priorities such as limiting spills to the different weirs, the priority of use of the different available storage volumes, or the operating time in the rainy season configuration of the treatment plants.
  The simplified model is recalibrated with the detailed model at each 15-minute computation cycle. This solution ensures rapid calculations and convergence of the optimization problem while ensuring realistic and stable solutions, whatever the weather conditions. The scenario is presented in the form of objective flows calculated by the simplified model for 26 key points along the network, selected for their management potential. These flow-objectives are also translated in the form of instructions for the ~50 main control structures (valves, pumping group, etc.) of the sanitation system. They are presented to the operators as valve positions, flow or water level instructions, depending on the management mode of the structure.

- Prediction of the optimal trend situation.
  The instructions for the main structures obtained in the previous step are injected into the detailed hydraulic model to provide the state of the system in the event that the proposed instructions are actually applied.

There are three 'objective' functions, corresponding to the three management strategies that have been set in MAGES. These strategies include:

1. The 'long-term dry-weather strategy', aiming to smooth overall contributions to WWTP while not increasing the risk of spills.
2. The 'overflow rain conditions' strategy aims at minimizing spills without increasing the risk of floods by overflow during medium to heavy rains. By anticipating the emptying of the collectors, it optimizes the treatment at the WWTP and the storage capacities in the basin and network.

3) The 'rain overflow time' strategy is designed for heavy rains, to fight primarily against the risk of overflow of the network on the roadway. All the outlets are then used to relieve the network.

Even if there are automated local control devices, the operator is able to act directly on 160 remote control devices such as valves or pumping stations (see Figure 23).

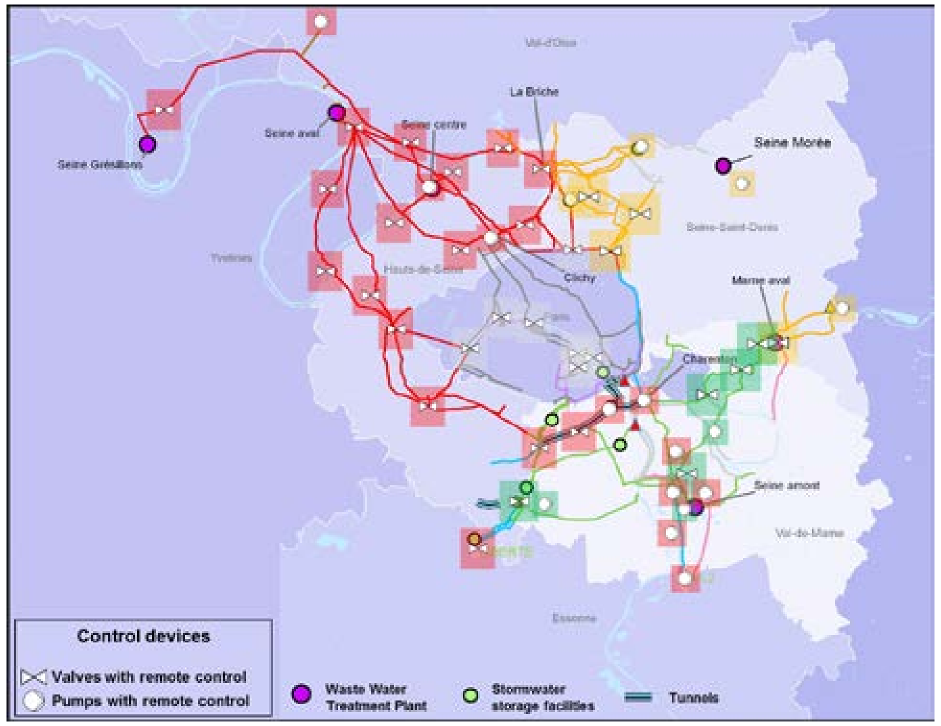


Figure 23. Main remote control devices. (Colour code for sewers refers to the operator: red for SIAAP, grey for Paris, orange for Seine-Saint-Denis, green for Val-de-Marne)

3.5.2 Current state and trend prediction by detailed modeling

MAGES relies on a deterministic modeling[10] of the urban water cycle, from the hydrology of the perimeter (transformation of the rain heights into runoff water to the network) to the hydraulics of the structuring network of the sanitation system. Real-time accurate reproduction by a detailed model of dry and rainy weather inputs, network configuration and meteorology conditions feed into the results of the modeling. Taking them into account is a real technical challenge whose main characteristics are presented below.

3.5.3 Dry weather flow assessment

The MAGES perimeter was divided into 60 input sectors, which are broken down throughout the network by 153 sewer inflow points. In order to reproduce the weekly and monthly fluctuations in wastewater and the seasonal variations in permanent infiltration water inflows that have been shown to correlate directly with groundwater levels, a process of recalibration of dry weather flow has been developed in MAGES.

On each catchment area, feed hydrographs of wastewater and infiltration water were constructed from the archived data. For the real-time adjustment of these hydrographs, the

10. Deterministic modelling in this case refers to all of the physical process involved in the flow calculation at each point of the network relying on mathematical formula to describe the hydraulic conditions such as slope, shape of sewer, sewer material with Strickler coefficient, hydraulic formula for each kind of devices, etc.

simplifying hypothesis adopted is that the global volume of dry-weather inputs modeled for the current day is best approximated by the volume measured at the treatment plants for the last known day of dry weather. A statistical analysis carried out with three years of self-monitoring data of the WWTP showed that the total volume of inputs calculated from the measurement of the last known day's contribution is a good estimate, within a confidence interval. +/- 11%, for 95% of cases. This method thus ensures that changes in dry weather production are taken into account correctly, in particular seasonal variations in infiltration water and wastewater inputs (especially during the summer holidays period), as well as inter-annual changes in wastewater production, particularly related to the changes in consumption of drinking and non-drinking water.

The adjustment variable used is the total daily flux of nitrogenous materials (organic nitrogen and ammonia, expressed in TKN) measured in the WWTP, directly correlated to the volumes of wastewater produced over the catchment area. The overall infiltration volume is deducted from the difference between the input volume and the wastewater volume. Finally, the correlations between the total volume of wastewater and infiltration water and the values per catchment of these two quantities make it possible to adjust daily hydrographs for each input basin.

3.5.4 Assessment of stormwater inputs

In order to have an accurate cartography of the precipitation data, the SIAAP use the CALAMAR® model. From the images of the meteorological radar of Trappes (78), distributed by METEOFRANCE and measurements of the 80 rain gauges operated by the four constituent *départements* of SIAAP, CALAMAR provides data at 5-minute intervals with the spatial distribution of rainfall over the covered area, and a resolution of 1 km^2. In addition to this measure, the 2-hour forecast, at 5 minutes intervals, is used as the MAGES input variable. The data for past and projected precipitation is then mapped onto the territory using radar images, divided into 1200 watersheds, representing a total active surface of 28 000 hectares. The volumes are then distributed to the 388 sewer inflow points in the hydraulic model (among which there are 153 points of dry weather inflow points).

3.5.5 Metrology

Metrology is an essential component of MAGES: it builds an understanding of the current state of the sanitation system and updates the models used for the elaboration of the trend and optimized situation. Metrology is a set of more than 2,000 sensors corresponding to flow, level, valve position, level or flow rate measurements. A measurement validation process based on several complementary methods was set up on each of the measurement points to ensure the quality of the input data of the system. In addition to these systematic and automatic validation methods, authorized operators have the possibility to intervene to inhibit the measurement of a given sensor, or even correct the value if they know it.

3.5.6 The detailed modeling

The modeling tools are the METE-EAU® software package for the hydrology of the upstream zones of the network and HYDRANET® for the hydraulic modeling, both developed by the company Hydratec. These tools have been adapted to meet the constraints of fast execution of calculation cycles and robustness of operation for operational use. Indeed, the modeling implemented extends over 500km of main sewers, modeled by 3 113 'user nodes' (and translated into 23 000 computation nodes). 150 management stations (basins, valves, pumping) were modeled, integrating the automated local management rules for existing ones.

To satisfy the execution time constraint (approximately 3 minutes for a 24-hour simulation), several processes for optimizing the calculation time have been implemented, notably the 'hot restart' of the results of the previous calculation cycle and a division into 5 interconnected sub-models. Calculations are performed sequentially by sub-models according to upstream - downstream logical tree (see Figure 24).

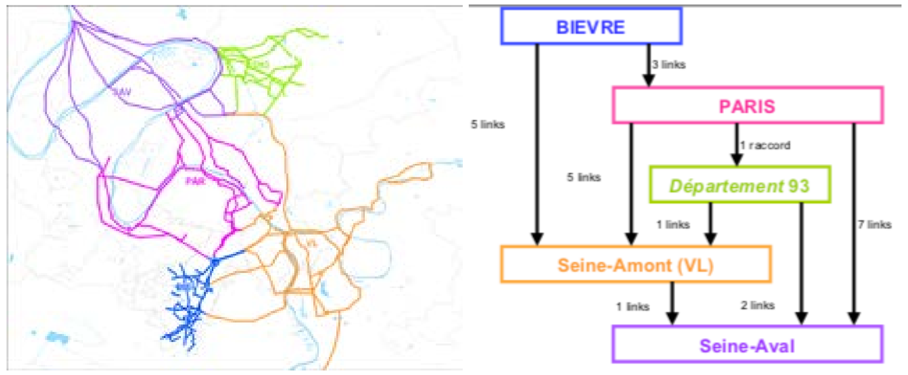


Figure 24. The five hydraulic sub-models and their links

3.5.7 The MAGES update process

In order to guarantee the coherence and the reliability of the results calculated by MAGES compared to the field reality, the model is updated according to a cycle of 5 minutes for all the information influencing the result of the predictive modeling. During this process, the following inputs are taken into account: the measurement and the rain forecast, the measurements (positions, instructions, flows) and the configuration of the works which result from the predictable and known maintenance works, but also from the interventions and incidents which are inherent in the operation of any sanitation system.

A first update function is performed on the control and storage structures, at each 5-minute cycle, using the previously validated measurements.

A second function of updating has been developed to take into account the operations of works in maintenance. The works programmed several months in advance are communicated to the model via a specific interface, as well as their translation for all that concerns the routing of inputs or the modification of the management rules of a control device. Once the operator has validated the beginning of the work, the model automatically updates itself on these new configurations of works, as of the following simulation cycle.

This update is also applied for any incident that occurs on the network, such as a set of maneuvers routing effluent following a WWTP operating problem.

Finally, in the absence of the updated data, the model reproduces an operating dynamic management based on the rules that are routinely applied by the operator for each local management station. The result is a baseline scenario, which provides consistent and credible results in a fallback situation that is when none of the update or registration data normally provided by metrology is available.

3.5.8 The optimised scenario construction

The optimisation aspect of MAGES includes an optimiser, which minimizes the cost of a 'multi-objective' function and a simplified model, quasi-linear, used to assess the cost of this 'multi-objective' function in different configurations of the main devices for the network management.

The 'multi-objective' function reflects the cost of spills, overflows, storage in the works, and the use of the stormwater pollution treatment systems. The room for maneuvering that this function allows are the saturation of the dry and rainy weather treatment capacity of the WWTP, the filling of the storage facilities, the use of the interconnected sewage network and, of course, the use of different combined sewer overflow devices.

The optimiser used is the MINOS solver developed by Stanford University. The simplified modeling and control of this optimization are carried out with the CSoft software, developed and distributed at that time by the company BPR-CSO, It is a model of the input-output type, able to calculate the flow, to reproduce the flow rate in the pipes and to explicitly satisfy the continuity equation at the nodes. The parameters of this model are calibrated from the validated measures where they are available, supplemented by the results of the detailed model for the other points (in particular those which are not instrumented).

The optimization module builds the optimization problem for the fifty key piloting devices that have been selected. The result consists of the optimal instructions that are proposed for each of these control devices, over a control horizon of 6 hours or 24 hours.

The automatic construction module of the problem formats the equations and inequality factors, which need to be optimised to solve the problem. The equations reflect the respect of material balances at the management stations and the hydraulic constraints (i.e. flow rates to be respected). The inequality factors represent the intervals to be respected (i.e. minimum flow and maximum flow at the WWTP). This module uses the results of online calibration to construct dynamic flow equations.

This same module then establishes the multi-objective function using the weights and penalties that are specific to the strategy in use. These 'objective' functions are stated above (see section).

In order to compare the gains of the optimized scenario with the trend situation on the basis of the same detailed simulation tool, all the instructions proposed for the optimized scenario are incorporated into the detailed model. Thus, the operator is able to judge the impact and relevance of these instructions, comparing their effects to the current management. The calculation resulting from the application of these instructions corresponds to the 'optimized trend scenario'.

3.5.9 The non-real-time mode

Besides the real-time system, there is a non-real-time mode. This mode allows several possibilities:

- to work on past events in order to study these events and learn from experience;
- to make studies for maintenance shutdown. This allows managers to study the best scenario which aims to avoid spillages or to reduce them when there is no other option;
- to test different operation scenarios;
- for training sessions.

This non-real-time mode is also necessary to replay past situations because the system keeps all the real-time results of the last three months in its memory. Beyond this limit, the non-real-time mode is used to 'replay' the situation with all that data which are all stored in the data base.

3.6 MAGES, an operations tool

3.6.1 Simplified architecture and processing cycle

The architecture of the system is based on the principle of modularity. The detailed model (METE-EAU and HYDRANET), the optimizer (CSoft with MINOS), the Human Machine Interface (HMI), the database where measurements and results are stored, the reception of meteorological data and metrology constitute many independent modules that interact with each other through the supervisor (controller) system.

Figure 25 illustrates the general IT architecture of the tool.

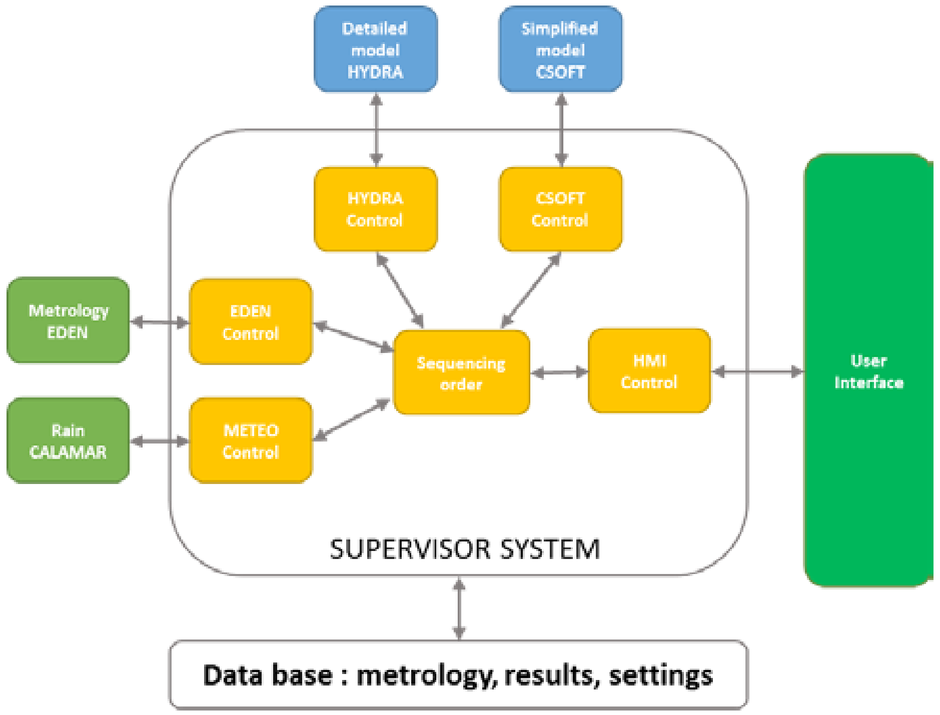


Figure 25. MAGES general computer architecture

The supervisor (controller) system was developed as part of the MAGES project, with the user interface. The supervisor is sequencing the exchanges between all the other modules. Its operation stems from the explanations provided previously:

- On a time step of five minutes, it retrieves and filters metrology and meteorology data, then updates the detailed model to calculate the current situation;
- In a quarter hour, it successively launches the detailed predictive model, the simplified model that produces the optimal set points, and then again the detailed predictive model. This results in the displays of:
    - The reference trend situation,
    - The optimum management scenario,
    - The trend optimised situation.

Figure 26 summarizes the nominal processing cycle of MAGES.

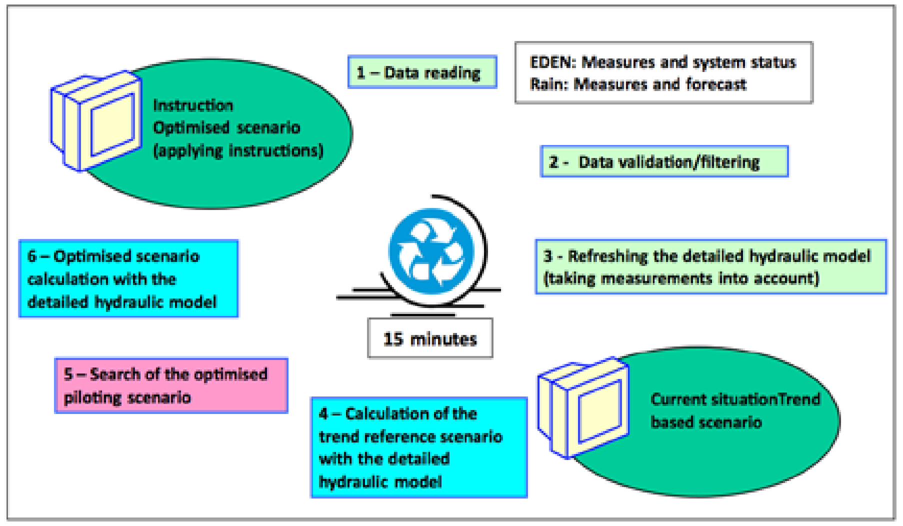


Figure 26. Simplified processing diagram

The hardware and software IT infrastructure has been implemented redundantly to ensure a high level of availability.

Beyond the various applications needed for configuration that have been delivered to the administrators of MAGES, two main applications are intended for users:

- The Human-Machine Interface for decision making application, which provides access to all the features mentioned in this article (current situation, baseline trend scenario and optimized trend scenario);
- The 'Maintenance shutdown' application, which provides information on planned shutdowns.

MAGES is accessible under the same conditions from the dedicated computers that are installed in the operators' control rooms, and from the computers that are located inside the SIAAP computer network. An Internet connection also allows the duty staff to access the same information from outside their office.

3.6.2 A global and shared vision of the system

The coherence of all the data provides a global and shared vision of the operation of the sanitation system. It places operators in a global management framework by providing them with information that goes beyond their strict management scope. With the current situation operators located upstream have the opportunity to know the impact of their actions on the downstream network.

Figure 27 provides a screenshot showing the entire perimeter of MAGES. It includes the structural collectors, the six WWTP and their operation setting (dry or rainy weather) and the piloting stations that are receiving instructions. Thematic indicators are also available such as the measurement and rain forecast, dry and rainy weather hydrological inputs, the stored volumes and the storage rates in the different sewers, the flows transited at the key points of the network, the flow directions of the main flow rates as well as the discharged flows at the 112 modeled sewer overflows. Each of these indicators is presented in the form of on curve (see Figure 28) calculated on the past compared with the observation (which can vary from 0h to 72h) and a forecast on the control horizon, which is 6h in rainy condition or 24h in dry condition.

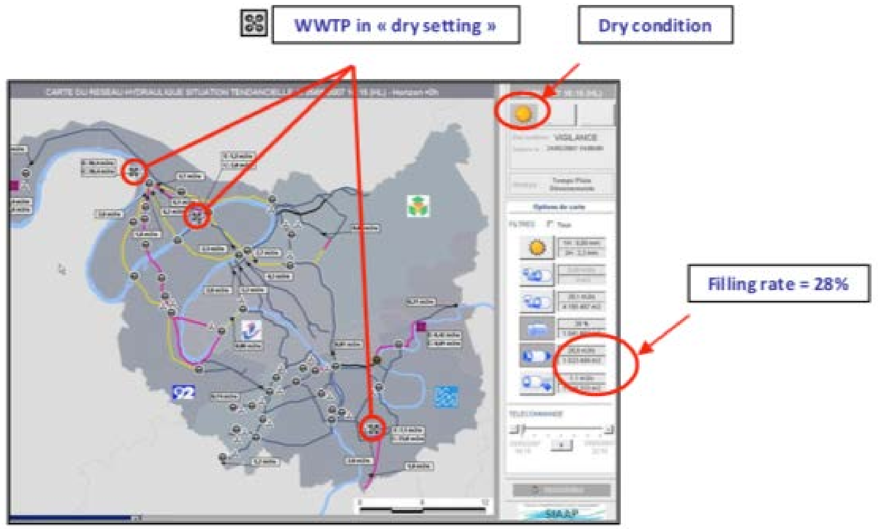


Figure 27. Global overview of the system and thematic indicators

This general vision can be zoomed in on each of five major input areas (Figure29). Each control-station has a synoptic window that describes its overall configuration using a symbolism common to all operators. These synoptic windows also constitute a portal to access local information.

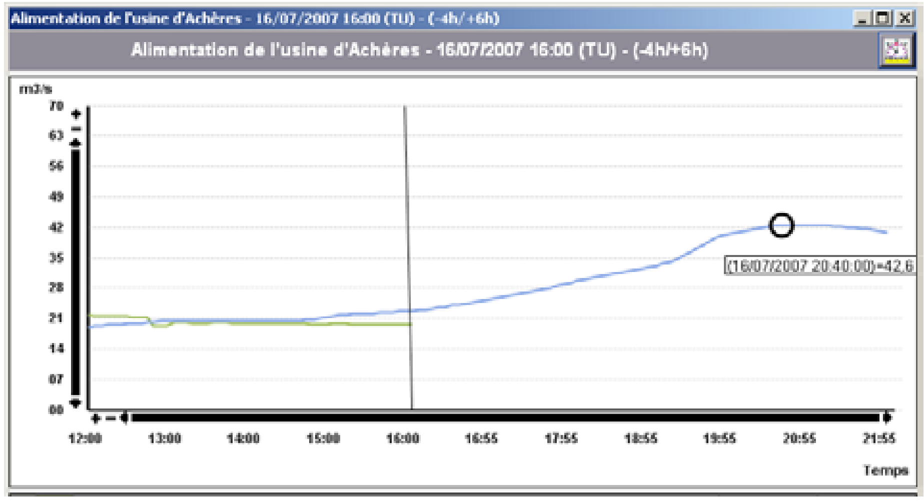


Figure 28. Forecast of a pic flow of 42.6 m³/s at 20:40 at Seine-Aval WWTP at 16:00
(green curve: measurement, blue curve: modelling)

3.6.3 The forecast and the optimisation

The trend situation for operators is predicted by the forecast of very high levels of water or flow in the network (see Figure 29), the prediction of the location of spills, the filling rates in the sewers and the operation during rainy weather of the treatment plants over a horizon that varies between 2 and 6 hours.

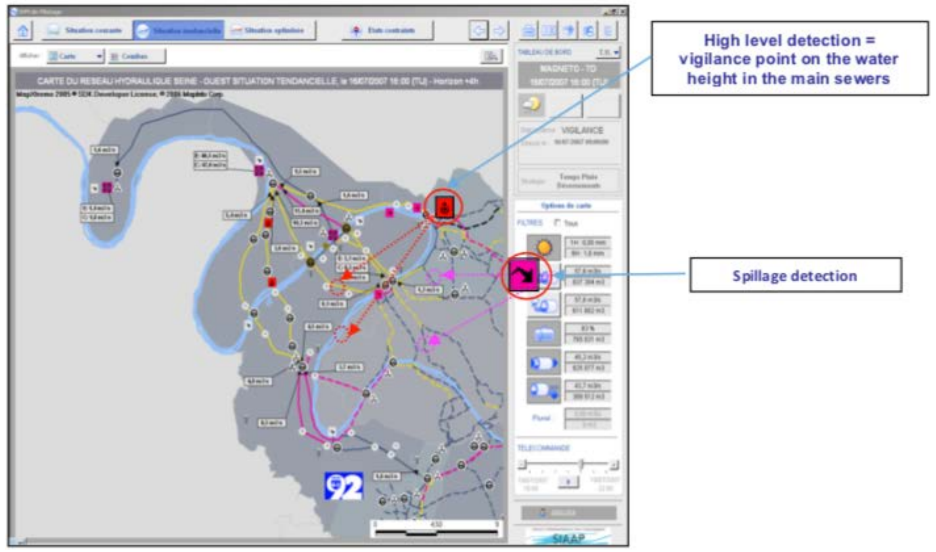


Figure 29. At 16:00, high levels anticipation of 4h, dumping points and storage rates in the Western network, scheduled for 20:00

All information in the previous figure is also available in the form of predictive curves for the various important locations of the sanitation system such as the flows entering the WWTP, entering and exciting the storages basins, arriving at the interconnection points, on the CSOs, etc. (see Figure 30).

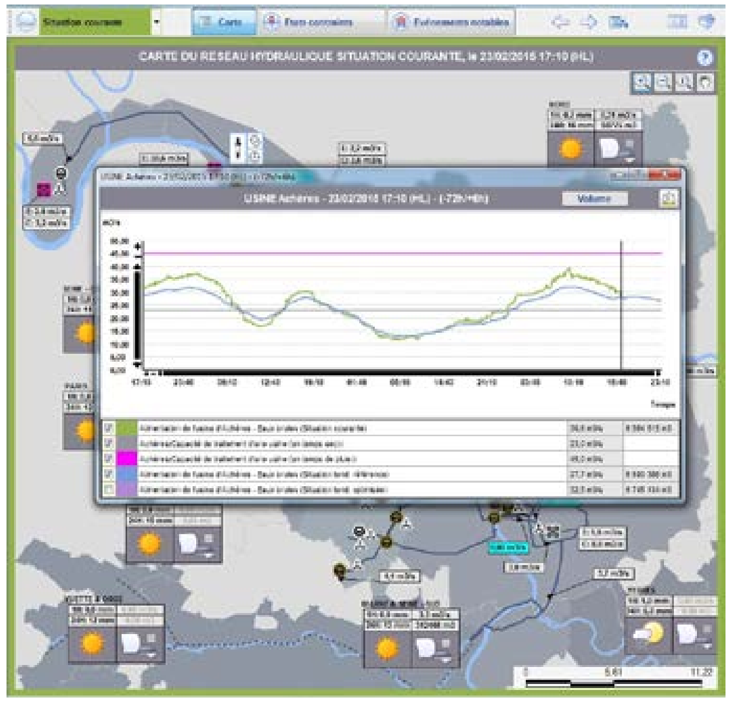


Figure 30. Screen shot of flow prediction at Seine-Aval WWTP planned (green curve: measurement, blue curve: model)

CASE STUDIES
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3.6.4 Conclusion

The technical solutions implemented for the construction of MAGES made it possible to satisfy the objectives of global and shared knowledge of the sanitation systems of the Paris region for different actors. This technological advance will be accompanied by profound changes in the operating methods of water treatment plants and networks. Indeed, with MAGES, the flow management in the Paris region is based on weather conditions and operating constraints, technicians are then enable to make responsive and concerted decisions. In addition, the decision criteria for the management of the network are built on the scale of the region and no longer only at the local level.

Beyond its real-time use, MAGES is also a tool for studying and assisting in the design and operation of new works, in order to make the most of available processing capabilities by optimizing volumes of existing or projected storage facilities.

3.7 Enablers and barriers

The implementation of the MAGES project was made possible because of converging opportunities and technical reasons:

- Paris region sanitation operators had a long experience with real-time control systems in sanitation. Their development and implementation started in the mid-1980s. In the early 1990s, each SIAAP member and the SIAAP itself were running a RTC system. This led to a shared technical culture background;
- The implementation of a global RTC system at SIAAP's was one of the main outcomes of the 1997's sanitation master plan;
- SIAAP's willingness to implement this outcome of the sanitation master plan was a key point;
- The financial and political support of the Seine-Normandy Water Agency (AESN) has also been a very important factor. The Water Agency funded this project with subsidies that covered 40% of costs and a loan of 20% with a zero rate. In addition to these funds, the Ile-de-France Région supported the project with 20% of subsidies.

Rather than barriers, it would be more appropriate to speak about resistance. When the project started, there was a slight fear about how the SIAAP would exert its leadership on this project. After the first working meetings, the resistance progressively disappeared, helped by the stimulating challenge that the project represented which the team was interested to solve and also by the commitment of leaders of each partner. After the first phase of slight resistance, each learned from the other and then a climate of confidence took place through an important work dedicated to the conception of a data dictionary and the follow up of the '*marché de definition*' or definition studies (see section 3.4). One other reason for the success of the project was that each partner kept tis own RTC system (see section 5).

3.8 Achievement and impacts: The contributions of MAGES and smart management

The development of MAGES accompanied a period of major evolution of the sanitation system in the Paris region because at the same time the SIAAP facilities were completing a profound transformation, downsizing the *Seine-Aval* WWTP (See 1.2. and 3.2.1).

At the end of the 1990s, the SIAAP had 3 large WWTP: *Seine-Aval*, *Seine-Amont* and *Seine-Centre*, *Marne-Aval* with smaller stakes. The SIAAP was just coming out of decades of chronic insufficient treatment capacity, the margins of management were low and the management was very static. The following decade led to a complete change of scenery linked to the political decision to reduce the size of the historic treatment plant: *Seine-Aval* which, as it is explained; must go from 2.1 Mm^3/d to 1.5 Mm^3/d involving the construction of new WWTPs in compensation. This evolution of the treatment system is also accompanied by a major transformation of the southeastern part of its transportation system intended to feed the *Seine-Amont* treatment plant. New connections and stormwater storage facilities with a capacity of 580,000 m^3 were created.

Thus the SIAAP went from a situation of a shortage of treatment capacity to a completely new situation with room for maneuvering. It is in this context that the dynamic flow management project comes into play. The commissioning of MAGES has brought a radically new vision because this remote management, assisted by powerful processing capacity and interconnected network, allows modification of the distribution of flows between the WWTP with much more flexibility and a global vision. The commissioning of MAGES greatly facilitated the assimilation of the changes that had just occurred. From static and local, the management has become dynamic and global.

Progressively the Flow Management Service of the Networks Department, manager of MAGES and the SAPHYRS control room, thanks to the knowledge learned on a daily basis, has become a 'control tower' with a global vision of the operation of the whole 'WWTP-networks'.

MAGES has progressively led to the establishment of procedures and the modification of organizations. The dialogue between WWTP has developed, as has the dialogue between the flow manager and the WWTP operators. The vision of the sanitation system has been radically changed.

3.8.1 Various forecast horizons

One of the peculiarities of MAGES and its developments is that it allows vision and use at different time-scales:

- 24 hours: this is the current real-time operation with the sharing of data, instructions to optimize the solicitation of transport, storage and treatment works, taking into account the recent past of dry weather or not;
- 1 - 10 days: this is the current operating horizon with a detailed and optimized programming of the maintenance operations, giving rise to a provisional bulletin of conduct of the exploitation;
- 1 to a few months: this horizon is that of feedback based on the 'Non-real-time' function of MAGES. It allows the feedback of experiences on past situations but also special studies such as the maintenance operations programming or exercise simulations;
- 1 - 3 years: it is the time of the multi-year programming of the shutdown operations and specific studies for particular operations.

Related to these times-scales, there are several outputs for the sanitation system operation. The following paragraphs detail some of these uses.

3.8.2 A shared and global vision

The first objective of providing a global and shared vision has been achieved since the commissioning of MAGES with the consistency of all the data that provides the overall vision of the operation of the sanitation system. It places operators in a global management framework by providing them with information that goes beyond their strict management scope.

The shared vision made it possible to set up a real cooperation of the different actors, which are part of a process of continuous improvement of the operation.

This shared vision materialized concretely, but the effects of transfers of water with sometimes very different qualities accelerated the process of sharing information. Today, bimonthly meetings bringing together plant and network operators have been set up to ensure the analysis of past situations, the optimization of operations, the sharing of experiences, and thus getting into a process of continuous improvement of the operations, based on the data provided by the MAGES tool. These exchanges have become essential to the proper functioning of the sanitation system.

3.8.3 Optimizing real-time operation

Based on the prediction of dry and wet weather inputs, MAGES provides in real-time, at all points in the network, the flows and water heights at the entrance of the WWTPs and at the characteristic points of the transport network.

The real-time knowledge of hydrographs with an optimized forecast over the next 6 hours provides relevant and essential information for operators to make the necessary decisions on the conduct of their installations. This predictive management makes it possible to better anticipate *a)* the start-up of the specific stormwater pollution treatment facilities or to change WWTP configuration from dry weather to rainy conditions, *b)* the regulation of the flow rate on the treatment units to avoid saturating them with a peak of pollutant load likely to exceed the design capacity of the treatment units, *c)* the coordination of the phases of storage and emptying of different reservoirs and tunnels tanks.

3.8.4 Forecast Bulletins for the operation of Networks and WWTPs

Faced with the findings of strong interactions between WWTPs and networks for efficient management, a provisional bulletin for the management of the SIAAP networks and WWTPs is drawn up each week. It is established in liaison with WWTPs and network operators and is distributed to all operational departments and functional departments responsible for operating reviews and monitoring of the natural environment.

This bulletin provides summary information on the situation of the availability of each of the WWTPs and networks according to the works and incidents. This situation is given for the current day, a forecast of the contributions and the distribution of flows for the next 10 days and taking into account the annual shutdown program for the next 3 months. This forecast is based on the non-real-time version of MAGES. The information is correlated with data from the natural environment (flow and temperature of the Seine) as well as trends for rain over the upcoming 10 days, and can if necessary be adapted to limit the impact on the environment. A synthetic map indicates the network shutdowns for maintenance or reduction of the capacity of the WWTPs. The situation regarding the H_2S and CH_4 gas risks in the networks is also described.

3.8.5 An adapted flow management for Seine-Aval *WWTP*

Among the 6 WWTPs, *Seine-Aval* plays a major role its capacity and location within the network. It is frequently used to help other WWTPs. The opposite is less true because only two plants can contribute to reducing, in limited proportions, the incoming pollutant loads on *Seine-Aval.*

Low flow rates are critical for this facility originally designed to handle daily volumes equal to or greater than 2.1 Mm^3/d. In summer, flow rates sometimes drop below 0.8 Mm^3/d and flow rates of less than 10 m^3/s are problematic. Also an operational procedure for real-time regulation of flow rates to avoid going below this threshold has been put in place. It relies on a transfer of water from the *Seine-Centre* and *Seine-Grésillons* plants supplemented by storage in the emissaries to support the night flow.

The main sewers that feed the *Seine-Aval* WWTP were originally designed to drive 2.7 Mm^3/d. With the reduction in capacity, the flow rates have become low making them susceptible to deposits. The recovery of these deposits during heavy rains pose operating problems that can lead to unacceptable exceedances of standards. To limit these risks, the operator requests a specific regulation with a rise in flow per stage of 5 m^3/s in time step of 15 mn allowing him to change configuration: physicochemical treatment of the stormwater in place of phosphorus.

3.8.6 Shutdown management for works

The provisional management of shutdown of facilities is a major issue for operators. Major construction and maintenance operations on the WWTPs, cleaning, inspection or rehabilitation of the wastewater transportation network are scheduled each year for periods sometimes of several months. Figures 31 and 32 show the summary of location, kind and duration for maintenance and duration of shutdowns.

A multi-year program is carried out based on the non-real-time version of MAGES. A procedure is used to develop the shutdown program for the following year submitted to the water police authority for approval after assessing the impact on water bodies. This coordination is essential to ensure that the program does not present major incompatibilities in terms of operation and unacceptable impacts by the receiving environment.

MAGES is one of the major tools for assessing the impact of water diversion from watersheds whose characteristics of domestic and industrial inputs can be variable.

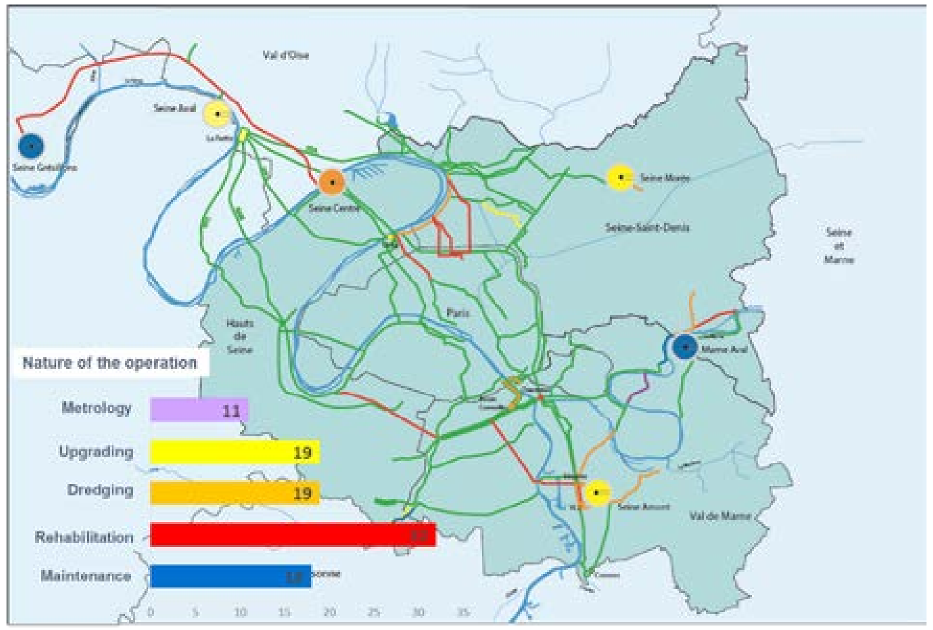

Figure 31. Location of different kind of maintenance operation (2016)

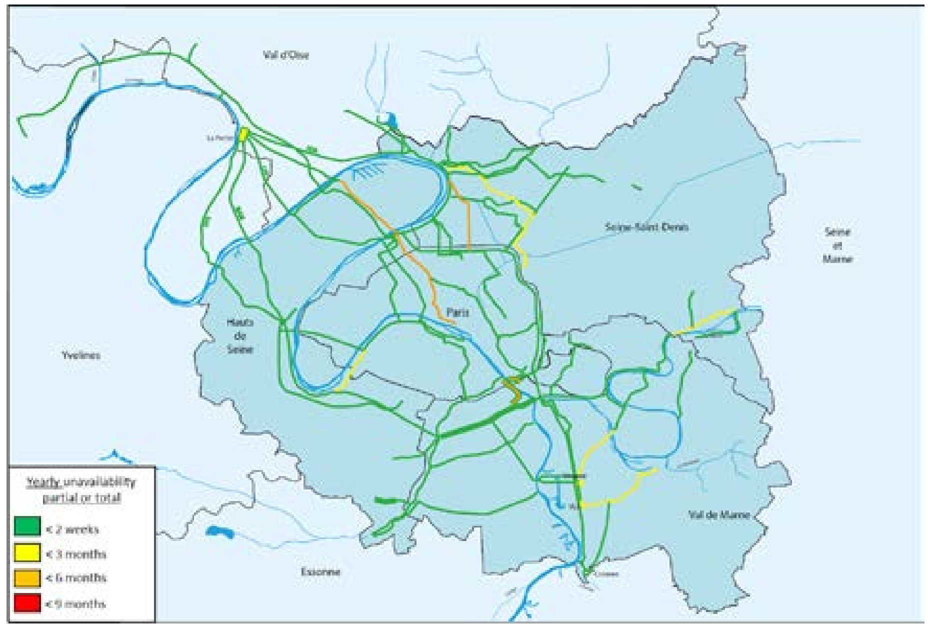

Figure 32. Duration of maintenance shutdown on the SIAAP's main sewers (2015)

3.8.7 The management of incidents

The management of all equipment malfunctions is also facilitated by the MAGES tool. The real-time updating of the characteristics of the transport, storage and treatment works of MAGES is a major asset to limit the impact of these incidents on the environment.

3.9 Cost elements

Speaking about the investment cost of the development and implementation of the whole project is quite difficult because costs take into account several topics and the system is under a continuous process of improvement and renewal of equipment such as sensors or hardware for computing system.

This project was financially supported by the Seine Normandy Water Agency and for a part of it by the Ile-de-France regional Council in the frame of a multiannual (1999 – 2009) contract for the financing of SIAAP's works. It appears in this contract as 'Dynamic flow management project' and the initial budget of €35 million covered the main initial investments related to the real-time management project (see Table 9). This same contract was for a global amount of work of €2.5 billion to improve SIAAP's sewage treatment capacity and performances, developing new sewers connections and storage facilities. This means that compared to the whole investment carried out by the SIAAP, the RTC cost for development and implementation is quite low compared to its outputs for a more efficient operation of the whole system.

Table 9. Main initial investment costs for the RTC implementation

Main contracts	Amount (non-actualized value)
Interoperable data exchange system (EDEN)	1.7 M€
Existing SCORE modernization including the new central command room, development for implementation of new facilities, networks and storage facilities, etc.	19.4 M€
Definition studies contest	4 M€
MAGES Development and implementation	8.5 M€
Miscellaneous : metrology development and improvement, complementary studies, etc.	4 M€
Total	37.6 M€

The operation of the whole system is supported by a team of 32 people and among them 16 people are involved in the rolling shifts 24 hours a day, 7 days a week

4. Links to the Sustainable Development Goals

MAGES is one of the SIAAP's tools that are in operation to fulfill the goals of the French regulation derived from the European Water Framework Directive and to optimize the operation of the system with the search of efficiency.

As stated in this section, MAGES is a smart system allowing a fine operation of the complex sanitation system that has been built over several decades. The main output is that it provides in real-time the current state of the system and the forecast both in dry or rain weather conditions. This greatly helps to adjust the operation for the best result taking into account the current conditions. In this way, MAGES contributes to reducing the impact of the Paris megacity on the receiving waters. Its future improvement and development will help to optimise the whole process and in this way will help to reduce the energy and reagents' consumption. These future improvements are explained further in the next part of this section (see section 6). By this way, MAGES helps to reach the several Sustainable Development Goals (see Table 10).

Table 10. Links to the Sustainable Development Goals

Sustainable Development Goals and Targets	
SDG 6: Clean water & sanitation **Ensure availability and sustainable management of water and sanitation for all**	
6.3	By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally
SDG 9: Resilient, sustainable and innovative infrastructure **Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation**	
9.1	Develop quality, reliable, sustainable and resilient infrastructure, including regional and trans-border infrastructure, to support economic development and human well-being, with a focus on affordable and equitable access for all
SDG 12: Sustainable consumption **Ensure sustainable consumption and production patterns**	
12.2	By 2030, achieve the sustainable management and efficient use of natural resources
SDG 13: Climate change action **Take urgent action to combat climate change and its impacts**	
13.1	Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries

Target 6.3

MAGES's contributes and will contribute more to a better management of Paris region sanitation. One of MAGES' main goals is to reduce the loads of pollutants discharged to the receiving water, especially during rain events. Several kinds of pollutants are of concern, including: reduced nitrogen, COD, micropollutants such as hydrocarbons and heavy metals.

By monitoring and adjusting the levels of these pollutants in the Seine, the SIAAP is contributing to improved sanitation at a local scale. On a global scale, the SIAAP is sharing knowledge on the technologies they have developed which help to greatly improve sanitation, providing the potential for these technologies to be replicated elsewhere in the world in the future.

Target 9.1

Performance is nothing without reliability. As a smart management tool, MAGES, already contributes to a reliable operation of the sanitation system: it helps to reduce significantly the spillage of raw wastewater, especially during shutdowns for maintenance.

By the global overview that MAGES provides to each of the operators, it enhanced the performance of the whole system and made it more adaptable to changing situations, which can be considered as enhanced resilience. It will help in the further developments to reduce energy and reagent consumption. In this way, it contributes to making the system more sustainable.

Target 12.2

The next MAGES developments will aim to reduce the energy and reagents consumption by optimizing the performances relating to the needs of the receiving waters. By doing this, the SIAAP aims to globally reduce its consumption. This is of course not the only field of natural resources management improvement.

Target 13.1

MAGES is one of SIAAP's tools to strengthen its resilience and adaptive capacity to climate problems. The recent flood events that occurred in Paris in 2016 and 2018 showed how these smart tools are relevant to manage crisis situations. Of course the global performance depends on the infrastructures' features but smart tools are helpful to optimize what you can expect from the different facilities.

In the future, the Paris region will have to adapt to a decrease of the Seine's flow related to climate change effects. The future development and improvements of MAGES (see below) are design to help to mitigate these new conditions.

5. Lessons Learned

The development and the implementation of MAGES are the result of a long process started at the beginning of the 1980's which ended in 2008 by the commissioning of this system; it means more than 20 years of investment in research and engineering in the field of real-time control. During that time, a strong background has been built on this experience by the SIAAP and its partners. This common technical culture is one of the key points for its success. Even if the goals of each system were different, even if the culture were specific to each partner, this shared technical background was very helpful to work on the integration of each system not in a single one but to make them interoperable (i.e. the systems are interconnected and can share information and data with one another). This is the other key point: the fact that each one of the parties that were involved in the project kept its real-time control system on his own (see section 1.2.2.5). The project of integrating the different systems is based in connecting them together and not in merging them into one single system.

In other words, when the MAGES project started, the context was mature. This does not mean that it was an easy project, especially regarding the human relationship between partners aspect.

Three things helped to go through these issues:
- The strong commitment of top management of each partner to go ahead in this project;
- The technical challenges aspects of the project made it exciting and every one found an extra motivation for this reason;
- The fact that the project has started with two studies with concrete outputs for all the parties : rainfall data treatment and setup of a real-time data sharing platforms between the SIAAP and each of the partners;
- The financial support from the Water Agency and the Île-de-France Region was also helpful.

The field of experience acquired from adapting this technology is quite broad. It relies on topics as different as:
- The concept of remote control and how to define the organization and rules for the management of the system.
  Beyond this topic there are several questions to address starting from ergonomic features of the man-machine interface to the staff organization. All questions are strongly related to the objectives of the system, its characteristics, :
  - Remote data transmission and transmission networks,
  - Reliability of systems and redundancies,
  - Numerical modeling and data processing,
  - Sensor implementation and maintenance,
  - Maintenance of different kinds of systems,
  - Cyber security.

The output of MAGES's implementation for SIAAP's operators is largely positive. In particular, it allowed:
- to develop advanced skills in hydraulics and urban hydrology in relation to the complexity of certain works and the geographical extent of the SIAAP transport system;
- to develop a new relationship with its partners, to federate the management of the Ile-de-France networks, around shared objectives;
- to take into account the overall operation of the sanitation system managed by SIAAP and the sharing by network operators and water treatment plant of a common tool;
- a particular attention on the WWTPs with a sharing of knowledge of the constraints of the ones and the others. The setting up of the 'weekly operation bulletin' is an illustration;
- a growing interest of the WWTPS for the forecasts given by MAGES on flows arriving to the plants;
- to have a powerful tool to assist in the planning of works shutdown and the updating of the master plan.

Of course there are possible improvements for the tool. Among them, there is one target of the project which has not totally been achieved: the implementation of 'a user club'. This was one of the aims of the 'replay' mode of MAGES and using it in particular as a tool for feedback about experiences. This would move one step more towards the creation of a common culture among the partners in the operation of the sanitation system.

CASE STUDIES
INTEGRATED SMART WATER MANAGEMENT OF SANITATION SYSTEM IN THE GREATER PARIS REGION

6. Next Steps

6.1 Integrating the recommendation of the updated sanitation master plan

In 2017, an update of SIAAP's sanitation master plan focused on the achievement of the WFD objectives was adopted. This master plan has confirmed the need for implementing storages facilities in order to significantly reduce the pollutant loads discharged in the Seine by the main CSOs and by *Seine-Aval* WWTP.

To achieve these goals three works are recommended in order of priority:
- 100 000 m^3 of storage capacity at La Briche CSO;
- 70 000 m^3 of storage capacity at Clichy CSO;
- 500 000 m^3 of storage capacity at Seine-Aval WWTP.

These works will be implemented based on a step by step assessment of their impacts on the receiving water.

These works and their management rules will be an important evolution for MAGES for an optimal operation of the sanitation system in order to reduce the stormwater impact on the Seine, including their impacts on WWTP performances.

6.2 From a dynamic flow rate management to an integrated pollutants load management and their impact on the environment

Dynamic flow management is one of the ambitious and innovative projects led by SIAAP. Despite the difficulties inherent in this type of project, since 2007 the system has been fully operational and it has become SIAAP's control tower.

As a management tool for a complex system, MAGES is far from having reached its maturity, as the constraints related to effluent pollution and the impact of discharges on the natural environment are not integrated in its current version. It offers significant development prospects and the next steps of the work in progress aims to prepare this development.

One of the important developments in the future is the management of a system that is increasingly complex and more and more responsive with the need for permanent performance because of an increasing pressure on the whole system related to the future population growth and to the forecasted effects of climate change on low flow rates. It means a reinforcement of the constraints reducing in some ways the 'right to make errors'. To make the most of it, increased data collected by a more developed monitoring system will have to be processed in real-time, in order to take into account the changes in the pollutant load and the acceptability of the environment while controlling the cost. Regulatory bodies require to comply with the discharge permits for WWTPs and for combined sewer overflow. The data processing tools are the essential complement to help the operators to make the most of the equipment implemented by the SIAAP. In this sense we are getting closer to 'smart systems', or smart systems capable of adapting to changes in the environment.

This evolution of SIAAP's smart system relies on three complementary fields:
- Making developments to introduce an evolution in MAGES that will make it able to deal with pollutants loads instead of only flow rate;

- Implementing decision support models in the operation of the waste water treatment plants;
- Connecting MAGES to a Seine quality model, to provide a river quality forecast to adjust the waste water treatment performances to the needs of the receiving water in order to meet the environmental quality standards.

6.3 From flow rates management to pollutant loads

Upgrading the system from flow rates to pollutant loads is still a challenge that will require an ambitious change in the system. The objective is to build a numerical model of the pollutant transformation during the sewage transport in the sewer taking into account solid transport and sewage dilution of some pollutants during rain events. The first step will be to collect data to understand the processes that are occurring in the sewer before proceeding to numerical modeling. This will require the development and the implementation of continuous monitoring systems in sewer networks.

6.3.1 Sewage quality monitoring

In several occasions, the system is subject to transitory phenomena at the WWTP inlet. The origin is elsewhere of these, further upstream on the network. In a moderately ambitious context of performances, the incidence of these particular situations was moderate. Today with penalties on performance and ambitious quality goals, things are different.

The variations of the pollutant load at the inlet of the treatment plants is often the origin of the malfunctions. Understanding these variations is often difficult due to the lack of data available. Take the following example: rapid load variations at the inlet of Seine-Aval WWWTP during rainy weather.

With regards to the ups and downs at the inlet of *Seine-Aval* WWTP (see Figure 33), these increase the risk of uncontrolled discharges and therefore of non-conformities to the consent. These are most likely to occur due to the accumulation of solid deposits during dry-weather and their flushing during rainy events. However, without adequate instrumentation, the information required to understand the dynamics of the situation or the respective contributions from each of the 5 sewers to the treatment plant is unavailable. Only a continuous measurement of the turbidity from each sewer would help to understand the situation and to guide any corrective measures. On the basis of this knowledge, provided by the implementation of continuous monitoring more upstream in the networks, it would be possible to consider the development of modeling the deposits and their flushing enabling a pollutant load forecast to be provided.

These metrological developments are an integral part of the MAGES evolution towards a 'MAGES- pollutants flux'. The implementation and deployment of continuous metrology in the sewerage networks is a difficult but indispensable exercise to ensure the operational knowledge of the complex functioning of SIAAP's network. This complexity is related to its extent and diversity of its structure which include: separate and combined sewers, variable pollutant concentrations in time, the type of industrial activities, etc. Therefore this level of detail is a prerequisite to ensure the success of a reliable pollutant loads forecast. The deployment of the instrumentation will be introduced progressively to take advantage of the feedback of experience of Clichy CSO's pilot site which has been equipped with continuous monitoring instruments.

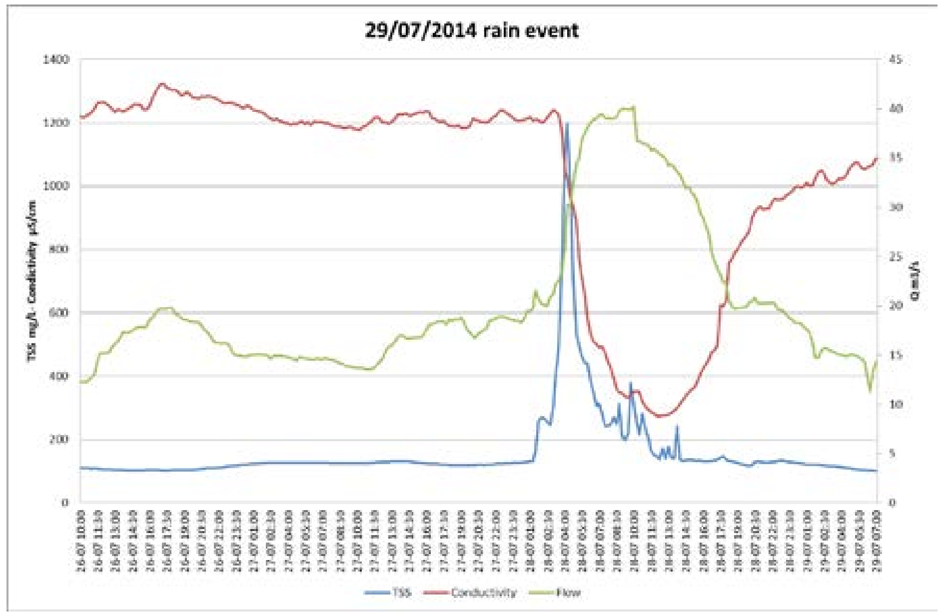

Figure 33. Real-time monitoring at Seine-Aval inlet – Flow (blue), turbidity (green) and conductivity (red)

6.3.2 Treatment plant instrumentation

Another field of instrumentation development concerns the water treatment plants. It is an important link in the system which is of increasing concern to operators. The most recent units now have continuous metrology, which are developed to run more complex plants with reactive processes. Optimised management, in particular for *Seine-Aval* WWTP, requires acquiring all of the knowledge base necessary to build the expertise needed to face all of the operating difficulties. The instrumentation installed in the plant will be an indispensable tool for both piloting this plant, and also for knowledge acquisition. These data will also feed the development of process modeling tools and the construction of precise and efficient control loops.

6.3.3 Metrology in the natural environment

At the other end of the chain is the receiving water, where similar needs exist. In the framework of the PIREN-Seine, a research program on the Seine, SIAAP's R&D department is conducting studies to develop autonomous and continuous measurement systems for the quality of the Seine known as CarboSeine®. These autonomous systems are intended to give an accurate picture of the quality of the Seine which is also subject to continuous variations in quality. Here too, knowledge of these variations is essential to understand the proper functioning of the Seine ecosystem and the dynamics of evolution of the behavior of pollutants released by the SIAAP facilities. In the future, CarboSeine® will also be an indispensable complement to the real-time integrated MAGES system coupling MAGES to a Seine quality numerical model. These data will be used as self-correcting data sets for the model and also validating the good management produced by SIAAP.

In addition, the feedback of these data to MAGES and to the WWTP operators will give a real-time picture of the quality of the Seine and of its possible fragility, thus highlighting the daily context of their performance objectives. These data will also make it possible to report to the State Authorities, or even potentially to users, the real impact of the sanitation system on the environment.

6.4 Developments in modeling

There are three areas in which modeling will continue to develop: 1) the transport of pollutants in the SIAAP networks, 2) the operation of biofiltration treatment plants, and 3) the quality of the Seine. In each case the models to be developed will rely largely on reliable and good quality metrology. As previously mentioned, the situations that must be managed are more and more complex and variable with variations in the distribution of the flows between plants, management of increasingly fine rain weather with the future presence of stormwater basins which will require management to empty. The quality of the Seine is variable too, but to a lesser extent.

6.4.1 Flow modeling

The modeling of the transport of pollutants in the SIAAP networks is an innovative project. Initially the modeling will concern the deposits of suspended matter in the main sewers of *Seine-Aval* WWTP. In addition, due to the continuous measurement of the sewers the behavior of pollutants in certain sectors of the SIAAP network will be measured, even simple modeling such as the dilution of ammonium in rainy weather, may be considered. It will however be interesting, if not necessary to also partner with university research centers to create the modeling.

6.4.2 The modeling of treatment processes

In terms of treatment process, biofilters have the characteristics of being very reactive with response times of an hour or so. This is an asset because they adapt well enough to the rapid variations of flows arriving at the Seine-Aval WWTP. However, it is also a constraint, as any operation error can result in a significant degradation of the discharged water quality. Therefore, the SIAAP is operating an increasingly complex sanitation system while being more responsive, with narrowed margins of error. This situation is particularly true in *Seine-Aval* WWTP, whose regulatory functions or buffer of the western part of SIAAP's system are vital for the proper functioning of the entire sanitation system.

To address this, SIAAP' R&D department is partnering with the University of Laval in Quebec and IRSTEA as part of the Mocopée research program (www.mocopee.com) to model the operation of biofilters. The aim of this program is to build models for predicting the operation of integrated processes in the sewage treatment of SIAAP's plants (i.e. lamellar physicochemical settling works and biofiltration treatment units). Unlike activated sludge treatment, which has been the subject of scientific studies for over 20 years and for which there are good models, there are few modeling tools available for physicochemical settling and biofiltration processes.

These models are constructed to predict the impact of changes in operating conditions (reagent injection, air injection, applied flow rate, applied pollutants loads, etc.) on the quality and performance of the treatment. The use of such tools aids in controlling the processes, both from the point of view of controlling residual concentrations at the outlet, but also from the point of view of controlling energy and reagent costs as well. The models should be seen as an aid for piloting the plant, and not as automated tools. Coupled with a pollutant load forecast and a performance directive, these tools will assist to the operations of these facilities.

6.4.3 Taking into account in real-time the quality of the Seine in MAGES

Another major development of MAGES is its coupling with a Seine quality model. This option was planned from the very beginning of the MAGES project, and implementing this step will be a step forward in management as it is the missing link towards integrated management of a sanitation system. By doing this, the SIAAP would make a very important step forward in sanitation management. This project will make possible to define the downstream sanitation system management constraint in an intelligent and adaptive manner according to the environmental requirements.

Thanks to the PIREN Seine research program, a detailed deterministic model of the Seine quality has been produced: Prose. This model will provide the base of a dedicated model adapted to real-time control.

7. Conclusion

Twenty five years after the implementation of the first SIAAP's real-time control system 'SCORE' and ten years after commissioning the major upgrade of this RTC, one can see how far it has come and several lessons can be learned from this course.

Through this example of SIAAP's real-time control system, it appears that sanitation knows the same evolution as many industrial sectors in the search for security and efficiency: the input of automatization and numerical modeling are more present, making sanitation transition to a mature industry. This appears to be relevant and necessary due to the fact that risks are becoming higher than ever, especially on an environmental point of view: the improvements of the receiving water quality and the public awareness to environmental issues are making failures in waste water treatment unacceptable. In these conditions, failures can now be close to industrial accident. In addition to that, we have to take into account the fact that the regulation is becoming stricter than ever before and in the end the 'right to fail' is no longer acceptable. Another aspect related to the transition through a real industrial approach of sanitation is related to the need of efficiency by searching for the better compromise between cost and performances. Real-time control can help to avoid new investments thanks to an optimized operation of the facilities.

The evolution of the RTC system is the result of a process in which the input of a long experience was one of the major elements for a successful story. This was particularly true if one considers the ambition of the project:

- a large and complex sanitation system combining the different approaches of 5 operators, each SIAAP's department and the SIAAP itself, in the sewage transport which mixes combined and separate sewers;
- the large extent of the territory is also a key issue especially if one takes into consideration the diversity of rain conditions which can vary very much from place to place;
- 5 operators means five cultures and five technical systems to work together, but one of the key points for success was that the project had been driven with the idea that each operator will keep its system and not merge them together in one system.

Ten years after MAGES' commissioning, the following lessons that can be drawn from it are as follows:

- Thanks to the information sharing between all the operators involved in the management of the sanitation system, everyone knows that they are working for a unique system. The recent two floods events of 2016 and 2018 in Paris showed that it is not only a mindset but a reality;
- In a sanitation system which relies on 6 interconnected sewage treatment plants, MAGES played a major role in the necessary shift to a global overview of the operation of the system;

- The organization has evolved to adapt to these new conditions. This has been particularly true for the maintenance works program. Now a three-year coordination program for maintenance work is developed and updated in real-time. This system allows that when shutdown of works are necessary, they are set exceptional discharges of raw water into the receiving waters. A weekly bulletin that gives all the forecast for the next coming week on the conditions for the operation of the system: available treatment capacity of each sewage treatment plant, ongoing works, but also sensitivity of the receiving water to pollution or a general meteorological trend.

The future of the system is the next point of focus for project managers. The new developments are focused on several fields:

- Strengthen the relation between sanitation system operation and their impacts on the receiving water in order to fulfill the achievement of the Water Framework Directive with better operational cost;
- Preparing the transition from a system based on flow management to a system which also takes into account pollutant loads;
- Introducing operation costs as management criteria;
- Preparing for new demands such as swimming in the Rivers Marne and Seine.

These evolutions are required to prepare for the future which will be more constrained due to the increase of population and the effect of climate change on the Seine flows which are forecasted to be lower. As in the past, where engineers and decision makers invested in innovation, one has to prepare for the future with smarter tools for a smarter sanitation system management to fulfill the expectations of the need of a 'water-wise' city.

CASE STUDIES
INTEGRATED SMART WATER MANAGEMENT OF SANITATION SYSTEM IN THE GREATER PARIS REGION

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TEXT BOX

Replacement of house service connections and NRW assessment (pilot) for achieving continuous (24x7) water supply

Country: India
City/region where project is based: New Delhi
Population (of area where the project is based): City population 257,803 (2011). Floating population per day 1.5 million
Key organisations /stakeholders involved in the project: New Delhi Municipal Council (NDMC), New Delhi
Authors: Pankaj Sampat

Water challenge

Despite having sufficient sources of treated water, NDMC is facing problems related to intermittent water supply arrangements, high level of water supply per capita, high Non Revenue Water (NRW), Unaccounted for Water (UFW) and lack of proper quantification of the water supplied because of non-metered distribution system. Water accounting and auditing is not in practice.

Project approach

The project is planned as a transformation of the entire water supply system in two phases (i) replacement of all service connections with Automated Meter Reading (AMR) meters and a pilot District Metering Area (DMA) for NRW assessment (ii) converting the entire city onto a continuous (24x7) water supply system

Total metering of the water flow in the distribution and at the point of service delivery to the consumers will facilitate the availability of the water flow measurements at service connections and DMA. Additional information, such as pressure and quality parameters, will help close monitoring of the distribution system through proactive water management practices. These practices, which use Geographic Information Systems (GIS), advanced data communication and analytical tools, are integrated on a single platform.

The flow measurement data will be used to prepare daily water balances and water accounts. The analytical reports will provide support to make decisions and address issues including accountability in reducing the water losses, tariff fixing, achieving equity, and behaviour change to reduce excess daily water consumption through awareness programs.

Phase 1

The project to transform the city water supply system from an intermittent to continuous (24x7) water supply system is conceptualised. The strategic infrastructure planning is done and has been approved by the NDMC authority. The selection of the contractor to implement the first phase of the project is currently in process where the bids are invited from leading infrastructure companies. The project implementation work shall commence from October 2018.

SWM adoption

We have adopted AMR and Automated Metering Infrastructure (AMI) ultrasonic and Electro Magnetic Flow (EMF) water meters to measure water flow, as well as sensors to measure pressure, turbidity, chlorine and temperature in the distribution system. The data will be transferred automatically to the server where the distribution network will be linked to GIS maps through advanced water management software. The daily water supply operations will be controlled and monitored using this information to achieve efficiency in water distribution by reducing water losses below 15% and ensuring water supply for at least 18 hours/day.

SWM technology will provide real-time data to support monitoring of water flow-quantity and pressure in the distribution network as well at various important points along the water supply system. This will enable the management team to identify the leakages quickly and to take preventive measures in time to control water losses.

Capacity building for handling this new information communication technology (ICT) based system may be a bit challenging. However, overall, the experienced team is capable of adopting SWM to gain these benefits after sufficient training. Water accounting and auditing is a new area, requiring modular design to introduce step by step in practice.

The project managers are also open to the use of other SWM tools and techniques, as they become available.

Strategic rehabilitation of overexploited aquifers through the application of Smart Water Management: Handan pilot project in China

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China

Summary

Where quality is not an issue, groundwater is more reliable than surface water supply from existing surface reservoirs and irrigation canals, especially during persistent droughts. However, unlike surface reservoir releases, groundwater abstraction is neither easily monitored nor effectively controlled by local water authorities due to the large number of wells that are not fully equipped with costly registered meters.

This weakness in oversight, combined with pressures to extend cropping, has inevitably resulted in over-abstraction and severe groundwater depletion in arid and semi-arid regions in China such the North China Plain, which has become China's granary. The over-abstraction has a number of serious consequences: It decreases the amount of water stored and thus the ability of aquifers to serve as reservoirs for drought relief. It increases the amount of energy required to lift the groundwater to the surface. It harms aquatic ecosystems by reducing the amount of groundwater discharging to streams (and constituting the streams' base flow) and by drying up wetlands and springs. Finally it leads to land subsidence.

Thus, in northern China where groundwater is intensively utilized, a number of challenges have been identified, such as: increasing gap between fresh water supply and demand in mid and long term; difficulties in groundwater management due to the vast number of unregistered pumping wells with pumping rate of less than 1000m3/d (registering and monitoring all of these wells would require a significant investment); current groundwater metering and monitoring systems of low efficiency.

Confronted with the aforementioned challenges, the project presented here aims at optimizing and controlling the real-time allocation and consumption of groundwater under climate variability. The focus is placed on developing and implementing a real-time monitoring, modelling and controlling system for groundwater management to address climatic variability and to prevent groundwater depletion. The main elements of this smart water system are: (1) automatic monitoring of groundwater levels in observation wells, (2) automatic monitoring of pumping rates of wells, (3) wireless transfer of those data in real time to a control center, (4) a real time model of the aquifer assimilating the data and (5) a method to exert control over the maximum seasonal pumping volumes of wells.

The development and pilot use of the smart water system is done in a typical aquifer sub basin located in coastal Guantao County, Hebei Province, China, which is part of North China Plain. The North China Plain is the site of extremely severe groundwater depletion, exemplified by the significant groundwater level drop under sites of intensive abstraction. The project will pilot a smart water system for the sub basin, which can be scaled up to the whole basin. The implementation of the project allows a comparative approach with different climate conditions, different cropping patterns and intensities farming, and different farming communities.

1. Background and context of the project

1.1 Groundwater overexploitation in China

The vulnerability of China to the impacts of climate change is high. Together with rapid economic and population growth and urbanization, long-term climatic trends have strained China's water resources to an extent that all major river basins in the North and North-West (except for Xinjiang and Qinghai provinces in the far West) are suffering from water shortage. In the past 30 years the aquifers in the semi-arid North China plain have been severely overexploited. In some places water tables have dropped at an average of about 2 meters per year. The natural flow system, in which an aquifer is recharged from the mountains and in the plain and discharged into the sea, has been reversed in coastal areas with seawater intruding into the aquifer (Kinzelbach, 1983; Tang et al., 2007).

The overexploitation is primarily a consequence of the intensification of irrigated agriculture to feed a growing population. While the natural precipitation in the North China plain is sufficient to support one grain crop per year under average rainfall conditions, the double cropping of mainly winter wheat and maize can only be achieved through the over extraction of groundwater resources. The situation has been aggravated by a decline in average annual precipitation by 14% over the last 5 decades, that has reduced the aquifer's recharge. When real-time monitoring and modelling systems are implemented in groundwater management, the over extraction of groundwater can be controlled by reducing irrigation areas, and adjusting the cropping structure. We can grasp the information of the irrigation location with more water consumption, then by using administrative and economic means, we can guide the farmers to reduce irrigation water consumption and indirectly affect the irrigation area and water use (Kinzelbach et al., 2004).

China could function as a laboratory to investigate the implementation of smart water systems application for groundwater use in irrigation, which in future can be transferred to other arid and semi-arid countries. China, as a developing country, faces severe water issues, and despite differences in climatic and economic conditions, the infrastructure and human labor conditions implemented in its water sector approximate those in other developing countries. It is therefore an excellent testing ground for implementation of technologies and rural institutional development aiming at sustainable groundwater allocation and drought mitigation (Li et al., 2014, Yu et al., 2017a).

1.2 Project initiation

In April 2009, a MoU between the Swiss Federal Department of the Environment, Transport, Energy and Communications (DETEC), and the Ministry of Water Resources of the People's Republic of China (MWRC) was signed. Our two partners, the Swiss Agency for Development and Cooperation (SDC) and the Swiss Federal Office of Environment (FOEN) have experience in the field of climate change, water and risk prevention in China. The MWRC and SDC jointly outlined the strategic orientation of the MoU-based project towards a more programmatic approach integrating various aspects of water management and tackling the risks related to groundwater over-abstraction in view of changing climate. In April, 2014, based on the framework, MWRC and DETEC initiated a pilot research project in Hebei Province, China, which concentrates on the rehabilitation and management strategy for over-exploited aquifers under a changing climate.

1.3 Policy Framework of Groundwater Over-Exploitation

This study is primarily aimed at creating control mechanisms to address groundwater over-exploitation. This is one part of a larger effort by the Chinese government, which placed environmental protection and climate change issues, for the first time, in its 12th five-year plan for the years 2011-2015. On January 12, 2012, China's State Council published a guideline to implement water resources management in China called the "Strictest Water Resources Management System". To implement this system, the guideline sets management criteria based on "three red lines" outlined in the approved National Integrated Water Resources Plan 2010-2030 by the Ministry of Water Resources (MWR). The Three Red Lines provide year 2015, 2020 and 2030 targets for total water used, water use efficiency and water quality to guarantee the sustainable development of China. Our study focuses on the first red line, total water used. The total annual water consumption within each administrative area is strictly capped by a fixed quota. One of the greatest challenges to implementing this red line is to control groundwater exploitation. As with surface water, groundwater exploitation limits are set first at the national level, then at the province based on those quotas, and then at the municipal and county level based on the provincial quotas.

In addition, each province is to set a reasonable variation range for the groundwater level. Especially in the groundwater over-exploitation areas, water level should be strictly controlled within this range.

A further push was made in December, 2016, when MWR, along with the National Development and Reform Commission (NDRC) and the Ministry of Housing and Urban-Rural Development (MOHURD) in China, jointly launched the "The 13th five-year plan for water conservancy reform and development", which articulates that the overdraft of groundwater should be strictly controlled and over-abstracting in severe overdraft areas should be diminished by 2020. Comprehensive measures have been implemented to control groundwater overdraft in pilot regions in China including our project site Guantao, such measures include the encouragement of water saving mechanisms in different sectors, increasing the use of reclaimed water, introducing desalinated water, shutting down high water-consuming companies and modifying the cropping structure, reducing irrigation area and other measures to reduce water demand, optimizing the regional water resources allocation and groundwater exploitation layout, replacing groundwater with surface water and conserving groundwater sources.

The project is aligned with the governmental strategies of water use control mentioned above and will translate them into concrete actions. The project aims at developing practical approaches to optimize water resources management at the regional level using smart water systems, and to improve national and international knowledge on regional-scale of real-time modelling and control for water resources management so as to increase climate change adaptation capacity, especially in developing countries.

1.4 Project pilot region

The project boundary has been defined in Handan pilot region. It was agreed by both Chinese and Swiss partners that Guantao county administrative boundary would be used as the modeling boundary for the Handan pilot region. Figure 1 illustrates the location of Guantao County. The modeling efforts involved a much larger area in the North China plain, however the monitoring/controlling efforts were focused on Guantao administration boundary and the surrounding Handan East Plain area. As the aquifer(s) boundaries surpass the administrative boundary of the pilot area, groundwater level monitoring points from neighboring counties were also included in the data platform. Additional groundwater level monitoring wells were installed to better define the model boundary. Guantao is a typical agricultural county in North China Plain with many small wells, each one serving a small irrigated area. The project is designed to make Guantao county a showcase for developing the methodology of aquifer rehabilitation and capacity building for subsequent up-scaling to the North China Plain.

Figure 1. Location of Guantao county.

1.5 Overall Goal of the project

The overall goal of the study is to use a smart water system consisting of an integrated real-time monitoring, modelling and controlling system to prevent groundwater depletion and build up the local community's adaptation capacity to climate change. The combined architecture of these three systems can be seen in Figure 2. The overall goal is going to be reached by achieving four objectives, which are presented in Table 1 and elaborated on in section 4 based on the results of pilot tests.

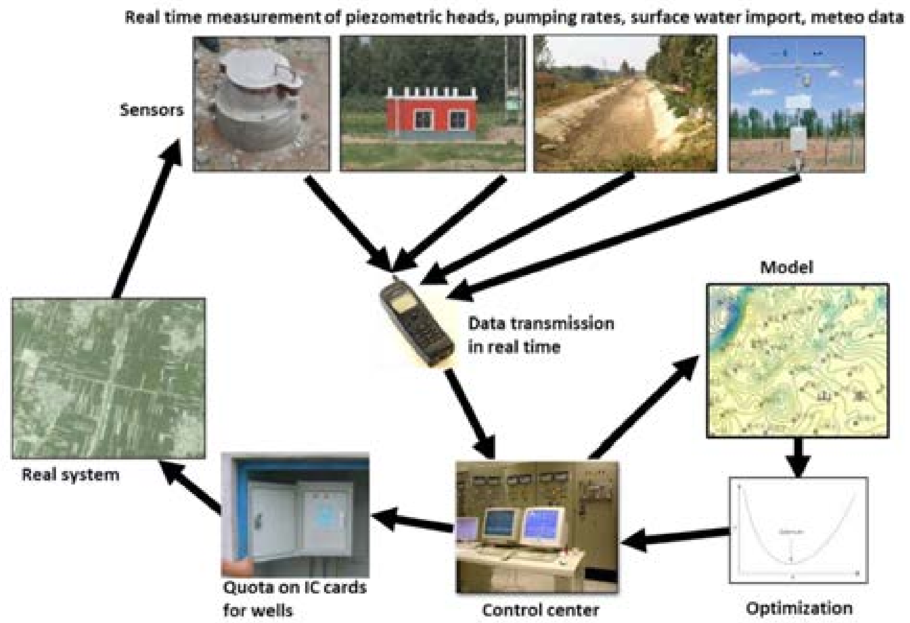

Figure 2. The Architecture of real time groundwater monitoring, modeling and controlling system.

Table 1. Four objectives of the project

Objective	Key indicators
1. Providing the data and information base for real time water allocation.	• Collection of groundwater level observation data, land use, meteorological station data, crop type, harvest and irrigation areas. • Pumping test and a complete hydrogeological report. • Real-time groundwater pumping monitoring system is developed and implemented.
2. Developing and implementing an integrated real-time monitoring, modelling and controlling system to stop or prevent groundwater depletion and build up adaptation capacity to climate change.	• Real-time groundwater model is developed and calibrated. • Overall groundwater monitoring/controlling system is implemented. • Developed a geo-strategic decision support system for abatement of groundwater over-exploitation.
3. Elaborating policy options with the stakeholders that are implemented by the local authorities.	• Control criteria and groundwater recovery strategies are established. • New regulations for groundwater pumping and water quota policies .are proposed • Functions, roles and responsibilities of each sectors are clearly attributed
4. Improving knowledge of using real-time monitoring, modelling and controlling system to stop or prevent groundwater depletion for arid regions in developing countries.	• New scientific findings of real-time groundwater monitoring and controlling published in scientific papers. • Publications regarding real-time groundwater monitoring/ modelling/controlling system • New/improved water resources management regulation/rules/methodology formulated in the project. • Other national/international partners show interest to install the system in their regions

2. Water challenge

2.1 Consequences of groundwater over-exploitation

Severe over-abstraction of aquifers has been common, especially in developing countries. It is estimated that 25 percent of the 800 km³ pumped annually from aquifers worldwide are not renewed by recharge and thus lead to depletion of aquifers. Aquifers can store water over years with minimal loss to evaporation and are therefore particularly suited as a mitigation tool in the face of droughts, which are expected to occur more frequently under climate change. To serve this purpose they must however be allowed to recover in times of above-average rainfall. Only under strict management will aquifers be able to relieve droughts reliably.

Over-abstraction has a number of serious consequences: It decreases the amount of water stored and thus the ability of aquifers to serve as reservoirs for drought relief. It increases the amount of energy required to lift the groundwater to the surface. It decreases the yield of wells and requires the drilling of even deeper wells. It harms aquatic ecosystems by reducing the amount of groundwater discharged to streams (and constituting the streams' base flow) and by drying up wetlands and springs. Finally, over-abstraction leads to land subsidence and fissuring of the ground.

A household survey financed by the World Bank (2012) reveals that more and more Chinese farmers are investing in pumping facilities to use groundwater for irrigation because it is more reliable than surface water supply than existing reservoirs and irrigation canals, especially during persistent droughts. Yet, unlike surface reservoir releases, groundwater pumping is neither easily monitored nor effectively controlled by local water authorities due to the large number of wells involved.

2.2 Water resource endowment in Guantao county

Guantao county, located in Handan Municipality of Hebei province, has been chosen as the pilot region for the project implementation in North China Plain. Guantao features semi-arid continental climate. The long term average annual precipitation is 530 mm with an annual potential evapotranspiration of 1516 mm. Annual average temperature is 13.4°C. Total annual water consumption is 112.6 million cubic meters (Mm³), of which agricultural irrigation consumes 98 Mm³, industrial water use 3.6 Mm³, domestic and other water use 11 Mm³.

The renewable water resources in Guantao are about 62.3 Mm³ per year, of which 57.65 Mm³ are from groundwater while the remaining 4.65 Mm³ is from surface water. The gap between renewable water resources available and water consumed in Guantao is about 50 Mm³ per year, and it is served by pumping excessively the available aquifers. The over-pumping includes 27 Mm³ per year from shallow aquifer and 23 Mm³ per year from a deep confined aquifer. The shallow aquifer is less than 150 m in depth, with average thickness of 19.78 m, and the lithology of aquifer is fine sand, medium sand and silt. The deep aquifer, on the other hand, is porous aquifer, and the bottom of which is more than 150 m in depth, with average thickness of 49.70 m, and the lithology is mainly fine sand. The direct consequence of over-pumping is the rapid drop of groundwater table in both the shallow aquifer (from 2 m to 25 m) and the deep confined aquifer (from 30 m to 60 m) within the past 20 years. Other consequences, include the deterioration of water quality and the increasing cost associated to the pumping requirements. Finally the widespread drop of groundwater table has led to serious land subsidence.

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2.3 Groundwater pumping wells in Guantao County

There are more than 6000 groundwater pump wells in Guantao County, of which 230 wells draw from deep aquifers. Most of the wells are not monitored or managed. In this pilot project, a small fraction of the irrigation wells were chosen to be operated and managed by well managers, who are responsible for irrigating the crop land covered by their respective wells (each covering about 60-80 mu, or 4-5.3 ha, serving 8-10 families). Each well is equipped with an electricity meter that allows well managers, who are village electricians, to prepay using an integrated circuit (IC) card at the beginning of every irrigation season with sufficient kWh to irrigate all the land they are responsible for. Each family pays its share of electricity cost (about 0.5 yuan/kWh, i.e. 0.08 USD/kWh) for pumping according to the electricity they use, with an additional fee (about 0.3-0.5 yuan/kWh, i.e. 0.05-0.08 USD/kWh depending on the farm land's distance from the well) charged for the service of the well manager. This system could be used as a control mechanism by enforcing an energy quota to each well.

The wells pumping from the deep confined aquifer are to be closed down, without exception, according to the Handan county government, and the process is underway. This water will be substituted for by water from the South-North Water carrier as far as household and industry are concerned and by alternative surface water resources in agriculture. This good decision was taken to protect the mining of the deep aquifer that does not receive any significant recharge and water levels drop can only be prevented from further decline by a zero abstraction policy. It should also be noted that the deep aquifer's pressure reduction is the main cause for land subsidence. For the project it means that closing down of all those deep wells has to be checked but no other action is required concerning the deep aquifer. Therefore, the scope of the project is concentrated on the rehabilitation of the shallow unconfined aquifer, which is the main source of irrigation water and prospective reservoir for drought relief. Before this project, Guantao County established a monitoring platform which could only collect short-term data, but rarely utilized the method in this project to control the withdrawal and utilization of groundwater on a real-time basis.

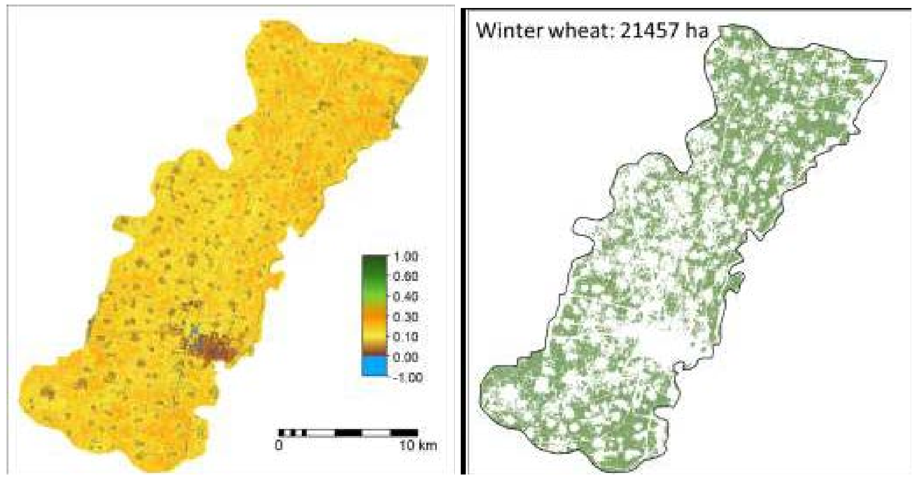
3. Smart Water Management (SWM) solution

The main purpose of the project is to develop and apply an integrated real-time monitoring, modelling and controlling system in the pilot area in China to support groundwater management under climate change conditions, including greater variability, and to restore an aquifer's ability to mitigate the effects of drought. The project intends to tackle two major issues. Firstly, to apply a system in China for improving groundwater management on the basis of monitoring, modelling and controlling groundwater abstractions. Secondly, to contribute to the global knowledge and support the south-south exchange of experience and best practices (Murphy et al., 2000; Anderson et al., 2015).

3.1 Preliminary assessment of the first phase

3.1.1 Data collection and processing

In the first phase all available data on water use, land use, cropping practices, geological structure of the aquifers, piezometric heads of shallow and deep aquifers, surface water imports, aquifer recharge and existing policies for water use and allocation was collected, and a first assessment and analysis of the collected data was made by an expert team. The data collection in this phase also included available remote sensing products of the area. Images from a Landsat 8 satellite were processed by extracting total crop area and winter wheat planting area in Guantao region (an example can be seen in Figure 3).



(a) (b)

Figure 3. (a) Normalized Difference Vegetation Index (NDVI) extracted from a Landsat 8 satellite, and (b) the extracted winter wheat planting area on December 6, 2013 for Guantao region shown in green

3.1.2 Initial assessment of groundwater monitoring system on the project site

Groundwater monitoring included groundwater level changes and groundwater pumping rates within the Guantao county. An initial assessment of the existing groundwater monitoring system and plans on how to proceed during the project implementation phase has been done.

(1) Groundwater level monitoring

In the first phase, within Guantao county there were 38 groundwater level observation wells, of which 25 were manually measured twice a year from 2006 (in spring and autumn), while the other 13 were monitored automatically with data of groundwater level and water temperature transferred directly every 12 hours to Handan Municipal Department of Water Resources and Guantao County Department of Water Resources. The locations of these automatic online wells are shown in Figure 4. There were three more automatic measuring points for groundwater level operated within the national groundwater observation network of the Ministry of Land and Resources, for which the data were provided by the Chinese project partner China Institute of Geo-Environment Monitoring (CIGEM). More groundwater observation wells were installed to define the model boundary of Guantao county in the next phase of the project since the existing wells were unable to cover the whole area of the county. The Handan Department of Water Resources had already received funding to finance 28 new online observation points, which provided real-time data for the project's data platform. Our project partner CIGEM also provided more manually measured data from observation wells through their network around the Guantao county border. These wells were equipped with automatic sensors and wireless data transfer through the project and the data was sent to the data platform. 10 sensors with wireless data transfer facilities were needed for the project to equip these wells at the county border.

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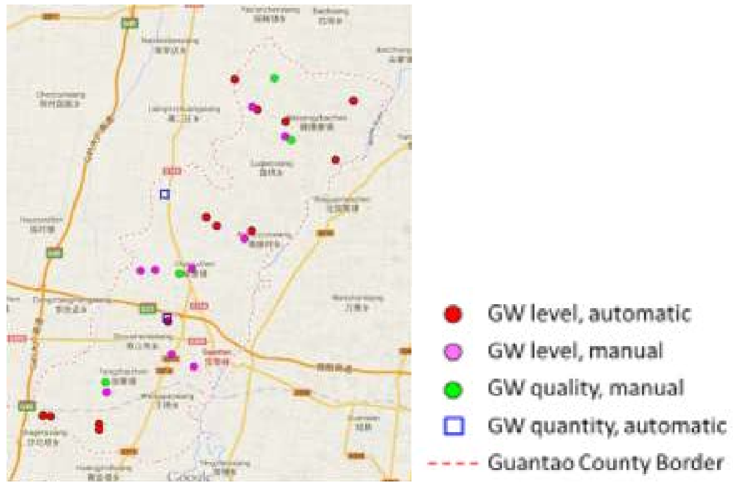

Figure 4. Available groundwater level measurement points in Guantao county in opening phase.

(2) Groundwater pumping monitoring

As monitoring systems for groundwater pumping did not yet exist in Guantao prior to this project, the volume of pumped groundwater was indirectly estimated from groundwater drawdown or irrigation practices. Generally, the pumping wells in Guantao were small in size, with some of the pumping wells sharing only one mobile pump. Installing a monitoring/controlling system for all the pumping wells in Guantao would involve a large effort and high hardware costs. However, it was discovered that monitoring the electricity consumption could be an alternative and easy way to monitor the groundwater pumping. As there are 2-3 power transformers in each village (many of which were exclusively serving irrigation), energy consumption can be monitored easily. While the electricity company also has all of the relevant consumption data on electricity use in the county, this data is not be accessible for us as each government division uses a different governmental company and there is no information sharing between them. As an alternative to acquiring the data from the electricity company, the power transformers can be equipped with an additional power meter, attached to the main cable, which can transmit power use data through General Packet Radio Service (GPRS) or Short Messaging Service (SMS). As the water levels during the pumping stages vary from well to well depending on the aquifer's local transmissivity, the energy use per cubic meter pumped is different for each well. Therefore direct water metering (either permanently using traditional water meters or short-term using electricity use to calculate water use), has to be introduced in all large wells for the efficient monitoring of water pumped from each well.

3.2 Data and information as the basis for real time water allocation

The data and information platform is crucial and fundamental in the whole process of the project, and therefore requires a lot of attention. The following section will illustrate the details of the design structure of data platform and data receiving and processing system.

3.2.1 Data platform design

A preliminary web-based data and information exchange platform has been implemented by GeoPraevent, a Swiss company providing geological and environmental solution services, and is illustrated below in have proposed a preliminary design (see Figures 5-7). The platform has the capacity to accommodate incoming real-time information from all of the existing wells in the national network, which are run the Ministry of Land Resources and the Ministry of Water

Resources of China. The design took into account that part of the observation network (the key hydrologic station) also served as a boundary condition for the real-time groundwater model, which is at the core of the control module. Suitable existing observation wells without monitoring devices were also identified and equipped with monitoring devices so they can be incorporated into these networks. New necessary observation wells were planned and sited for drilling, and were chosen according to their sensitivity in showing the reactions to interventions. Interventions such as a reduction of pumping rates or artificial recharge through unlined irrigation canals or recharge ponds presently being excavated were readily detected. The initial set of production wells to be controlled, were chosen in correspondence with the available observation wells.

The hardware for the data platform consists of 2 servers provided by General Institute of Water Resources and Hydropower Planning and Design (GIWP) of China and located at GIWP in Beijing. They had to be equipped with a backup system as well as a module for receiving GPRS input.

A separate internet connection (Wide Area Network, WAN) is connected to the firewall. Behind the firewall the data connections are divided according to their source and target. Connections are routed into the demilitarized zone (DMZ). From the DMZ the data can be transferred into the protected local area network (LAN) zone. The server is connected with the LAN interface for regular data processing.

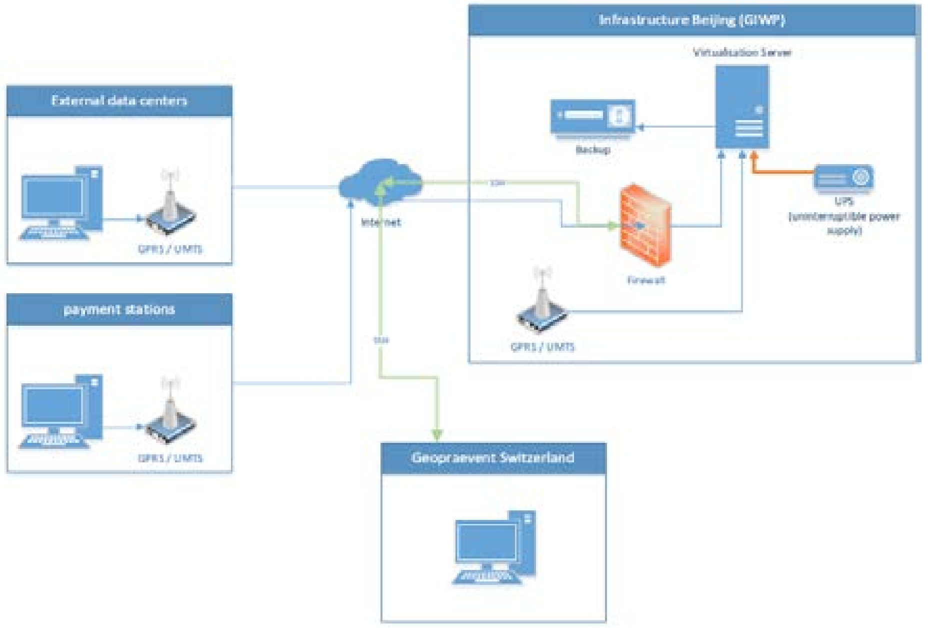

Figure 5. Illustration of infrastructure for supporting the data base platform by GeoPraevent.

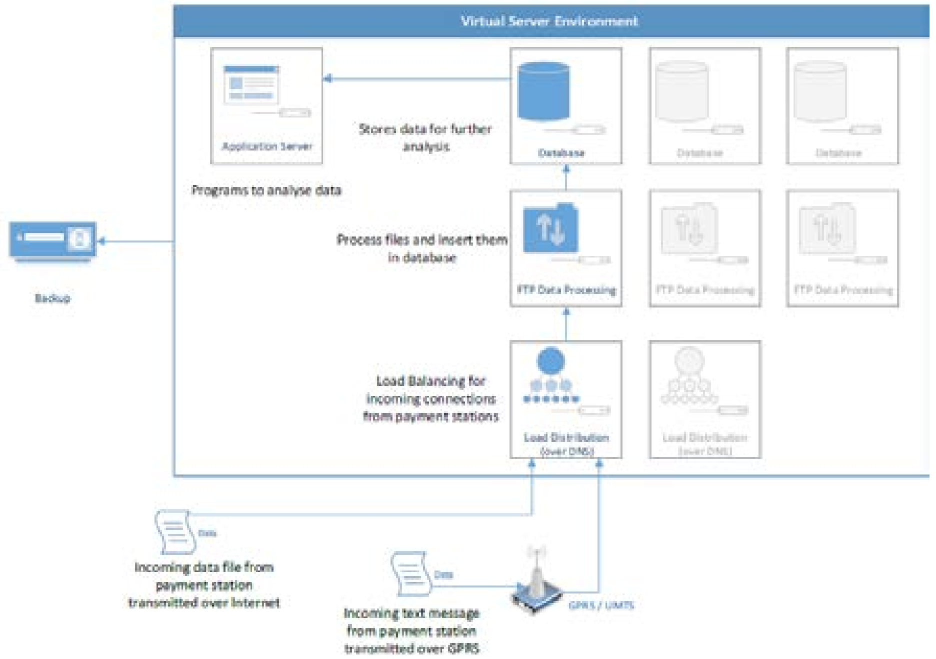

Figure 6. Data processing concept, designed by GeoPraevent.

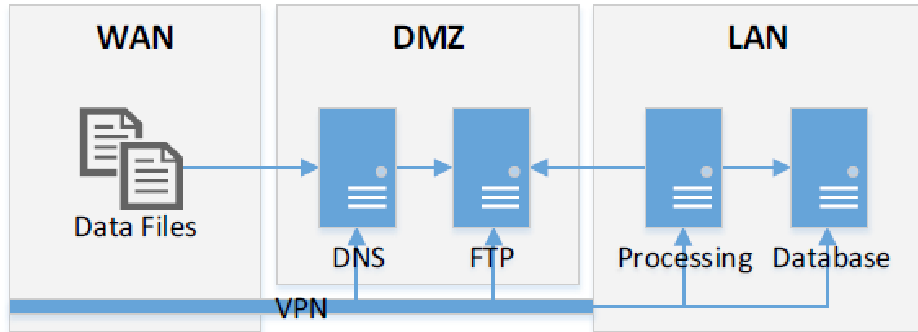

Figure 7. Security concept in Beijing for incoming data, designed by GeoPraevent.

3.2.2 Data receiving and processing system

The data server in GIWP server room in Beijing has been online since autumn, 2015. The server configuration, including firewall installation and backup settings, were designed and installed by Geopraevent experts in early 2016. The server has been configured to receive, process and visualize the dynamic real-time data from different data sources. A generic receiving unit has been built up to process the specified incoming data. After checking and discussing the sensors with Geopraevent, the correct response definition for every sensor type has been achieved.

(1) Data reception

The real-time data from the groundwater-monitoring sensors of different producers (e.g. Haisen, Hengyuan and Itron) have all been successfully received by the server. These data include the time series and the electric energy consumption at an interval of around once every 30 minutes. While some difficulties arose in the implementation of data reception from the RSA and Hengze sensors, these problems were solved in cooperation with the sensors' producers.

For example, when RSA implemented the SMS readout system on the server, they could not retrieve the data from the server due to a problem with an unstable server connection. To solve this issue, RSA proposed a back-up method, in which the SMS readout method was changed to the GPRS readout system: the data was then sent from the field directly to RSA's database via the GPRS system and then forwarded to the server in the form of a report. Similar implementation was carried out with Hengze sensors. Instead of being sent directly to the server, the data was first transmitted and saved in Hengze's database, and then the server read the data from Hengze's database. This automatic readout method has solved these issues.

The devices monitoring electricity consumption were provided by Lofty Electronics Ltd. Each device consists of an electricity meter and a data transmission unit. Real-time electricity data from the Lofty meters have also been received by the server including power, current, voltage, etc. at the frequency of around once every 2.5 minutes.

(2) Data processing and visualization
The database is designed to support all of the different sensor types without any special adaptation. The data visualization is presented on a web data portal (https://www.gwm-handan.cn/geoview/#/login), which users can view in real-time data after login. The locations of the sensors are shown on the satellite map of Guantao (Figure 8). By enabling the "Live" function, it shows the sensors sending data to the server in real-time as pulsing red circles.

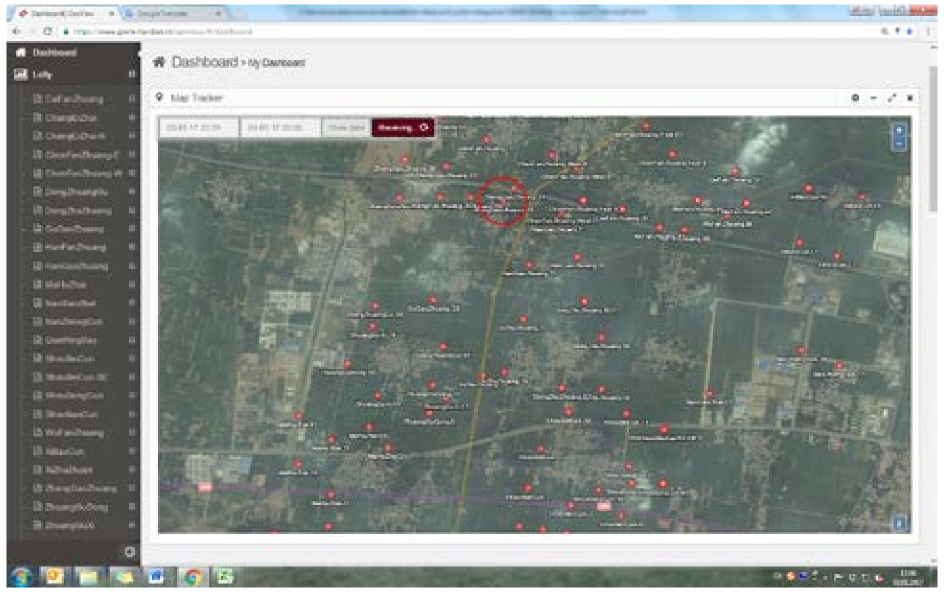

Figure 8. Screenshot of the real-time data portal based on satellite map. Users can click any red circle to view the real-time data of a sensor.

In the data portal, the list of the villages and the sensors are shown on the left of the page (see Figure 9). As an example, by selecting a specific sensor, the real-time data monitored by selected sensors can be viewed. Users can customize the results by selecting the variables listed at the bottom of the page such as 'Pumping volumes' 'Water level' and 'Pumping electricity' and view a certain period of time series by zoom-in or -out.

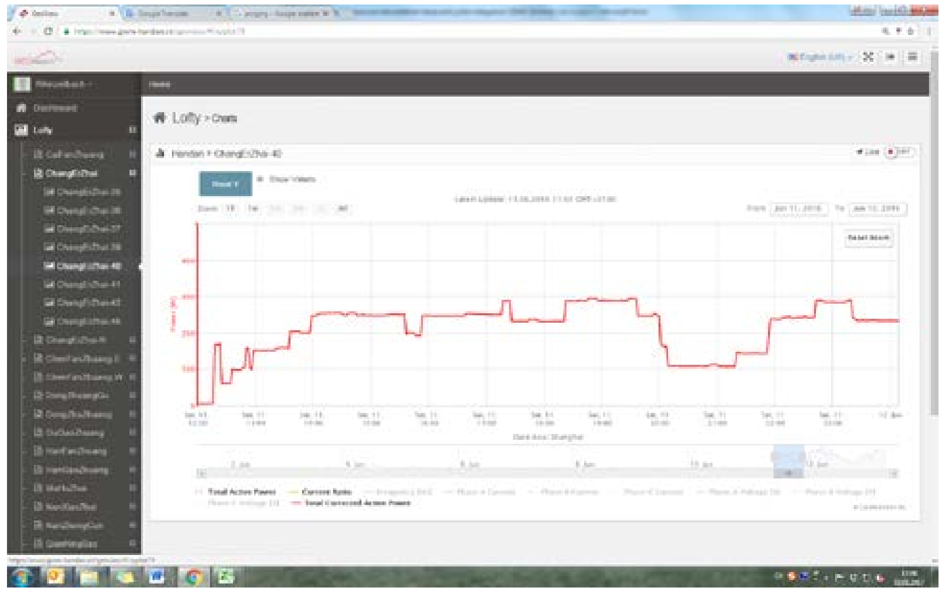

Figure 9. An example of real-time data display, received from the ChangErZhai-40 station. Users can pick any sensor and view data from a certain time period. The chart illustrates the real-time power of pumping well transformers, which reflects the current working condition of pumping wells.

3.3 Real-time monitoring system

3.3.1 Groundwater level monitoring

In Guantao, 14 new observation wells were installed and monitored in 2015/2016 by the Chinese Geological Survey (CGS), through matching funds. Similarly, 20 automatic monitoring wells were installed bythe Hebei Provincial Department of Water Resources and 29 wells including 13 automatic monitoring wells and 16 manual monitoring wells by the Handan Department of Water Resources. The map in Figure 10 indicates all locations of wells monitored in 2015 and 2016.

There are three types of data: (1) the automatically recorded data from CGS/CIGEM, (2) the automatically recorded data from Hebei province through Guantao DWR and data collected manually from (3) manual observation wells by Hebei province four times a year, in February, end of May, end of September, and end of December. In order to match the data from manual and automatic observation wells, we have to interpolate the data (using a linear interpolation on time interval) collected from the manual observation wells to estimate the values during the missing recording times. After the groundwater level data was collected, further analysis has been made, e.g. the comparison among data from different observation wells, or the trends of groundwater levels in recent years.

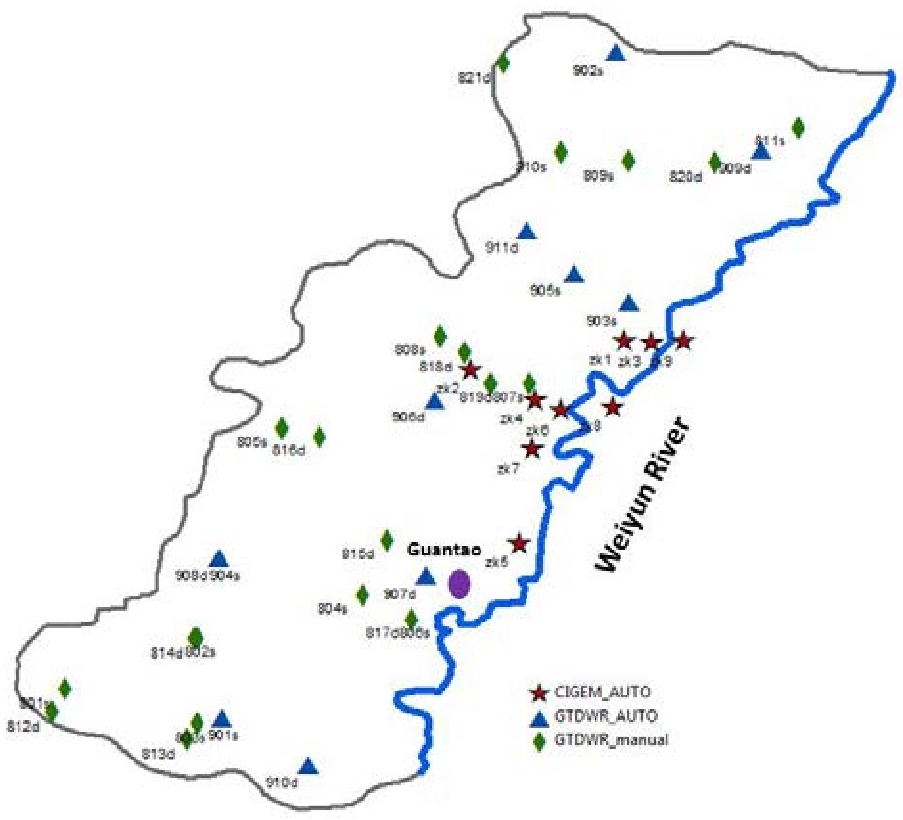

Figure 10. Location of piezometers monitored in 2015/2016 within the project area.

3.3.2 Groundwater pumping monitoring

Significant progress has been made concerning the installation and operation of the pumping monitoring systems with the efforts of the Swiss team and the local partners. All of the selected 5 pairs of the experimental flow meters from different producers have been installed or relocated in Guantao. As it is expected that that the use of sensors from different producers might result in different results while performing the conversion of electricity to water quantity, we need to experiment on each type of sensor brand. To allow the comparison on water consumption, we included a pair of sensors for each brand, with one installed at one location with water saving equipment and the other at different location without water saving equipment, respectively (in order to explore the mitigation effects of utilizing water-saving equipment on groundwater over-exploitation). Four out of five pairs of the experimental meters are in operation and have been sending data to the server. These experimental meters differ in cost, meter type and data transmission methods, which allows a comparison concerning the implementation of the different meters and techniques in practice. An overview of the meter information and current development status is summarized in Table 2.

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Table 2. Meters and current development status.

Meter (Producer)	Meter Type	Measurements	Data transmission	Price per Unit	Current development status
Haisen (Tangshan)	Mechanical flow meters (Nylon)	Flow rate, Electricity consumption, Water level	Own protocol, direct transfer to IP	4400 CNY	Installed, data received
Hengyuan (Shijiazhuang)	Ultrasonic flow meters	Flow rate, Electricity consumption, Water level	Own protocol, direct transfer to IP	12000 CNY	Installed, data received
Hengze (Qingdao)	Mechanical flow meters	Flow rate	Own software, transformation into datasheet	3000 CNY	Relocated, data received
RSA (Iran)	Electricity meters	Electricity consumption calibrated for flow	Own software, transformation into datasheet	10000 CNY	Relocated, data received
Itron (France/Suzhou)	Mechanical meters	Flow rate	Own software, transformation into datasheet	7600 CNY	Installed, data received

The locations of the installed flow meters (5 pairs) are shown below, together with the locations of 100 experimental electricity meters (from Lofty) on transformers and the locations of the wells monitored by the experimental electricity meters.

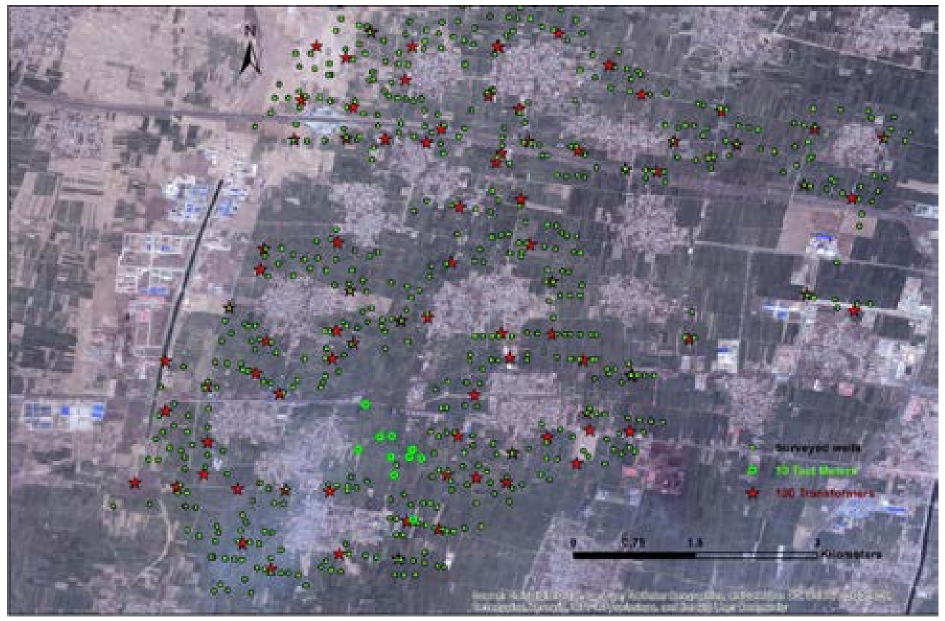

Figure 11. Locations of 10 test flow meters (green circles), 100 transformers on which the experimental electricity meters were installed (red stars), and the wells monitored by the electricity meters (green dots).

3.3.3 Pumping electricity monitoring

Essential progress has been made in monitoring pumping electricity in three respects: (1) securing the cooperation with Guantao Department of Electricity and Power Supply (DEPS) regarding electricity data sharing, (2) correctly installed and tested in the pilot region (Shoushansi District) in Guantao, and the data sent by the experimental meters have been received on the server. (3) Two sets of pumping tests were carried out in March and June 2017, respectively to establish the relation between electric energy consumption and groundwater abstraction.

To calculate the exact conversion factor, the historical data of groundwater abstraction and electricity consumption data are collected. The conversion factor, α, is defined as the electric energy consumed for a unit of water pumped. It is the key parameter to convert the electricity consumption to the volume of the groundwater pumped. Due to the uncertainty of the groundwater abstraction data, we used multiple sources. Meanwhile, as the electricity consumption data collected include the electricity used for non-agricultural purposes, we subtracted the electricity consumed for non-agricultural purposes from the data collected. The conversion factor over the region is an average of the conversion factors of the pumps across the region weighted by the volume of water pumped.

To determine the relation between the electricity consumption and the groundwater abstraction, 209 pumping tests were performed on the individual wells that are monitored by the experimental electricity meters. The results from the pumping tests show that there is a considerable variability in the values of the conversion factor (α), i.e., the electricity consumed for pumping one cubic meter, ranging from 0.2 kWh/m^3 to 0.9 kWh/m^3 (Figure 12). The corresponding pumping rates at the wells range from 10 m^3/h to 48 m^3/h. The variability of the conversion factor can be caused by various factors including the depth to the groundwater table, the hydrogeological conditions, the condition of the pumps and the accuracy of the electricity meters on the pumps. It is challenging to derive a uniform relation between the electricity consumption and the groundwater abstraction.

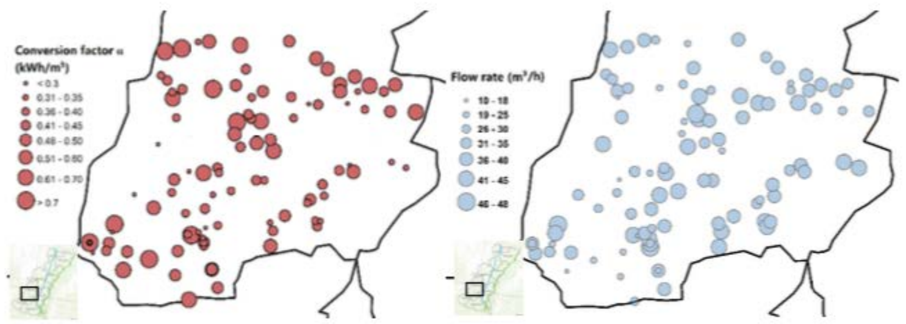

Figure 12. Spatial distribution of conversion factor (left) and measured flow rate (right).

Considering the variability of the conversion factor, regression analysis was conducted based on the pumping test and the results showed that the rated power of the pump, drawdown during pumping, irrigation type and accuracy of measurement all influence the value of conversion factors. Thus, we used the value of sample averages plus the correction based on the results from these tests as the determined conversion factor of each meter.

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3.4 Real-time modeling system

3.4.1 Water Balance modeling

To estimate the water balance of the shallow groundwater aquifer of Guantao, the input data of precipitation, groundwater abstraction, surface water runoff and the groundwater levels are required. The reliability of the model results is highly influenced by the quality of the input data. In contrast to the precipitation measurements, groundwater abstraction was not monitored in Guantao and could only be estimated based on the irrigation norm and the times of irrigation; this is considered to contribute the most to the errors in the inputs. Thus, efforts were made to improve the water balance calculation by using reconstructed groundwater abstraction data based on the historical rural electricity consumption data. Electricity records reflect the energy consumption for irrigation and thus are considered as more reliable data set than the groundwater abstraction set estimated by the water authority.

One particular issue that should be taken into account is the unreliable method of using pumping tests to determine the conversion factor α over the pilot region where the tests were being carried out. Due to the lack of information of individual pumps outside the pilot region, it is not yet practical to use the aforementioned method to calculate the annual conversion ratio over Guantao. To resolve this issue a conceptualized method was proposed in which we assume that the total amount of water pumped in a year in the whole region is lifted at once by a super pump from the shallow aquifer to the ground surface. In this scenario the electricity consumption and conversion factor can be estimated based on the energy balance of the pump. After separating shallow groundwater from deep aquifers, we can calculate the water abstraction. We can then compare this with the collected water abstraction data (estimated by Guantao department of water resources), enabling us to draw conclusions based on the data in Figure 13. It can be seen that a consistent time series of the groundwater abstraction was reconstructed from the electricity consumption for irrigation, and it agrees generally well with the abstraction reported up to 2006.

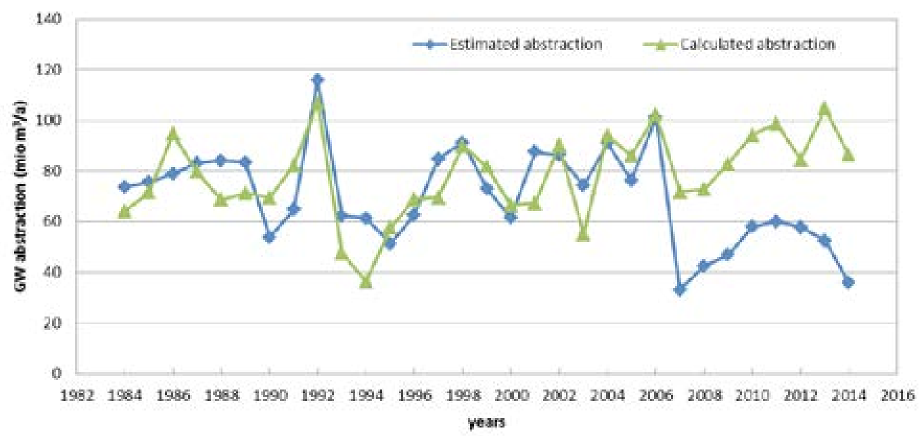

Figure 13. Shallow groundwater abstraction calculated from electricity consumption. Groundwater abstraction (million m^3/year)

To express this concept mathematically a box model of water balance was established, the water balance equation can be written as:

$$R_{pr} + R_{river} + R_{channel} + R_{backflow,channel} + V_s \cdot (1 + c) \cdot \beta - V_s = \Delta H_s \cdot \mu \cdot A$$

Where, R_{pr} is the precipitation infiltration, R_{river} is the seepage from the Weiyun River, $R_{channel}$ is the seepage from the channels, $R_{backflow,channel}$ is the irrigation backflow from the channel water, V_s is the abstracted shallow groundwater for irrigation which was reconstructed from the electricity consumption, c is the ratio between the deep water and the shallow water abstractions, β is the infiltration rate of the backflow from the groundwater irrigation, ΔH_s is the change of the depth to the water table in the shallow aquifer, μ is the porosity of the shallow aquifer and A is the area of Guantao.

From this equation, we can estimate the change of groundwater level. The calculated and observed depth to the water table and the corresponding change of storage in the shallow aquifer are shown in Figure 13. It can be seen that there is little difference between calculated and observed water depth.

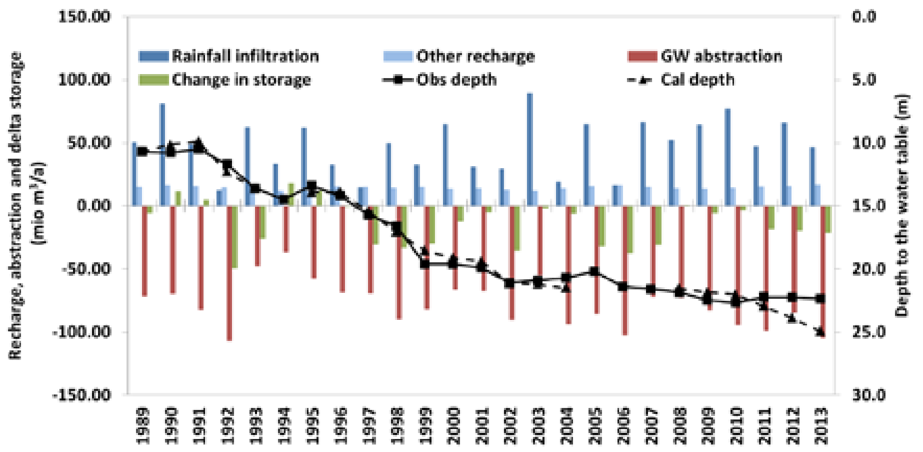

Figure 14. Calculated and observed depths to the water table (excluding jumps in the "bad years") and the corresponding change in storage (Groundwater abstraction (million m³/year))

3.4.2 Irrigation Calculator Guantao Web Implementation

An irrigation calculator has been set up by the Hydrosolutions company (a consulting company and one of our corporation companies) to compute the water requirements for crop growth considering different crops, irrigation systems and soils given the local climate. Various weather data sets (from the local meteorological station, neighbor county meteorological stations, international stations and a global station) have been taken into account to provide local climate information. The irrigation calculator was firstly implemented as a Matlab program. Input data such as the meteorological time series, crop and soil parameters can be entered into an Excel spreadsheet. When starting the main program, this information is read out and parsed into drop-down dialog boxes, from where the user can select the desired data (see Figure 15). Different fields with different selections can be added conveniently.

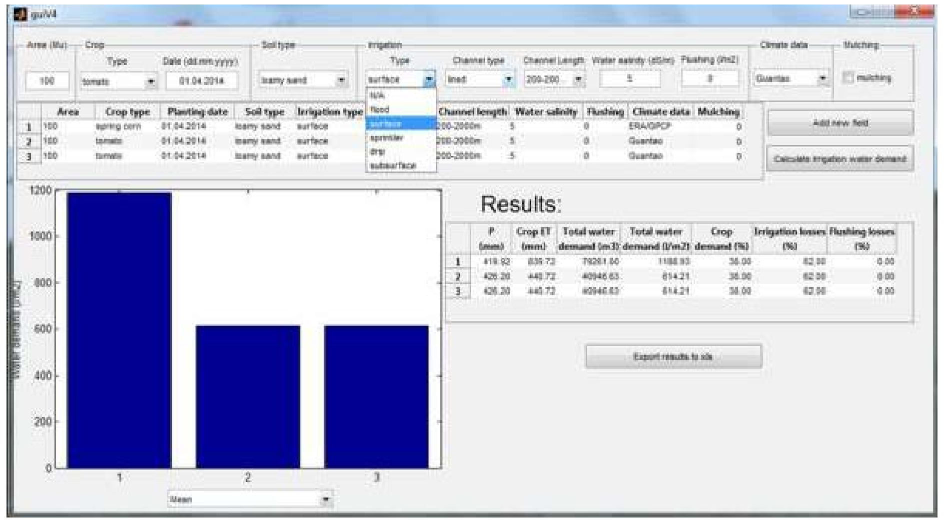

Figure 15. Screenshot of the Matlab-implementation irrigation calculator user interface.

A Hydrosolutions' Guantao Irrigation Calculator has been later implemented online and is available at: http://app.hydrosolutions.ch/IrrigationCalc-Guantao/. With this calculator, stakeholders can calculate monthly crop water demands for particular crops as a function of soil types and planting dates, given the particular long-term climate of Guantao County.

The new web-based tool uses the FAO AquaCrop web-service to calculate irrigation water requirements as a function of crop and soil types as well as data of the local climate. by using-predominantly

Monthly irrigation water demand can be calculated when navigating to the 'Irrigation Demand Calculator' tab on the page (see Figure 16) below.

Figure 16. Main elements of the irrigation water demand calculator. Panel 1: User interaction panel. Panel 2: Visual representation of monthly irrigation water demands using climate norms data for calculation. Panel 3: Advice panel on optimal cropping dates for the planting month using long-term climate norms. Panel 4: Tabular Data (also available for download, see Panel 1).

3.4.3 Real-time groundwater model development

We developed a Guantao groundwater model using a structured grid discretization. This model requires considerably less computation time, which allows it to be provided via a web Shiny-based app (Shiny is an R package[1] that makes it easy to build interactive web apps straight from R.). The model with unstructured grid also allows much faster computation of the ensembles required for the real time model. The groundwater model of Guantao is constructed using standard MODFLOW under Processing Modflow (PMWIN). The conditions of model structure, boundary, water sources and sinks, parameters, observation wells, etc. are considered in the model. The numerical model is run in two states. One is the steady state model used to calibrate the values of hydraulic conductivity and recharge ratios under constraints. The other is the transient model used to manually calibrate specific yields. We used a linear regression model between measured and modelled groundwater heads to demonstrate the effectiveness of the model, and the R^2 of the comparison between simulations and observations is around 0.8. Thus the fit to the observed data is very good considering the data situation relating to both steady state model and transient model.

3.4.4 Online toolbox of groundwater modeling

An online groundwater simulation tool has been developed by the Swiss Federal Institute of Technology Zurich (ETH) for the local authorities, which will be periodically updated and modified using monitoring data2. The goal is to facilitate the planning of water allocation for irrigation with respect to its impact on local and adjacent groundwater levels. Understanding the heterogeneous temporal and spatial response of the aquifer to anthropogenic impacts as well as its interaction with other elements of the water cycle (e.g. recharge, channel infiltration, infiltration of irrigation water etc.) presents a challenge. Our tool, based on a finite difference numerical groundwater model (MODFLOW), captures these systemic properties and allows the decision makers to assess the effect of different water allocation scenarios. The novelty concerns the fact that the model is embedded in an interactive web-interface, accessible to the users through the internet with all standard web browsers of computers, tablets or smartphones. Users can run a scenario, modify parameters and visualize the projected change in groundwater level as a consequence of their actions. The default prediction implies continuation of the status quo practices. The users can alter this practice and explore new strategies. The toolbox features include: easy online accessibility, efficient updating and maintenance, instant response and fluid interaction, customized user-friendly operation and license free software. The main window of the online toolbox can be seen in Figure 17. The contour plot on the right side of the screen shows the changes in groundwater level resulting from the simulated water allocation as compared to the current situation (initial condition). The panel on the left allows the user to choose different settings. The selected district to be worked on is highlighted by a thicker solid black line. By default, when a district is selected, the current practice values are loaded and the result shows the outcome when maintaining the status quo. Note that water levels change with time for the default values, as present practice is not in an equilibrium state. By dragging a rectangle on the map, one can zoom into a particular area. Double-clicking any location on the map allows zooming out. When clicking anywhere on the map, the plot will automatically show the drawdown over time relative to the initial heads at that specified location.

1 R is a programming language. R package is a set of functions that could be easily used in R programming.
2 The model is built based on historical data, and new current data are used to modify the data.

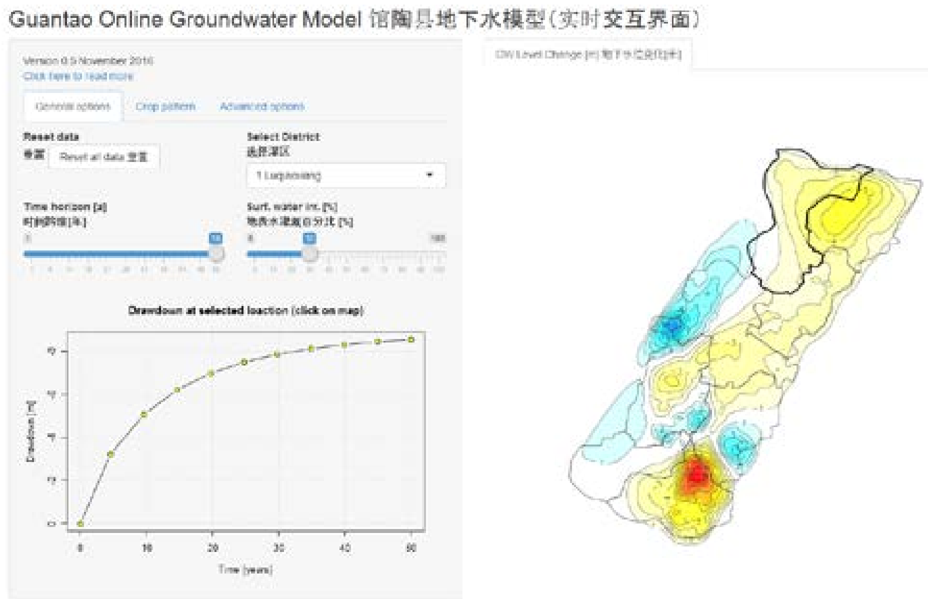

Figure 17. Main window of the online toolbox.

3.5 Management Rules and Policy Module

3.5.1 Water right and water allocation quota

The local government has set a quota of 150.5 m^3/mu (about 2250 m^3/ha) for irrigation water use. However, due to a lack of water monitoring devices, farmer's use of groundwater is actually uncontrolled and free of charge. The farmer survey conducted in March and April 2016 also asked about farmers' attitudes towards environment and groundwater management. Results show that only 3% of the farmers know of the irrigation water quota or water rights. More than 90% of the farmers noticed that the groundwater table had decreased in recent years and were worried about associated problems. About 70% of farmers support the policy of using quota/water rights to limit the quantity of irrigation water, and 60% of farmers will reduce the use of groundwater if volumetric charges of groundwater are implemented.

Hebei province government started the work of water rights verification and registration in 2015. Each farmer household will obtain a water right certificate with a valid date of three years. The water right certificate records the following information:

- Name of water user;
- Land size;
- Water rights per mu;
- Annual water rights;
- History of water rights transfer.

An implementation plan of the agricultural water pricing reform in Guantao was designed in April 2017 (referred to herein as "the plan 2017"). According to the plan 2017, three levels are defined as a basis to collect fees for agricultural water use and to reward farmers for saving water: the water right of 150.5m^3/mu, the water quota of 222m^3/mu, and the water limit of 296m^3/mu. Water used within the water right of 150.5m^3/mu costs the present base water price 0.32 CNY/m^3, above the water right an additional water fee of 0.1 CNY/m^3 is charged, and above the water limit of 296m^3/mu an additional water resources tax of 0.1 CNY/m^3 is charged (Yu et al., 2017b).

The surface water fee uses a water quota of 222 m^3/mu as the starting level for charging an additional water fee. For consumption below the established water quota, only a base water fee of 13 CNY/mu/irrigation is collected, whereas above the quota an additional 20% (or more) water fee will be collected. Above the water limit of 296 m^3/mu a water resources tax charge will be added. The water price structure for groundwater use is shown in Figure 18.

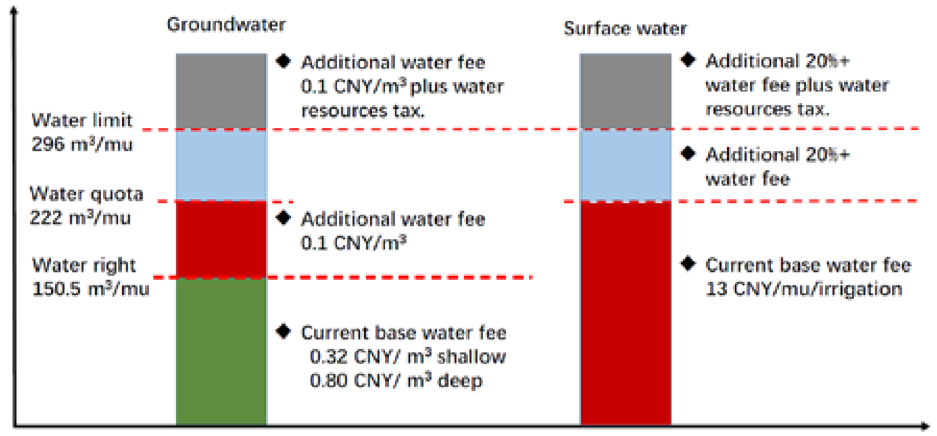

Figure 18. Comparison of irrigation water price for groundwater and for surface water in Guantao according to the plan 2017.

In the plan 2017 rewards are also proposed as incentives to encourage water-saving behavior as shown in Figure 18. Water saved within the water right can be sold to the government, traded in the market, or saved for the next year; water saved within the water quota can be rewarded by no more than 0.2 CNY/m^3 for savings in grain crop irrigation, and by no more than 0.1 CNY/m^3 for savings in non-grain crop irrigation; water saved at total amounts above the water quota is not rewarded.

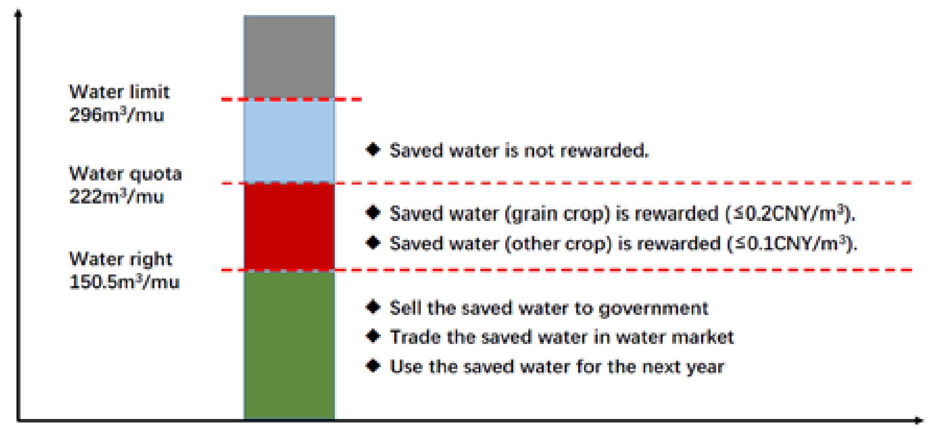

Figure 19. Irrigation water price for groundwater in Guantao from the implementation plan of the agricultural water pricing reform in Guantao.

The present rules of water right, quota and price in Guantao are still experimental and overall very complicated. For transparency and communicability, it is suggested to simplify these fee collection rules. In a pure quota system, especially in a region such as Guantao, where local rains contribute significantly to crop water supply, the violation of quota will only be apparent at the end of the season, when no more change is feasible. A base fee proportional to water use can be transparently collected together with the electricity fee. In the simplest approach,

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an effectively increased electricity fee should have the same effect as the complicated scheme proposed. This procedure does not exclude a rewarding system for farmers who stay below the sustainable quota.

3.5.2 Implementing water quota price through electricity consumption

Until now, water fee and tax have not been collected due to lack of an effective monitoring system for pumping. In March 2017 Hebei provincial DWR decided to adopt the method developed in the project. Using an average conversion factor from pumping tests of five typical wells of each county, electricity consumption is converted into groundwater water pumping volume as the base for water tax collection. In the plan 2017 for Guantao, fee and tax collection will be according to water meter readings wherever meters are installed (and function) and according to the water consumption estimated from electricity conversion everywhere else. This has given the official green light to use the electricity-water conversion method developed in project phase 1 for water fee/tax collection.

For the overall monitoring and total volume control of groundwater pumping of Guantao county, we recommended a method at transformer level for overall pumping control (see Figure 20). The fee/tax collection, however, will be at single farmer household. We proposed a fee collection structure (Figure 20), which makes use of the existing electricity fee collection system. A village electrician is responsible for paying electricity bills for every transformer in the village to the Department of Electricity and Power Supply. This bill is paid from the electricity fees collected for every single well attached to that transformer according to its electricity use. The village electrician can also be the person responsible for water fee collection according to electricity use and the proposed method of conversion. Farmers pay for their water use at the same time as they pay electricity bills. The proposal has received positive feedback from the local DWR. An additional suggestion is to include the village electrician as a key member into the village water use association. In this way they can be fully informed and updated with the newest local water policy changes concerning quota and price. This suggestion has already been included in the plan 2017.

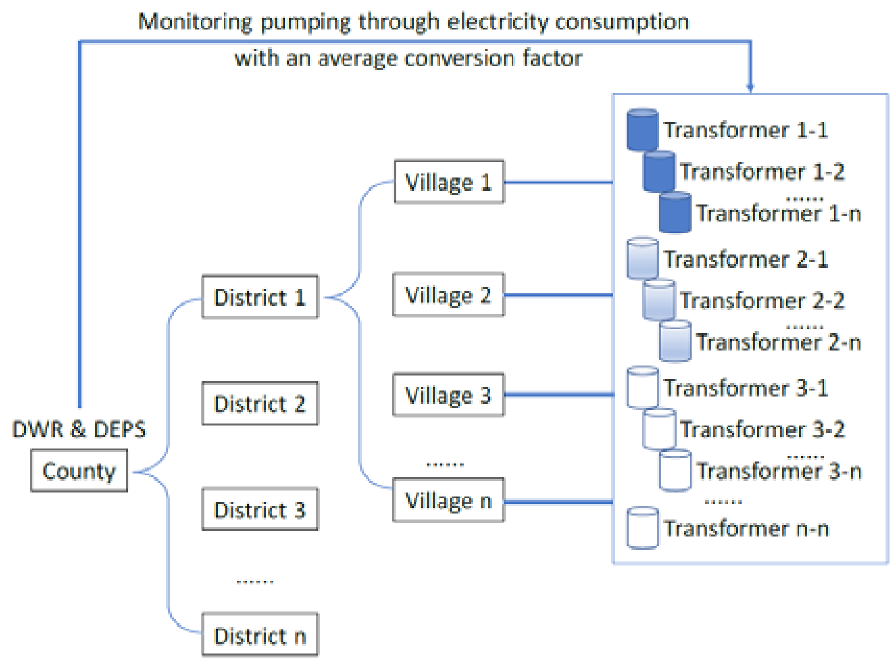

Figure 20. Illustration of county administration structure and monitoring of groundwater pumping through the electricity network.

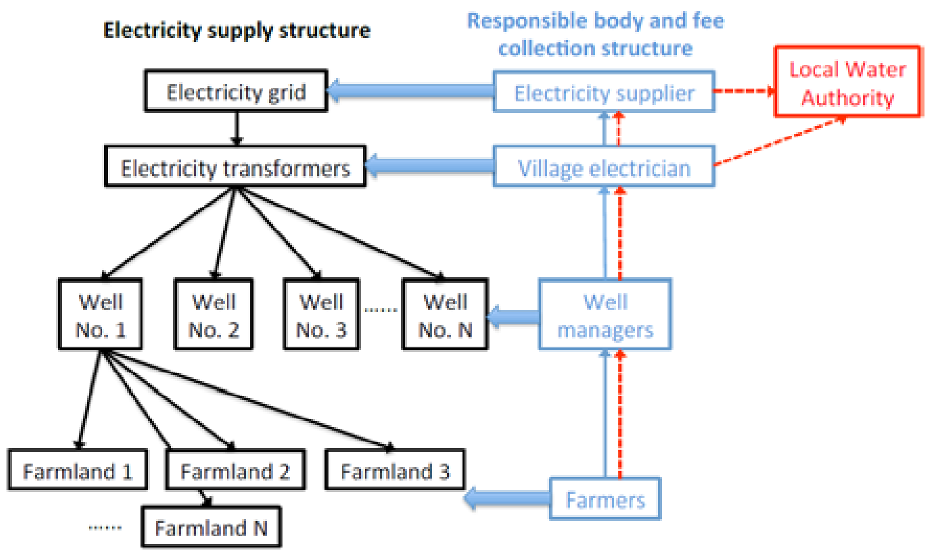

Figure 21. Proposed water fee collection structure for next phase.

4. Links to the SDGs

The Handan pilot project was conducted within a quite complex context. To some extent, the Handan pilot project serves as a pioneer for sustainable water management system building in China, as it shows the capacity for using smart technology to protect and recharge regional groundwater supplies and to introduce more sustainable water management. Groundwater over-abstraction is not caused by a single reason. Climate change, human impacts (from different sectors), poorly matched production – resources' distribution are among the many causes. All of these pose various difficulties to work to be done, which can only be overcome with an assembly of methods (e.g. water diversion construction projects, water savings projects, alternating high water consuming crops and many knowledge products reporting to the policy makers, such as water right allocation). The results gained and lessons learned within this pilot project can provide the technical support necessary to the implement these methods in other regional areas both in China and internationally. The monitoring and control methods introduced could also be up-scaled to larger areas requiring over-abstaction control. Links to several SDGs are as shown in Table 3, with descriptions below.

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Table 3. Links to the Sustainable Development Goals

Sustainable Development Goals and Targets	
SDG 2: Food security through sustainable agriculture **End hunger, achieve food security and improved nutrition and promote sustainable agriculture**	
2.3	By 2030, double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment
2.4	By 2030, ensure sustainable food production systems and implement resilient agriculture practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality.
SDG 6: Clean water & sanitation **Ensure availability and sustainable management of water and sanitation for all**	
6.4	By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity
6.a	By 2030, expand international cooperation and capacity-building support to developing countries in water and sanitation-related activities and programmes, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies
6.b	Support and strengthen the participation of local communities in improving water and sanitation management
SDG 11: Sustainable cities and communities **Make cities and human settlements inclusive, safe, resilient and sustainable**	
11.b	Encourage official development assistance and financial flows, including foreign investment, to States where the need is greatest, in particular least developed countries, African countries, small island developing States and landlocked developing countries, in accordance with their national plans and programmes.
SDG 12: Sustainable consumption **Ensure sustainable consumption and production patterns**	
12.2	By 2030, achieve the sustainable management and efficient use of natural resources

Links to SDG targets 2.3 and 2.4: One of important outcomes of the projects is the irrigating calculator, which is designed as a web tool to calculate the irrigation water demand of the main crops grown in the project pilot region. The total irrigation water demand of a whole region can be determined by cumulating the water demands for all crops with their respective areas. This provides a good plan for sustainable agriculture through ensuring equitable water for irrigation and makes the best use of water, so as to prevent that large arable areas may be left un-irrigated when water shortage occurs and secure agricultural productivity and farmer's income. By increasing farmers' knowledge of sustainable water management and providing better tools to allow more sustainable access to irrigation, these tools support resilient agricultural practices, sustainable food production and increased knowledge sharing for better decision-making for farmers.

Link to 6.4 and 6.A: 5 sets of water meters have been installed at the farmland with and without water saving facilities respectively, so that the effect of the water saving methods could be evaluated. This gives valuable feedback every year to the decision makers on how to adjust irrigating plans and the crop planting patterns. By increasing the farmers' awareness of water use and savings, they become able to adjust their irrigation practices to become more efficient and to use less water. The local departments of water resources are crucial in educating farmers of water saving since they have more expertise and motives.

Link to 6.B: This project is a great example of real time groundwater monitoring and its management through scenario based modeling on a pilot scale. Based on our model of using several decision support tools provides users with much easier access, such as computer, tablets and smartphones, and the irrigation calculator online tool of groundwater modeling. Training on the use of these tools has been conducted during the implementation of the project. The local technicians are now getting familiar with these technics and will definitely put them into their daily work in the future.

Link to 11.B: In addition to the informative tools and research that this project provides the government for decision making and planning for resilience to extreme weather and emergency situations, our findings also enable us to provide informed policy recommendations to the government to assist with effective and efficient policy decision for groundwater management in China. Our hope is that by sharing the results of our pilot project we can also assist other developing nations to implement smart tools and technology to address sustainable groundwater abstraction.

5. Outcome & lessons learned

5.1 Outcome

As presented in Table 1, the Handan pilot project has four fundamental objectives, and these objectives need to be fulfilled from May 2014 to December 2020. The project has been divided into two phases, and the first phase ended in March 2018. making major progress. Several outputs realized during Phase I have been illustrated in previous sections. Table 4 lists the task completion of Phase I of the project.

Table 4. Task completion in Phase I

Outcome/Outputs	Completion in Phase I
1. Providing data and information base for real-time water allocation	
1.1 Build up a central data and information exchange platform	Completed
1.2 Aquifer characterization of Guantao county	Completed
1.3 Water balance data for the chosen area in Guantao County	Completed
1.4 Groundwater table monitoring system	Completed
1.5 Real-time groundwater pumping monitoring system is developed and implemented	Completed
2. Developing and implementing an integrated real-time monitoring, modeling and controlling system to prevent groundwater depletion and build up adaptation capacity to climate change	
2.1 A water allocation tool for optimizing the choice of options to achieve a balanced groundwater reservoir is operable.	Completed
2.2 Real time groundwater model of the region is developed and calibrated	Almost completed
2.3 Overall groundwater monitoring/ controlling system is implemented	Continuing
3. Strategy options are elaborated through dialogues with the stakeholders and implemented by the local authorities.	
3.1 Control criteria and recovery strategy are established	Continuing
3.2 Strategies of optimizing surface water allocation will be elaborated and implemented in the Guantao region	Continuing
3.3 Strategies of groundwater control and recovery will be assessed, elaborated, and implemented in Guantao region	Continuing
3.4 Suggestions on legislation of conjunctive use of water resources according to water availability is proposed	Continuing
4. Improved knowledge of using real-time monitoring, modeling and controlling system to prevent groundwater depletion for arid regions in developing countries.	
4.1 Capacities and competences to operate the real-time monitoring/ controlling system are established	Continuing
4.2 Knowledge of a functional and tested real-time groundwater control system with supporting policies and strategies to be transferred to other water scarce regions in China	Continuing
4.3 Enriched experience of knowledge and technology of real time groundwater controlling transferrable to other developing countries	Continuing

5.2 Lessons learned

The project has made great progress since 2014 and achieved numerous results. However, during the project implementation we also experienced difficulties and have learned associated lessons. The following points summarize the lessons learned during the project operation. Special attention should be paid to these lessons so as to guarantee a successful continuation of the project implementation:

(1) Farmer's cooperation is important for monitoring system's installation and functional operation.

In Handan pilot region we have installed 10 sets of experimental meters of 5 different brands with two sets each, metering similar wells with and without water saving devices. All these different meters from different manufacturers were installed with much more effort than was expected in the project planning phase. Some of the meters were broken because of the careless (or intentional) removal/pulling of the power cables, and some were never operated due to farmers' refusal to use the installed water saving facilities. In summer 2016, all the experimental meters were moved to wells of which the owners/well managers were more cooperative. This problem does not only happen to our project meters, but also to the meters that have been installed with local monitoring wells. This results in delay of meaningful and reliable data to be collected.

Farmers' unwillingness to cooperate is partially motivated by their suspicion that the metering will eventually cost them additional fees. Another reason is that farmers feel that water saving facilities installed through the local water saving projects made them pay higher electricity bills for pumping the same amount of water. The successful operation of the metering system and water saving facilities will rely on farmers' cooperation. Necessary education and compensation will be necessary to maintain the farmers' cooperation on these issues. At the same time the pricing of water has to be reviewed to guarantee that farmers who use water savings do not end up paying more for a cubic meter than farmers who do not care about water saving.

(2) Integration of all the existing real-time data sent by different systems to one data platform proves to be a challenge. Our project experience could help future data integration of the local monitoring systems already installed or to be installed.
In Handan pilot region integrating 5 different varieties of pumping meters and 100 electricity meters for electrical transformers have shown quite some difficulties. The different meters from different manufacturers need different software to read the data from the signals sent to the central server at GIWP. The 100 sets of Lofty electricity meters also need their own software for reading the incoming data. For all metering companies and especially for the Iranian company, the business model is to install meters at low cost but to provide paid services for the customers afterwards. So they require sending the data to their own servers. After long discussions and negotiation between the project team and different meter manufacturers, an agreement has been reached that the manufacturers would provide the data format information, while Geopraevent provides code to read signals from different providers to extract data and saved in the database. In two cases the solution was found in giving Geopraevent access to the firm's database.

Sharing of the data from the devices installed on almost 1000 pumping wells and the 20 groundwater level monitoring wells installed by the local funds was agreed by Hebei provincial Department of Water Resources before the steering committee meeting, but the data has not been shared so far. The reason for this is that Hebei Provincial Department of Water Resources has not yet compiled all the data nor integrated them in one data platform, although it was supposed to be done by them. All the data are scattered in different softwares on different servers of various department divisions. This also shows how big a challenge it is to compile and integrate all the data from the monitoring devices installed by the local projects into one provincial system, as they are all in different formats. Our project experience could be useful to help the local authorities of data integration.

(3) The installation of electricity meters and monitoring electricity consumption needs cooperation with electricity sector
It took several months and several field visits to find out the reason why the electricity readings from the project electricity meters and the meters from the electricity department were inconsistent. The joint field investigation of the project expert team and implementation team, together with the electricity department finally found out that the electricity meters installed for the project were not properly installed. All the meters have to be re-installed. This shows the need for close cooperation with the electricity sector, not only because of their technical expertise and their ownership of the transformers, but also because only they can provide the data for the past, and even more important, in the future. Installing additional meters helps the project team to access more data directly and in real-time. However, for the scaling up of the effort in future, we urgently suggest to the water authorities to cooperate with the electricity department. Sharing their electricity data is a more cost-effective approach for groundwater abstractions monitoring than installing additional electricity meters.

(4) Importance of the calibration process
As the meters are produced by different manufacturers, various formats of output data are received, making it essential to integrate all of the monitoring data and transform them into normalized data values as quickly as possible to ensure the data is standardised.

5.3 Future plans

Phase II of the project was planned to commence in March 2018, however, the plan is still under examination for approval. In the second phase of the project, the aquifer will be managed as drought-relief storage using the real time groundwater monitoring, modelling, and control system. Different control strategies will be applied to achieve best results under different circumstances. The recovery of groundwater tables is a long-term process and can only be reached over a time span of decades.

6. Conclusion

One of the most salient problems of non-sustainable water use worldwide is the over-pumping of aquifers. A prominent example is the North China Plain aquifer system, which is heavily overexploited mainly by agricultural water use. Emptying of aquifers is more deplorable as they are the only over year storages for water available and thus capable of combating prolonged drought conditions. Extraction of groundwater by innumerable wells is not controllable. The difficulty posed by managing them is the major reason why many aquifers in the world are over-pumped. With new technology, the challenge of bringing these aquifers back to a sustainable extraction mode can be tackled.

To rehabilitate the aquifer in the North China Plain, we proposed a real-time monitoring, modeling and controlling system where in the final stage all major pumping wells can only be operated by an Integrated Circuit (IC) system carrying the quota allowed for each well. This system was tested and then adapted to and implemented in a pilot region in Guantao County of Handan Municipality in the North China Plain. The first phase of pilot project lasted from 2014 to 2018. In this phase we designed and introduced a strategy of managing resources which allows this equilibrium to be reached. In parallel, a system for monitoring and control of groundwater levels and groundwater abstraction have been built and tentatively operated putting a priority on enforcing pumping restrictions for the wells exploiting the deep aquifer. The planned goals have been realized.

The technical knowledge of controlling groundwater well fields in real-time has been developed in Switzerland. Developing a control system in the agricultural context of China, demonstrating its functionality and then transferring it to developing and transition countries has a high potential to contribute to drought mitigation and climate adaptation world-wide. This objective is in line with SDC's focus on sustainable development.

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TEXT BOX

Water And Energy Driving to Sustainable Development in Cotacajes, Bolivia

Country: Bolivia
City/region where project is based: Cotacajes Village
Population (of area where the project is based): 80 families (400 inhabitants)
Key organisations /stakeholders involved in the project: Local authorities (Secretario General, Mayor, Secretario de Relaciones, Secretario de Actas, Vocal); Local Electrification Committee (LEC); PRODENER (NGO), the Finnish Cooperation (AEA/IICA Program); women and young people.
Authors: Andrés Calizaya Terceros(PhD), David Chávez Pereira(B.Eng.), Anibal Cazas Bascopé(B.Eng.), Adriana Barrón Mondaca(Lwy)
Link: www.prodenerbolivia.com
AEA Project Link: energiayambienteandina.net/fichaBolivia_1.html

Water challenge

In the Cotacajes village, people rely on water from the local river for their domestic water needs. This untreated water can pose health risks to users. Furthermore, farmers rely on traditional irrigation practices that are less productive at distributing water, and the village has little access to electricity, instead depending on candles and kerosene lamps.

Project approach

The project objective was to build a small hydropower (SHP) system to improve the quality of life for residents of the Cotacajes village. It has been implemented through the formation of a Local Electrification Committee (LEC), composed of members of the beneficiary community in which there is active female participation. This LEC organized the works for the construction of the hydropower system, through the self-construction modality, under the supervision of the NGO PRODENER, with funding from the Finnish Cooperation (AEA/IICA Program). The hydraulic cross-flow turbine of the SHP was designed and built by PRODENER and then installed in cooperation with beneficiaries.

The hydropower system generates electricity for the population of Cotacajes village, and provides a source of clean water for domestic uses. Furthermore, a micro-irrigation pumping system is powered by the SHP for local farming, as well as other productive activities as carpentry, welding, honey bee production, grain mill and rice peeling. The SHP consists of a derivation system that produces 35 kW and is equipped with a cross flow turbine for 180 l/s and 34 m of head (the height of the flow).

Currently, beneficiaries pay a fee for energy consumption at a level that is similar to the previous expense paid for the use of candles and kerosene lamps. The entire project was carried out in 1.5 years, adapting to the availability of beneficiaries' time, without harming their family support activities.

Results and links to the SDGs

The project is well linked to the Sustainable Development Goals in which hydro-energy plays an important role, as the Cotacajes hydropower system improved life quality and well-being of the beneficiary population and neighbourhoods through increased access to clean water and electricity. Specifically, the project has resulted in:

- improved health care 24 hours (better living conditions for those responsible for health, light and conservation of vaccines in the sanitary post);

- generating extra incomes to a subsistence economy (grain mill and rice milling locally, reducing the transport fee and saving time);
- improved safety, particularly at night (avoiding fires in houses and falls to the river and to irrigation channels);
- greater access to food and food security (pumping water to high lands to increase irrigation area and increasing the production of native flowers for the honey bee production);
- improved education of children and youth;
- greater participation of both genders and vulnerable groups;
- the implementation of more productive projects;
- in a short term, the implementation of a technical training centre (carpentry, welding, metal-mechanics, honey bee production, handicrafts and sewing)

SWM: Potential and barriers

Once they have completed a training program, the beneficiaries carry out the operation, maintenance and administration of the SHP. Aside from the training, the operation is fully autonomous, and an intelligent system has been installed that activates an alert system. The alert system warns both the local operator and the PRODENER technicians about possible failures, via SMS to mobile phones (Arduino by PLC controller). For example, when the amount of water in the main feed channel decreases, an alert is sent to indicate that the operator must immediately control this anomaly. Another alert can also indicate that the turbine is running over the normal speed. The local trained operator knows what to do, but for PRODENER it is also very important to know what is going on at the SHP and how the operator is solving the problems.

The community has a cell signal whose antenna also receives energy from the SHP and facilitates communication to address any problem in the operation of the turbine according to local capacities, since more complicated aspects will require specialized assistance. In the near future we expect to have an internet connection, which would enable us to assist the operators remotely, for example by videoconference or WhatsApp.

Flood and Drought Management Tools Case Study

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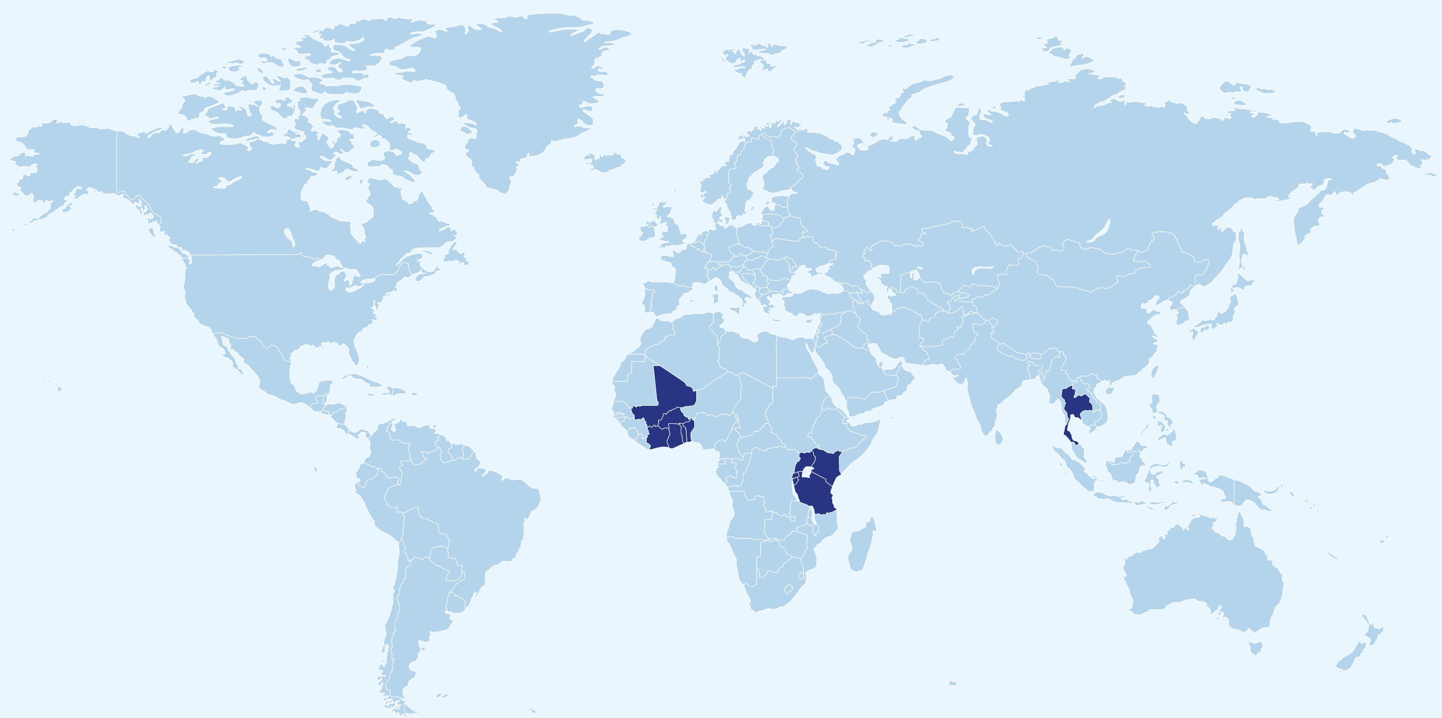

Thailand (Chao Praya Basin)

Tanzania, Kenya, Uganda, Rwanda and Burundi (Lake Victoria Basin)

Benin, Burkina Faso, Côte d'Ivoire, Ghana, Mali and Togo (Volta Basin)

1. International Water Resources Association (IWRA), 2. International Water Association (IWA), 3. DHI

Summary

The high prevalence and severe impacts of flood and drought events on water resources, human communities and ecosystems demonstrate the need for building resilience against such events. Inadequate access to climate, hydrological and other data required for effective decision-making has left communities and organisations unable to properly prepare and plan appropriate management techniques as a method of protection.

To address this need and enhance capabilities for planning for extreme weather events, a smart water management (SWM) approach was initiated: the Flood and Drought Management Tools (FDMT) project. The project is funded by the Global Environment Facility (GEF) under its International Waters (IW) portfolio, and is being implemented by UN Environment and jointly executed by DHI and the International Water Association (IWA). Its objective is to improve the ability of water managers in transboundary river basins to recognize and address the implications of the increased frequency, magnitude, and unpredictability of flood and drought events arising from climate variability and change. Planning approaches supported by the project include Transboundary Diagnostic Analysis/Strategic Action Programme (TDA/SAP), Integrated Water Resources Management (IWRM), and Water Safety Planning (WSP) processes. The project is developing a methodology to support water utilities and basin organisations, involving web-based technical applications to share data and planning tools with stakeholders in their basins.

The Flood and Drought Portal (www.flooddroughtmonitor.com) is the main output of the project and has a series of technical applications supporting stakeholders to carry out baseline assessments using readily available satellite data, impact assessments through the analysis of the data, planning options and a means for disseminating information to relevant groups or individuals. Within the Portal, there is a data and information tool which provides near real-time satellite based data related to determining floods and drought, seasonal and medium range climate forecasts, climate change projections and information relevant for basin and local planning. Other applications hosted on the Flood and Drought Portal include water indicators, drought assessments, water safety planning, issue analysis, and reporting. Each application or tool can be applied individually or together to include information about floods, droughts and future scenarios. The applications in the Portal support planning across scales from the water utility to transboundary basin level, enabling both water basin authorities and local water utilities, which supply drinking water to citizens, to be better prepared and equipped for extreme weather events.

The methodology and tools have been developed to have a global approach to flood and drought planning, which can then be applied to local settings around the world, and three pilot locations affected by extreme weather challenges were selected to develop, test and validate the FDMT methodology. The FDMT project was implemented from 2014-2018 in the Chao Phraya Basin (Thailand), Lake Victoria Basin (East Africa) and Volta Basin (West Africa). Further to the near real-time SWM tools used within the FDMT project, implementation of the project was assisted through capacity building, stakeholder engagement and information dissemination. Stakeholders in the pilot basins, including basin authorities and water utilities, were consulted regularly over the course of the project, including technical training workshops and stakeholder feedback throughout the project. The pilot basins participated in testing and provided feedback to support development of the applications in the Portal. The Portal already has users from 42 transboundary basins from across six continents who have access to the tools and satellite data required to support their short- and long-term planning and management for flooding and droughts.

This case study provides an overview of the FDMT project, beginning with a background and context of the pilot basins and water challenges that they face. Following this, the SWM solution, the Flood and Drought Management Tools, is illustrated, including project elements such as capacity building, inputs, enablers and barriers. The case study finishes with a discussion on how the project and its impacts are tied into the SDG's and lessons that can be drawn from the FDMT project experience.

1. Background

The FDMT project responds to a growing sense of urgency around the need to improve resilience within river basins, and for this to become a critical part of water management plans. Consequently, the International Waters (IW) focal area of the GEF has identified the increased frequency and unpredictability of floods and droughts as a priority concern in transboundary contexts, along with the other multiple drivers that cause depletion and degradation of shared water resources.

Based on these issues, the project was designed to develop a methodology for basins, which uses SWM tools and decision support systems (DSS) that will allow the access and integration of information on floods and droughts. The DSS has been tested and applied in 3 different pilot basins; however it will be available for all other GEF IW basins. This includes training modules available at the end of the project to ensure that methods can be applied to other basins.

The 3 basins chosen as pilots include the Chao Phraya basin in Thailand, the Lake Victoria basin in eastern Africa and the Volta basin in western Africa (see Figure 1). The selection of these three basins was made on the basis of their environmental, social and economic conditions, the transboundary nature of their basins, and their varying degrees of technical capacity in each region. Furthermore, it was beneficial that the executing organisations (IWA and DHI) already had previously established regional knowledge and networks with local stakeholders in these three basins.

In addition to the three pilot locations, the FDMT project draws from experiences within two 'learning basins', the Nile and Danube basins. In these learning basins, collaborations with water management authorities enable IWA and DHI to share and develop the methodology and tools with organisations that have previous experience with flood and drought planning tools. Although the experience from the learning basins was important for developing the FDMT methodology, it is not further documented within this case study.

Expanding further, the FDMT approach strives to have global implications for all transboundary basins. This global approach prompts the need for a flexible methodology that ensures that these SWM tools will be available and relevant for stakeholders within any transboundary basin.

Figure 1. Global map outlining the three pilot basins involved in the FDMT project.
Source: http://fdmt.iwlearn.org/

The following sections outline the context of each of the three basin pilot studies.

1.1 Chao Phraya Basin

Countries within basin: Thailand
Catchment area: 160,400 km^2
Population: 30 000 000
Urban population: 32%
Dominant language: Thai

The Chao Phraya River Basin is an important basin in Thailand as it contains 30% of the country's land mass and 40% of the population, including the capital city, Bangkok. Bangkok is located at the delta of the Chao Phraya River (see Figure 2) and contains half of the basin's population, generating almost 80% of the basin's GDP. This basin was selected due to the rapid pace of its development, economic global importance and its persistent drought and flood events. Despite not being a transboundary basin, there are important lessons to learn in relation to cross departmental agencies (there are more than 30 government agencies dealing with water).

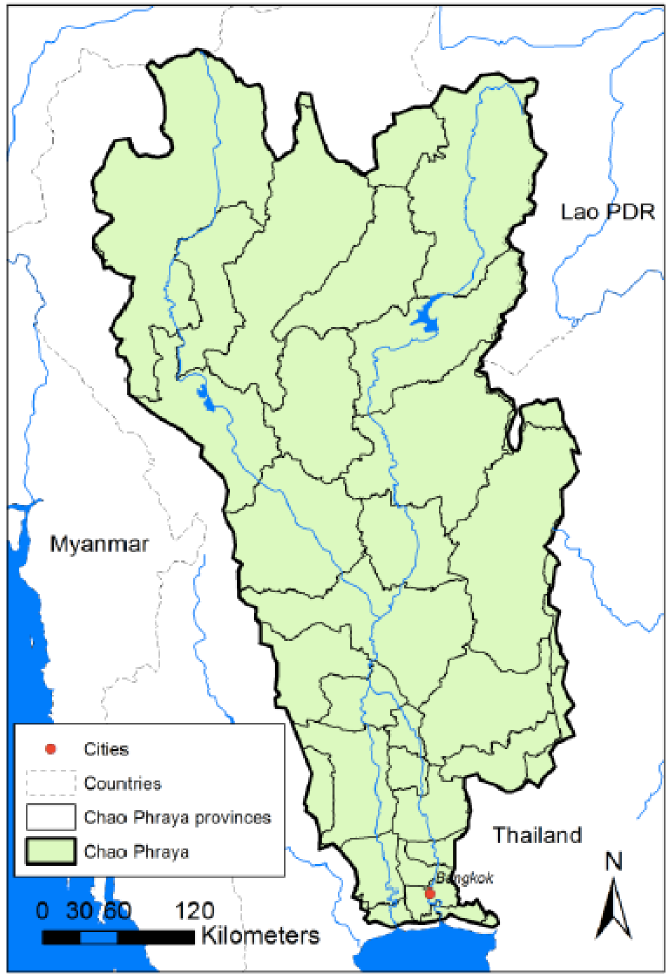

Figure 2. Map of the Chao Phraya basin in Thailand, with the capital and largest city, Bangkok, located at the southern point.
Source: GEF IW:LEARN 2016c.

Climate and Hydrology in the Chao Phraya basin

• Seasonal monsoon winds contribute to the high seasonal variability of rainfall in the basin, with the mean rainfall during the rainy season (May – October) contributing 90% of the total annual rainfall.

• For agricultural practices to survive during the dry period, more than 3000 dams have been constructed in the basin over recent years. The two largest dams control 22% of the runoff from the basin and many barrages divert off the main channel for irrigation schemes.

• The northern region of the basin has higher temperatures due to its tropic latitude and inland location, while the south has generally milder temperatures.

• Water service facilities provide domestic water in urban areas, while groundwater wells serve rural communities.

Within this context, the basin faces numerous socio-environmental problems. Agricultural lands cover 90% of the basin, concentrated in the southern region, which has undergone intensification causing encroachment of forested regions as well as soil erosion and sedimentation. This reduction in forest cover is detrimental to the land's ability to retain water, increasing the risks of flash floods and landslides.

Unsustainable groundwater extraction, especially in Bangkok for industrial purposes, has created an annual sinking rate of 10cm of the land the city sits upon. This sinking phenomenon will continue to grow into a greater issue of concern in the future as climate change generates sea level rises and larger waves hit the coastal region. The sea level rise is already underway, with stronger waves, coupled with upstream dams depositing less sediment along the river-mouth, contributing to significant coastal erosion.

Additionally, solid waste and untreated wastewater released from Bangkok and other highly populated areas are leading to the basin's poor surface water quality and watershed degradation. This impacts the ecosystems there, contributing to the loss of native species and the health of people living in proximity to these polluted water bodies.

Key Stakeholders

BASIN ORGANISATION
Hydro and Agro Informatics Institute (HAII)

WATER UTILITIES
Metropolitan Waterworks Authority (MWA), Provincial Waterworks Authority (PWA)

ADDITIONAL WATER RESOURCE AGENCIES
Office of the Natural Resources and Environmental Policy and Planning (ONEP),
Royal Irrigation Department (RID),
Electricity Generating Authority of Thailand (EGAT),
Thailand Meteorological Department (TMD)

To aid in the management of these issues, several institutions exist in the Chao Phraya basin. National committees and boards develop policies for water resource management and conservation, namely the National Economic and Social Development Board, the National Environment Board and the National Water Resources Committee. Energy production, including hydropower generation is managed by the Electricity Generating Authority of Thailand (EGAT). There are a number of different committees linking stakeholders and deciding how water is allocated for different uses. The Royal Irrigation Department (RID) also works with EGAT to direct water allocation planning in the basin, especially during the dry season. In 2017, the Office of National Water Resources (ONWR) was established and is in charge of setting overall water management policies and has the final say in allocation of water. Two water authorities oversee potable water supply; the Metropolitan Waterworks Authority (MWA) works in Bangkok Metropolitan, with the Provincial Waterworks Authority (PWA) operating outside the Metropolitan limits. Within this institutional landscape, there is a strong need for collaboration between stakeholders, in particular around sharing data and information.

Regarding technical capabilities, the stakeholder organisations in the project engaged with in the Chao Phraya basin have a good degree of capability to manage and interpret data needed for planning. EGAT has strong technical capabilities with respect to modelling of water level, and the Hydro and Agro Informatics Institute (HAII) has extensive experience with real time data, modelling, data integration in the country and Decision Support Systems (DSS). Furthermore, the Thai Meteorological Department (TMD) and Geo-Informatics and Space Technology Development Agency (GISTDA) are involved in climate modelling and forecasting from remote sensing and satellite data. At the local level, the capabilities of the water utilities are different, where the use of climate data varies depending on priorities. There is therefore an opportunity to build the capacity of water utilities particularly around interpreting the information and integrating this in the management and planning of water resources for water service provision.

1.2 Lake Victoria Basin

Countries within basin: Tanzania, Kenya, Uganda, Rwanda and Burundi
Catchment area: 251,000 km^2
Population: 35 000 000
Urban population: 32%
Dominant language: English

This lake basin, located in eastern Africa upstream of the Nile basin, is shared among five countries, Tanzania, Kenya, Uganda, Rwanda and Burundi, with the greatest proportion located in Tanzania (see Figure 3). Lake Victoria itself covers a significant portion of the basin, 68,800 km^2, making it the largest freshwater lake in Africa, and second largest in the world. The FDMT project concentrates primarily on Kenya, Uganda and Tanzania in this pilot, as these countries when combined cover 80% of the catchment, however, indirect links to Burundi and Rwanda are also made through the basin authority.

Climate and Hydrology in the Lake Victoria basin

- The climate in the basin is equatorial: hot and humid, with bi-modal rainfall patterns.
- Long rains dominate the March – May season and short rains from October – December.
- The greatest input to the lake derives from precipitation and as such, climatic variations in recent years have caused large changes in the water levels.
- Other hydrological contributions come from the several rivers flowing into Lake Victoria, the most notable of which is the Kagera River which contributes 33% of the total inflow.

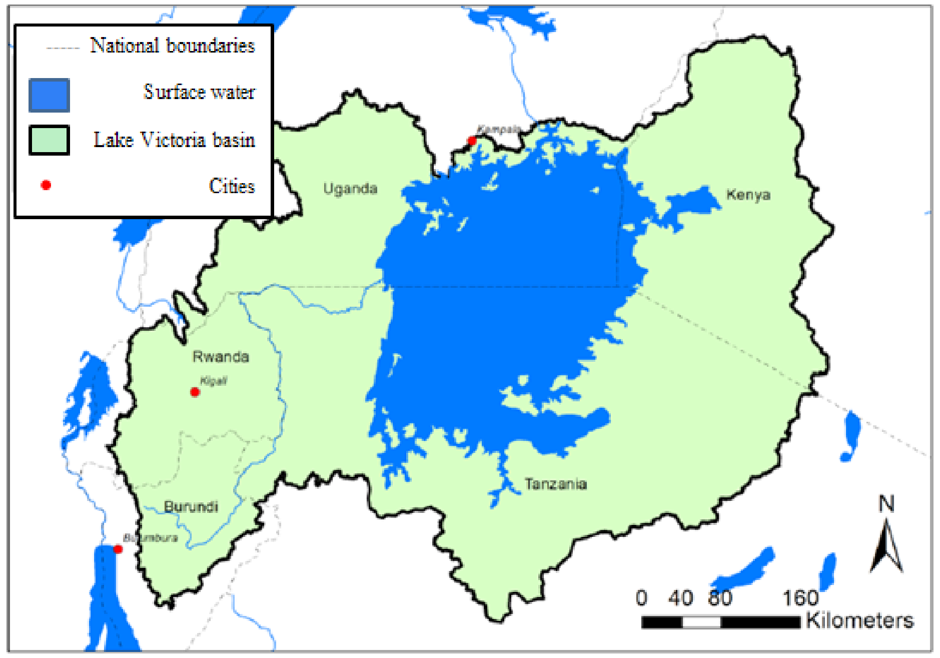

Figure 3. Map of the Lake Victoria basin, displaying the coverage in Tanzania (44%), Kenya (22%), Uganda (16%), Rwanda (11%) and Burundi (7%).
Source: GEF IW:LEARN 2016b.

The climate and water supplied by Lake Victoria have provided favourable conditions for agriculture, fishing and other economic activities, which in turn have contributed to the high population density of the Lake Victoria basin. With an average of more than 500 people/km^2 and as much as 1200 people/km^2, it is one of the most densely populated regions of the world (Tong et al. 2016). Most of the population lives in rural areas and small towns, but in recent years there has been a shift towards urbanisation. Among this population, there is a dependence on natural resources, with agriculture and fisheries being the most substantial livelihoods.

Rapid urbanisation and resource mismanagement have contributed to the many environmental issues within the basin, including pollution, biodiversity loss, habitat destruction and soil erosion. Rivers flowing to the lake carry high amounts of silt and nutrients from agriculture processes and untreated wastewater, causing severe eutrophication and dead zones which are unable to sustain life in parts of the lake. Growth of the commercial fishery industry has also significantly contributed to the lake's ecosystem deterioration, with an 80% reduction in indigenous fish species. Furthermore, land cover changes have resulted in a 70% reduction of the original forest cover in the basin.

Key Stakeholders

BASIN ORGANISATION
Lake Victoria Basin Commission (LVBC)

WATER UTILITIES
Kisumu Water and Sewerage Company (KIWASCO),
National Water and Sewerage Corporation-Jinja (NWSC-Jinja),
Mwanza Urban Water and Sewerage Authority (MWAUWASA)

In response to the many environmental concerns within the basin, a few local institutions promote the need for improved water resource management and provide general supervision and co-ordination on all matters relating to the environment. The key basin-level organisation that coordinates sustainable development within the region is the Lake Victoria Basin Commission (LVBC), established in 2005. LVBC is a specialised institution of the East Africa Community (EAC) that developed from the EAC's Lake Victoria Development Programme (LVDP), a mechanism established in 2001 to coordinate various interventions in the Lake Victoria Basin region and to turn the Basin into an economic growth zone. Within each member state (Tanzania, Kenya, Uganda, Rwanda and Burundi), the LVBC has National Focal Points who are responsible for coordinating national initiatives related to the Basin. There is also coordination between the Member States and the LVDP. The National Focal Points are the main links between the LVDP and the Member States, and are responsible for coordinating and harmonizing the activities related to the Lake Victoria Basin conducted by the various Ministries in the Member States, NGOs, special interest groups and other development partners. National ministries contributing to these issues are, for example, the Kenyan and Ugandan National Environment Management Authorities (NEMA) and the National Environment Management Council (NEMC) in Tanzania.

1.3 Volta Basin

Countries within basin: Benin, Burkina Faso, Côte d'Ivoire, Ghana, Mali and Togo
Catchment area: 407,093 km^2
Population: 23 000 000
Urban population: 30%
Dominant language: French

The third pilot basin within the FDMT project, the Volta basin, is located within western Africa and is shared among six countries: Benin, Burkina Faso, Côte d'Ivoire, Ghana, Mali and Togo. The FDMT project focuses on Burkina Faso and Ghana, which occupy approximately 85% of the basin, while the remaining countries in the basin are indirectly engaged through the basin authority, the Volta Basin Authority.

Climate and Hydrology in the Volta basin

- Climate is within the sub-humid to semi-arid West-African savannah zone.
- Rainfall patterns are seasonal, with large year to year variability, especially in the northern parts of the basin.
- Further inland of the basin, the aridity increases, the growing season becomes shorter and rainfall is more erratic.
- Potential evaporation rates are very high, especially in the north of the basin, with temperatures as high as 44°C.
- The river network of the Volta basin is displayed in Figure 4, with water from the Black Volta, the White Volta and the Oti-Pendjari tributaries flowing into Lake Volta, which feeds into the Lower Volta and eventually discharges into the Gulf of Guinea.
- Lake Volta is the largest man-made reservoir by surface area in the world, created by the construction of the Akosombo Dam in 1964.

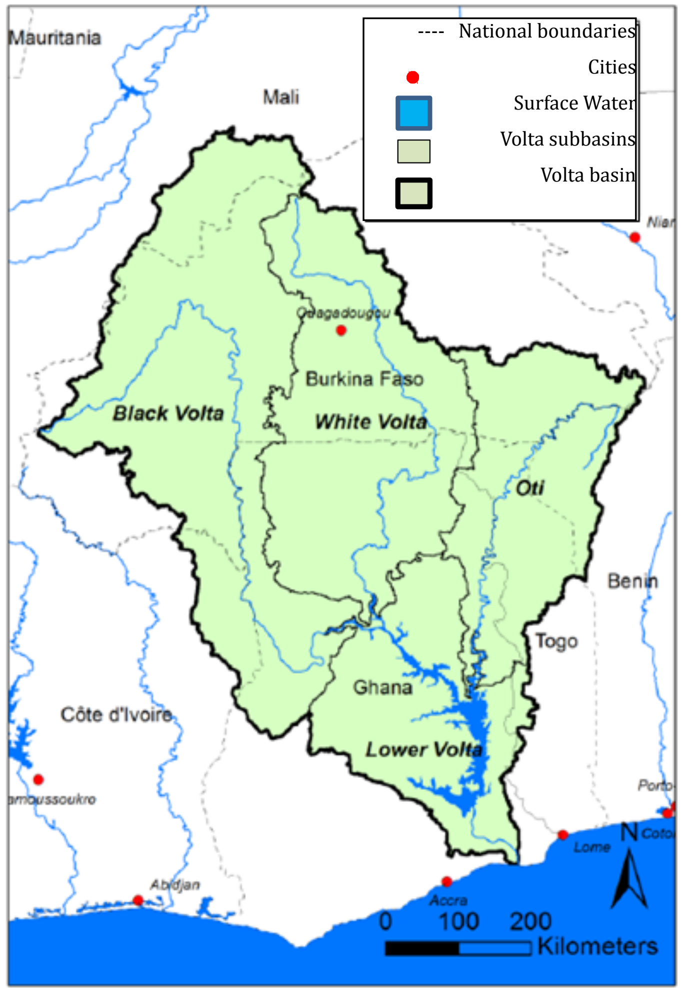

Figure 4. Map of the Volta basin, displaying the Volta River system and countries falling within the basin's reach.
Source: GEF IW:LEARN 2016a.

In a setting of a changing climate and increasing population pressures, the Volta basin faces competing demands for water. Over 23 million people reside within the Volta basin, a figure set to increase rapidly over the next ten years, with an estimated growth rate of 2.5-3%. Of these inhabitants, 70% reside in rural areas and depend on the basin's water resources, with rain-fed agriculture as the main livelihood in the Volta basin. Rain-fed and irrigated agricultural activities contribute 40% of the basin's economic output. Due to this reliance on rainfall, the effects of climate change on precipitation patterns will have significant impacts on the people within the Volta basin, who will likely turn to irrigation to meet their water needs, further increasing reservoir water demand.

Ghana Water Company Limited is the state owned water utility providing drinking water supply to all urban communities in Ghana. It operates 88 urban water supply systems across the country (GWCL 2018).

The principal dam operators in Ghana are the Volta River Authority (VRA), Ghana Water Company Limited (GWCL) and the Ghana Irrigation Development Agency (GIDA), for the purpose of hydropower, water supply and irrigation respectively. Energy is generated from several dams such as the Akosombo and Kpong dams. In Ghana, this energy supply is the main contributor for power production, for example the Akosombo dam supplies 70% of its power needs, and hydropower supports major industries in the region, such as mining and aluminium production (World Bank 2015). For continual power production from these sources, the dams require dependable annual inflow, stored within the Lake Volta, with the greatest amount of replenishment deriving from run-off (World Bank 2015). Industries as well as municipalities require water supplies to promote economic growth and development, elements that are key to helping one of the poorest regions of the world (Ndehedehe 2016).

In Ouagdougou, Burkina Faso, drinking water is supplied by the Ziga Dam. Ziga Dam is operated by the National Office for Water and Sanitation (ONEA), providing about 70% of domestic water supply to Ouagadougou, the main urban centre and capital of Burkina Faso. With the extension of the dam in 2016, it was projected that ONEA can maintain a sufficient water supply to the city of Ouagadougou at least until 2030 based on projected population growth and climate change. The capacity of the dam is designed to withstand a 2 year drought, and is also an important buffer during high rainfall events to prevent downstream flooding. The Bagré Dam, located near Bagré Village in the south of Burkina Faso, is a multi-purpose dam constructed in 1992. Before the expansion of the dam in 2014, seasonal spilling of the dam contributed to severe flooding in northern Ghana. The impact demonstrated the importance of close cooperation between Burkina Faso and Ghana to provide sufficient warning of planned spills of the Bagré Dam.

Key Stakeholders

BASIN ORGANISATION
Volta Basin Authority (VBA)

WATER UTILITIES
Ghana Water Company Limited (GWCL),
National Office for Water and Sanitation (ONEA)

ADDITIONAL WATER RESOURCE AGENCIES
Water Resources Commission (WRC) – Ghana
Agence de l' Eau – Burkina Faso

Until recently, the Volta basin lacked basin-wide coordination to help address the many challenges across the five basin countries. Across the different countries within the Volta basin, policies are complex and lack coordination, with the different government agencies involved. The VBA, as well as catchment organisations under relevant national water agencies, attempt to bridge national water policies and give an overall view of the water resource management within the basin. All the basin states are committed to Integrated Water Resources Management (IWRM), however major differences in management and institution-building styles are an obstacle to basin-wide cooperation.

Compared to the other two pilot basins of the FDMT project, the Volta basin is limited by institutional and technical capacity, and presents a challenge to overcome these limitations. However, it should be noted that the Chao Phraya basin may have fewer, yet different challenges due to its non-transboundary nature which requires less institutional coordination.

2. Water challenge

2.1 Floods and Drought

Floods and droughts can challenge a water system as they are at the extremes of what is normally expected. Extreme weather events, including floods and drought, are an increasing concern in the Chao Phraya, Lake Victoria and Volta basins. Many drivers contribute to these events, including the changing climate, population growth, increasing demand for water and other resources, changing land use and urbanisation. These factors have increased the prevalence and risk of droughts and floods in southeast Asia and Africa over the last several decades (Pongpiachan et al. 2012, Kundzewicz et al. 2014). The descriptions below outline the specific situations in each of the three pilot basins.

2.1.1 Chao Phraya (Thailand)

The Chao Phraya basin endures frequent flood disasters due to the combined reduction of flood retention areas and flood plains to make way for increased development, rapid urbanisation and the intensification of agriculture practices. Furthermore, Bangkok is prone to inundation because of its low elevation relative to the nearby sea, the land subsidence from groundwater abstraction and the filling in of khlongs (urban canals).

This basin experiences a variety of floods, including:

- general flooding (unusual presence of water on normally dry land),
- river flooding (overflowing rivers),
- ocean flooding (inflow of sea water onto land) and
- flash flooding (heavy rainfall during a short period of time) (Pongpiachan et al. 2012).

Severe flash floods, which occur regularly, impact the capital city during the rainy season, and in 2011, severe floods triggered by a tropical storm lasted for more than five months (Pongpiachan et al. 2012). The floods during the 2011 monsoon season had drastic impacts, inundating large parts of Bangkok (see Figure 5) and 20 000 km^2 of farmland, affecting over 13 million people and causing more than 800 deaths. Analysis of this extreme flooding event has shown that there is an increasing potential for future similar floods, with the sea level rise in the Gulf of Thailand likely to prolong the duration of such events (Promchote, 2016). The researchers conducting this study recommended progressive monitoring of pre-monsoon and monsoon onset rainfall, soil moisture, and sea level height in the basin (Promchote, 2016). This monitoring would allow water managers in the basin to better anticipate the characteristics of future flood events as well as to manage timing and volume of water from reservoirs in order to mitigate the flood impacts.

Figure 5. Bangkok highways inundated in 2011 during the largest flood in recent history in the region.
Source: http://www.mowe-it.eu/wordpress/thailands-strategy/

Previously, floods have been controlled by the government of Thailand through grey infrastructure, such as the construction of multi-purpose reservoirs and dikes, to contain floodwaters. This method has been successful in reducing the impacts of flooding events through reducing their extent, however the infrastructure is expensive and flood water might rise faster than with no infrastructure, increasing the overall flood risk. Further projects to better manage floods were initiated by the Thai government following the 2011 disasters, including the construction of larger flood ways, flood barriers, reservoirs, and a better data management system (Jikkham & Wipatayotin 2014).

On the other end of the spectrum, very little rain falls during the dry season (from November to April) in the Chao Phraya basin due to the seasonality of Thailand's climate, making droughts a regular occurrence as well. They are especially problematic in causing saltwater intrusion in the Chao Phraya River, when the rainwater and dam flows are not sufficient to keep the saltwater from the Gulf of Thailand from entering the river. A significant reduction in dry season rainfall in 2015 meant that Bangkok struggled to provide water to its residents, asking farmers to refrain from irrigation of rice patties and causing large losses in agricultural production that season (Tang 2015).

The government of Thailand is now developing strategic plans to act as guidelines for proper water management for the next 20 years (Apipattanavis et al. 2018). The plans take economic, social and environmental issues into consideration and include (i) integrated water resource management; (ii) government policies and the national economic and social development plan; and (iii) the United Nation's Sustainable Development Goals (Apipattanavis et al. 2018).

2.1.2 Lake Victoria

Similarly, the Lake Victoria basin faces continual threats from serious floods and drought, with most rainy seasons resulting in at least one flood event. River flooding is the predominant type of flood event in Kenya (Gichere et al. 2013) and in recent years, changes in rainfall and temperature weather patterns have increased the number and severity of floods and dry seasons in the whole basin. The water level within Lake Victoria has experienced great fluctuations in the last century due to irregular seasonal and annual rainfall, with implications for water users at the source of the basin and downstream.

Precipitation pattern changes in the basin cause more intense and unpredictable flooding, and drought events not only affect the availability of water resources, but also the health of aquatic ecosystem and the main socio-economic activities in the basin. Major reductions in food production, availability of water and ability to generate hydroelectric power are the consequences of drought events in the Lake Victoria basin. Flood disasters have their own troubling impacts in the basin, including the displacement of people, increqsed disease prevalence, and the loss of properties, livelihoods, and in extreme cases, life.

With the risks and hydrological uncertainty created from more common occurrences of extreme weather events, managing resources in this region becomes increasingly difficult. This challenge for management is magnified in a transboundary river basin of five countries, where there is competition for water resources and different systems for monitoring and managing these resources.

2.1.3 Volta

Finally, like the other two pilot basins, floods and droughts are also a prevalent occurrence in the Volta basin, especially in recent years. Ghana has the highest risk of water related hazards among the Volta basin countries, particularly in the north of the country. Major floods in northern Ghana over the past 25 years have caused the destruction of thousands of hectares of farmland, and a serious flood in 2007 caused the death of 56 people, affecting more than 300 000 others.

The upper and mid regions of the basin, including Burkina Faso, experience droughts on a regular basis. These droughts negatively affect food production and other agricultural products, as the rainfall and reservoirs for irrigated agriculture cannot meet the needs during periods of water scarcity. In addition, during these periods of water scarcity, the hydropower production potential from the Askombo dam is significantly decreased. This has serious impacts for the people of Ghana, who rely on this hydropower for much of their electricity needs. Severe droughts in 2006 and 2007 meant major energy shortages to several industrial sectors in Ghana, thus affecting the region's economic stability and potentially reducing foreign investments by investors who do not wish to risk the likelihood of an unsteady energy source.

Increasing changes in the climate further threatens the stability of the climate in the Volta basin. The predicted negative impacts of climate change in the basin include increasing temperature, reduced rainfall and reduced availability of water, water quality deterioration, reduced hydropower production, spread of water-related diseases and increased poverty.

2.2 Data Availability and Sharing

The severity of these extreme weather challenges highlights the urgency to improve the ability to recognise and address flood and drought risks as well as to improve resilience and cooperation within river basins and amongst end-users. Basin authorities, water utilities and other regional stakeholders need to cooperate to make adequate short- and long-term plans based on sound data (Pongpiachan et al. 2012). This recognition leads to the second problem that exists across the three pilot basins; the lack of data; and where data exists, lack of access, as well as poor technical and planning capabilities to be able to forecast and prepare for floods and droughts.

Across the three pilot basins, varying degrees of data availability, sharing and ability to interpret information exist. In the Chao Phraya basin, a significant level of data and programs exist including climate, hydrological and geophysical data as well as decision support systems to address issues such as flooding, however there are still challenges with sharing that data across different stakeholders, specifically the large number of government agencies. Meanwhile in the Volta and Lake Victoria basins, there is limited data available for authorities and water utilities to use. Historical data sets are minimal, and often data that exists is not reliable due to limited resources to validate it. In addition, the limited resources of basin authorities hinder the capacity to fully engage in projects such as the FDMT, particularly in the Volta and Lake Victoria regions. These restrictions in the two African basins also reflect the situation in many other developing countries.

While a data sharing protocol does exist in the Lake Victoria Basin, designed to improve data availability between basin countries, local stakeholders have found that this protocol is not useful for sharing data and is not functioning as its intended purpose. A stronger protocol or a different method for collecting and distributing data is necessary for water utilities and basin organisations in the Lake Victoria region to access and use the information required for planning for droughts and floods.

2.3 Previous Solutions

Two projects in the Chao Phraya basin have worked on the potential to improve data and management for flood and drought planning. The *Integrated Study on Hydro-Meteorological Prediction and Adaptation to Climate Change in Thailand* (IMPAC-T) project was initiated in 2009 by universities in Thailand and Japan, with support from the Japanese Science and Technology Research Partnership for Sustainable Development. It bridges sectors, including academia, funding agencies and operational authorities, to enhance observation data, develop integrated water resource simulation models and better understand climate change (Davis et al. 2015). It concluded in 2014 and is continued by the new project, *Advancing co-Design of integrated Strategies with Adaptation to Climate Change in Thailand (*ADAP-T), which promotes dialog between government, citizens, and other stakeholders to construct an adaptation strategy to climate change impacts such as floods and droughts (IMPAC-T 2016).

In addition to these initiatives, the *Development of Climate and Disaster Risk Assessment and Application of Risk Information in Development Planning in Thailand* (THPRA) project was implemented in two provinces of the basin from 2015-2016. Supported by the United Nations Development Programme and several Thai national agencies, it produced a user-friendly guideline for conducting climate and disaster risk assessments.

In the Lake Victoria basin, there have been several programs established to address water problems, but few to address flooding and drought directly. Key examples of large projects underway in the region are the *Lake Victoria Environmental Management Program*, aimed at addressing environmental degradation, as well as the *Lake Victoria Water Supply and Sanitation Programme* and *USAID Sustainable Water and Sanitation in Africa projects*, both focused on improving the delivery of water supplies and health of people in the basin.

Several external organisations have programs operating in the Volta Basin to improve institutional capacity for transboundary water management. These organisations, such as the Agence Française de Développement (AFD), African Development Bank (AfDB) and the Global Environment Facility (GEF), work to promote stakeholder communication and consultation in the Volta basin, as well as helping to collect and share hydrological data. Efforts have been put in place to re-inforce the hydrometric network in the Volta basin. A Hydrological Information System on the water resources of the basin is being established under the Volta-HYCOS project which started in 2006. The *West African Science Service Center on Climate Change and Adapted Land Use (*WASCAL), funded by the German Federal Ministry of Education and Research (BMBF), is a large-scale, research-focused Climate Service Centre designed to help tackle climate change related challenges and enhance the resilience of human and environmental systems to the increased climate variability. WASCAL collects a large amount of data, and stores them on an online public data-exchange platform on the WASCAL Data Infrastructure, to facilitate the acquisition, management and exchange of data resources.

Despite the current projects operating in these basins, there is still a clear need for a data sharing tool with management instruments to assist in the planning for and management of flood and drought events in these basins.

3. SWM Solution

Building on the previous projects listed above to address the challenges of flood and drought risks in the pilot basins as well as providing a generic solution that can be applied in any transboundary basin, the Flood and Drought Management Tools project proposes a new methodology. The FDMT methodology uses a collection of SWM applications to provide stakeholders in transboundary basins with a package of resources to support short-term (operational) and long-term (strategic) planning. The applications are essentially components of an online Decision Support System (DSS); the Flood and Drought Portal, to support robust risk planning and analysis processes in transboundary basins, improving preparations and resilience for extreme weather events.

The project developed technical tools to support flood and drought planning processes which, previously, may not have fully exploited the information available. The project also aimed to develop an approach and tools that work both on a transboundary level and the local level. GEF International Waters projects have planning methods which focus at the transboundary level. However, decisions made at the regional level (basin) and the local level need to be linked to plans at a larger scale. The project will address this aspect of inter-level communication by providing tools for both scales within a single DSS.

The FDMT project provides climate and water related data and planning applications at different scales to support the baseline and impact assessments. The DSS, in the form of the Flood and Drought Portal, facilitates the inclusion of information about floods, droughts and future scenarios into short- and long-term planning activities based on the predefined processes outlined in Table 1. The types of planning supported include the processes developed by the GEF – TDA and SAP, as well as general IWRM at the basin level and WSP at the utility level. Another aspect of the FDMT project is using an approach that works both at the transboundary and local level. As such, IWRM is used at the basin level to support planning of WSP at the local (water utility) level.

Table 1. The planning and management processes supported by the FDMT applications.

Process Name	Acronym	Description
Transboundary Diagnostic Analysis	TDA	A tool developed by GEF IW to address environmental problems that are transboundary in nature through identifying, quantifying and setting priorities, using the best available scientific evidence.
Strategic Action Programmes	SAP	Builds on the priority threats identified in the TDA process, to outline the actions needed to resolve these threats, specifically in transboundary waters.
Integrated Water Resources Management	IWRM	A process of planning that integrates the management of several inter-related aspects, including water, land and other related resources for improved sustainability of these resources.
Water Safety Plans	WSP	An approach to mitigate risks through using comprehensive risk assessments that address health related risks and provide an analysis of all steps in the water supply from catchment to consumer.

The technical applications can be used individually or together to create one integrated workflow area in an online platform, that is available to basin organisations and local users, including water utilities to inform their respective planning approaches (see Figure 6). The online Portal is the entry point for end users to access data and information from models, indicators and planning approaches to support planning and resilience building against floods and droughts in the basins.

It is recognised that stakeholders and users require the appropriate capacity to be willing and able to interpret technical data and different planning techniques, such as the SWM solutions presented by the FDMT project. As such, an important aspect of the FDMT methodology is also around capacity building, user engagement and information dissemination. This involves working with stakeholders to build tools that are most relevant to them, training users in how to interpret data and use such tools as well as integrating the technical tools into their existing planning practices. As part of this step in the project, consultations and training sessions with stakeholders in the three pilot basins took place, allowing input from basin and local stakeholders into the methodology and tools. This is an important aspect of the FDMT project as it contributes to the long-term sustainability of the project outputs and continuation of the tools after the project's initial four-year timeline is complete.

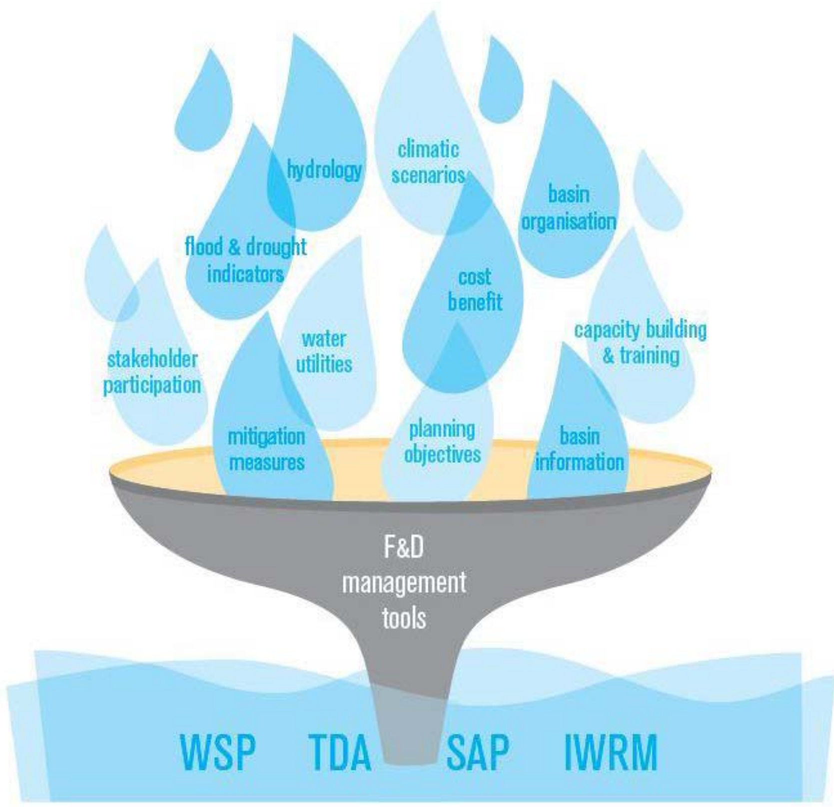

Figure 6. Infographic depicting the integration and inputs to the FDMT tools, to support different types of planning.
Source: FDMT Project Factsheet (2015)

3.1 The Flood and Drought Portal

Based on stakeholder consultations, understanding the needs and challenges described previously, and the need to support existing planning approaches described in Table 1, the FDMT project is providing relevant tools through an online Portal, called the Flood and Drought Portal. The Portal is the principal entry point for users to access all data and technical applications in one easy-to-use interface. It is versatile in that each application can be used individually or all together, applied to any global context and provides a means to disseminate information to relevant groups. Figure 7 shows the home screen of the Portal, which can be accessed at http://www.flooddroughtmonitor.com/home. The Flood and Drought Portal is free to access and is openly accessible for anyone online, with the only requirement being the need to register an account and to select one of the available basins as your working basin. Instructions and videos have been created to help users go through the registration process, which are available via the project website at http://fdmt.iwlearn.org.

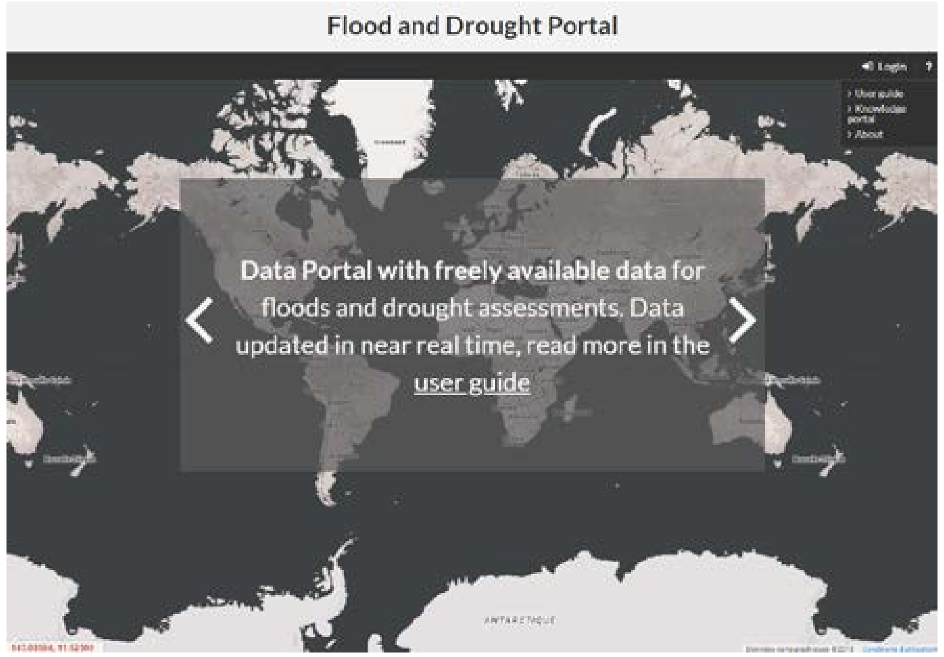

Figure 7. Home screen of the Flood and Drought Portal used within this project.
Source: http://www.flooddroughtmonitor.com/home.

3.2 Applications

The Portal contains a number of distinct applications and over the course of the project, additional applications will be added based on stakeholder input/feedback. The first of these applications, the Data and Information tool, supplies specific information regarding climate and water related data for each basin. The other applications do not provide the data itself, but rather inputs and structure for planning frameworks and templates that can be used by water managers in any basin. Figure 8 displays the list of applications, as it appears online. This section outlines a short description of each of these tools.

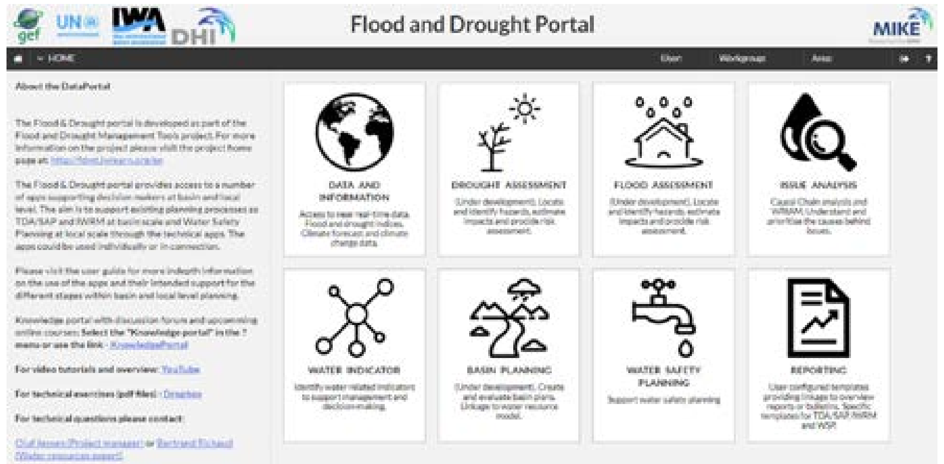

Figure 8. The menu screen of the Flood and Drought Portal, displaying the eight main applications and their uses.
Source: http://www.flooddroughtmonitor.com/home

3.2.1 Data and Information

The first tool presented by the FDMT project is the data and information application. Within this application, basin-specific information is available to users as GIS layers and time series. This information relates to data in Table 2, from the following topics and sources:

- Climate
  - TRMM, CHIRPS, CRU, GPM, PERSIANN rainfall
  - Temperature and PET
  - Flood index and combined drought index
- Forecast and climate change
  - Seasonal and 2-week forecast (NOAA)
  - Climate change (CORDEX)
- Vegetation and soil moisture
  - NDVI
  - Soil Water Index
  - Agricultural stress index
- Water levels in lakes and reservoirs
  - JASON data
- Physical and Socioeconomic data
  - Population
  - Urban expansion
  - Flood risk

Table 2. Available data in the data and information application of FDMT.

Climate	Vegetation	Soil moisture	Socio-economic	Drought and Flood Indicators
Key input for environmental assessment • Historic • Near real time • Forecast • Projection	**Impact on agricultural sector** • Crop distribution and crop growth • Historic • Near real time	**Water availability** • Drought assessment • Flood risk • Historic • Near real time	**Socio-economic impact** • Static data • Historic • Future	**Hazard assessment** • Statistical measure providing a clear indication of a state

The tool makes up a basic data set of spatially distributed information needed to produce a baseline assessment, available as near real time satellite data (approximately 48 hours), short term and seasonal forecast data for up to nine months in advance, and climate projections. Furthermore, users have the ability to download data as raster files into a commonly used netcdf or csv format, which is compatible with most GIS tools.

The FDMT project does not itself generate the climate data, but rather collects it from other sources (e.g. NASA: https://lpdaac.usgs.gov/dataset_discovery, Copernicus(ESA): http://land.copernicus.eu/, NOAA: https://www.ncdc.noaa.gov/data-access) and processes the information before making it available in the application and relevant for decision making. As mentioned in the previous section, there is limited access to data, particularly in the African pilot basins, prompting a need to provide a basic set of data. As such, the data provided in the application originates from global and freely available data sets and, satellite based information. Accessing satellite data allows the inclusion of other transboundary basins within the FDMT methodology. The process for making data available within FDMT includes acquiring, managing and processing the data by DHI. Quality assurance of the data sets and conversions to the appropriate file type and spatial region happen during this data processing, before being pushed to the web-server. While real time data was not deemed necessary to meet the objectives of the project, near real-time data was seen as critical for assessment and identification of drought and flood hazards. One of the criteria for this type of data selection was the ability to retrieve and process the data in as close to real time as possible.

Within the data and information application of the Portal, users view a map of the focus area (basin) which the user selected during the registration process, over which the selected data layers are displayed. The application contains a list of all available data types, each with a corresponding description box available when the data type is selected. This description briefly explains the information and provides the original source link. For data which derives from satellites, the description box also includes the spatial and temporal resolution, satellite name, as well as dates and scope of coverage. A more detailed description of available data sources can be found within the user guide for the data and information application.

Once users have chosen the data they would like to work with in the application, these data sets are available for viewing and analysis. Spatial data can be overlaid on the focus area map for specific dates and using a legend of colours to depict values related to that data type. Figure 9 gives an example of the display of the rainfall (TRMM) data set, showing the spatial spread in the Chao Phraya basin for 25 July 2017. The tool operates on different spatial resolutions, producing area weighted time series for the entire basin, the user location, subarea layers and point locations.

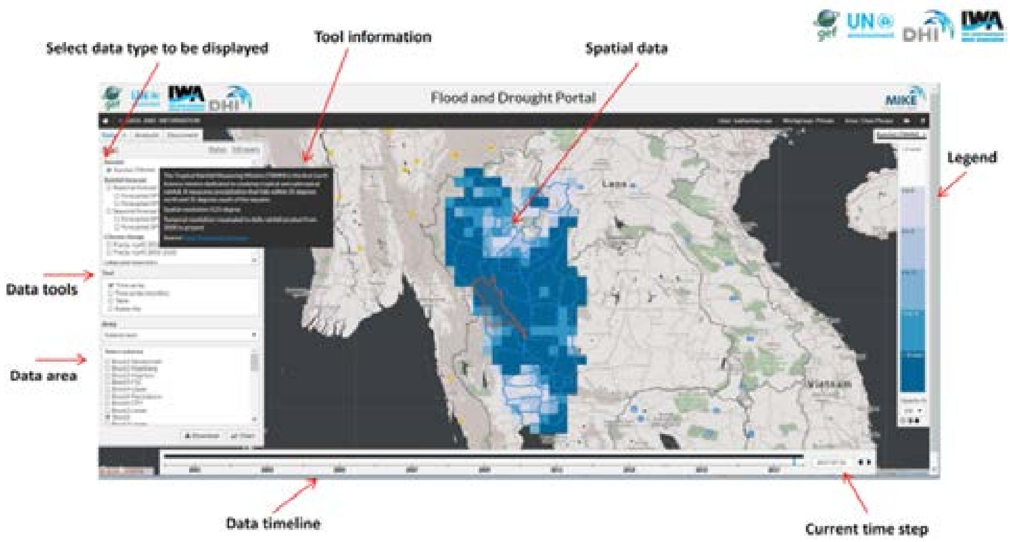

Figure 9. Screenshot of the data and information application displaying a sample of available data, and information box for selected data set.
Source: Jessen & Cross, 2018.

After data selection, there are different options for processing and analysing such data in the application. Depending on the data type, the information can be accessed using tables or plotted onto charts for time series across several time frames or as envelope or column plots. Figure 10 gives an example of a time series plot for monthly rainfall in the Volta basin in 2017. The data and information application also includes a variety of flood and drought indices to determine the current and forecasted hazards. For example, the combined drought index is composed of three warning levels (watch, warning and alert) by integrating three drought indicators: standardised precipitation index (SPI), soil moisture and remotely sensed vegetation data.

CASE STUDIES
FLOOD AND DROUGHT MANAGEMENT TOOLS CASE STUDY

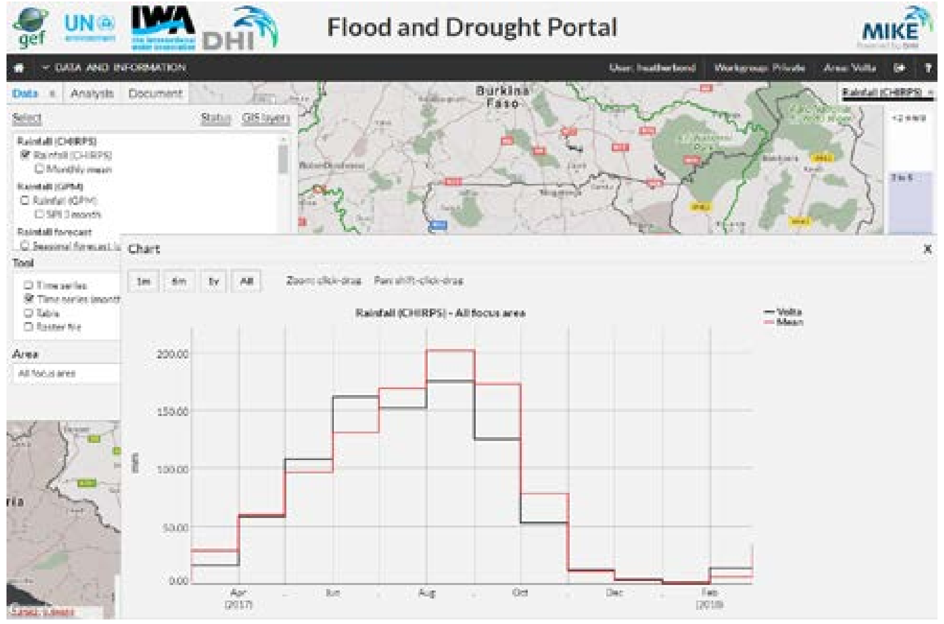

Figure 10. Screenshot of the output from the time series tool of the data and information application, displaying a monthly rainfall plot for the Volta basin from CHIRPS. This could be useful as a medium term drought forecasting application.
Source: http://www.flooddroughtmonitor.com/home

Finally, a document menu of the data and information application lists and gives access to relevant reports. The documents can be fact sheets with more information on specific data types, videos showing the temporal and spatial change of a data type, custom made drought reports or other documents associated with the specific focus area.

3.2.2 Flood and Drought Assessments

Both the flood and drought assessment applications establish prediction and early warning systems as part of a proactive risk management process, through identifying current and upcoming hazards as well as their associated level of risk. The main objective of these applications is to detect when and if a drought or flood hazard might occur, along with the location, and severity of this hazard.

The procedure for completing a flood and drought risk assessment begins with determining the location and timing of a flood or drought event, followed by quantifying how the area and sectors exposed to this hazard will be impacted. After the impact assessment, a vulnerability analysis examines the causes behind the drought or flood impact and the priority of these causes. Vulnerability analysis provides the means for interventions or mitigation measures to be targeted specifically against the underlying causes for the drought or flood impacts. While the flood and drought assessment applications function similarly, they are slightly different. The drought assessment application provides warning and risk analysis, whereas the flood assessment application mainly focuses on selected datasets and indicators as well as a rainfall runoff model to predict extreme events.

Hazard identification is the first step users are prompted to complete within the drought assessment application. Identification uses different types of indices to detect the location and timing of hazards. Drought indices cover the entire spectrum of drought types: meteorological, agricultural and hydrological drought. In the drought assessment application, a warning menu allows users to choose from drought and rainfall indices which are layered over the basin map, with an adjustable threshold value set by the user that highlights the areas affected by a specific hazard (see Figure 11). An information dialogue box can be opened for each index, describing the data set, its source, coverage dates and calculation, if applicable. This warning application is important for supporting the detection of upcoming drought events across the basin.

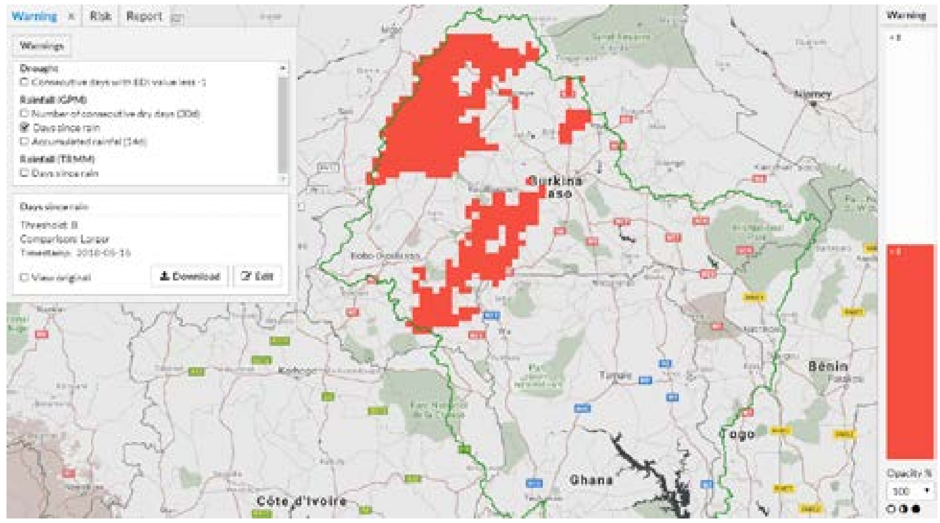

Figure 11. Screenshot for the drought assessment application, showing the available warning indices, threshold value and warning legend for 'Days since rain' index in the Volta basin.
Source: http://www.flooddroughtmonitor.com/home

The other key tool within the drought assessment application is the risk menu, which has an interface for impact assessment and vulnerability analysis for the identified drought hazards. The main output of this page is a map with overlaid hazard and vulnerability values (see Figure 12). The vulnerability tool supports the understanding of exposure to the hazard through layering raster files of sensitive regions over the hazard graphics. Areas are particularly sensitive and exposed to drought events through impacts such as reduced crop yield, livestock losses, socioeconomic impacts or reservoir depletion. This is assessed in the application by delineating areas that rely on rainfed irrigation or urban areas relying on surface water resources. The risk assessment uses the combination of the hazard and vulnerability elements, as risk is often expressed as hazard x vulnerability. This risk analysis identifies areas or groups at different risk levels, which will then be the targets for adaptation or mitigation planning.

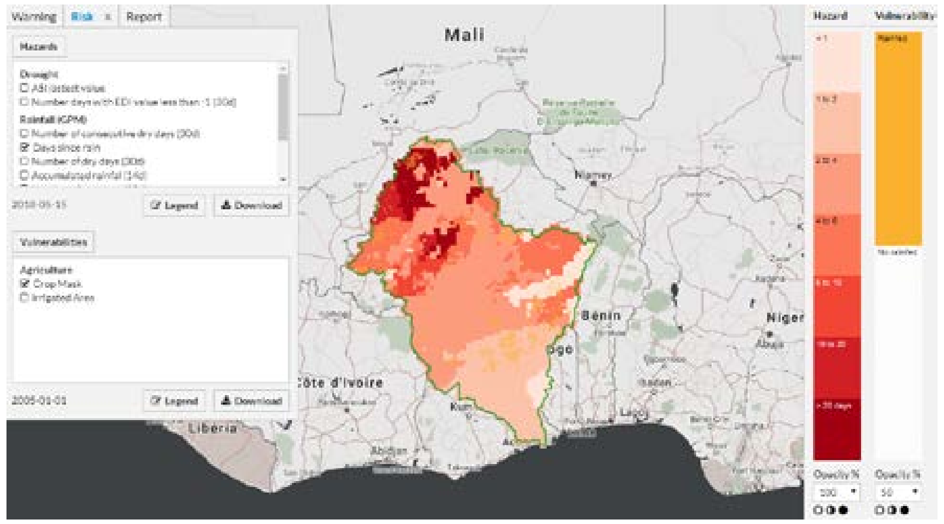

Figure 12. Screenshot of the drought assessment application for 'Days since rain' risk and 'Crop mask' vulnerability in the Volta basin.
Source: http://www.flooddroughtmonitor.com/home

Similarly, the flood assessment application supports detection of flood events through providing flood indices and risk assessment tools. These indices are also overlaid on the basin map and are based on data from flash flood potential index, rainfall measurements, global surface water, and medium range rainfall forecasts (see Figure 13). Other tools within the flood assessment application are the creation of charts and tables using the indices and a rainfall runoff function that has the ability to show historic and future runoff, evapotranspiration, recharge and rainfall. An analysis tool for rainfall runoff is also available within the flood assessment application, where users are able to run simulations of rainfall runoff using climate data within the application, based on the NAM hydrological model.

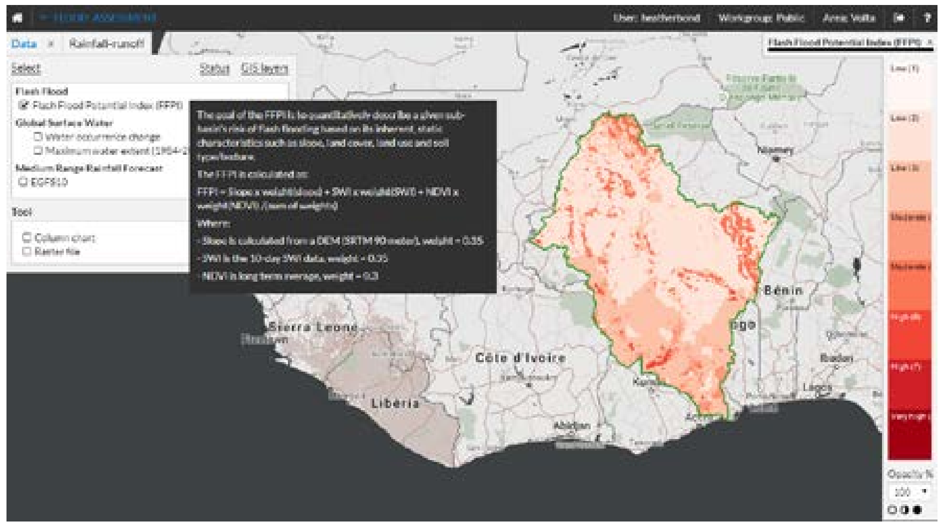

Figure 13. Screenshot of the flood assessment application for 'Flash Flood Potential Index' with the information box, data layered over the Volta basin map and legend.
Source: http://www.flooddroughtmonitor.com/home

3.2.3 Issue Analysis

The issue analysis application is designed to identify and analyse key environmental issues affecting water resources in a region. The application also examines and evaluates the causes behind associated impacts of each environmental issue based on the Causal Chain Analysis (CCA), a method using an ordered sequence of events linking a problem's causes to its effects (see Figure 14). After the identification of issues and causes, a rapid assessment prioritises the issues according to the level of severity. This is based on the Water Resource Issues Assessment Method (WRIAM), a process which provides an evaluation of a given issue, a value which can be used for comparison with other issues and a record that can be re-assessed in the future. Ultimately the issue analysis application assists users in understanding the deeper causes contributing to environmental issues such as droughts and floods, and in assessing the severity of each problem, so that they can shape their planning activities accordingly.

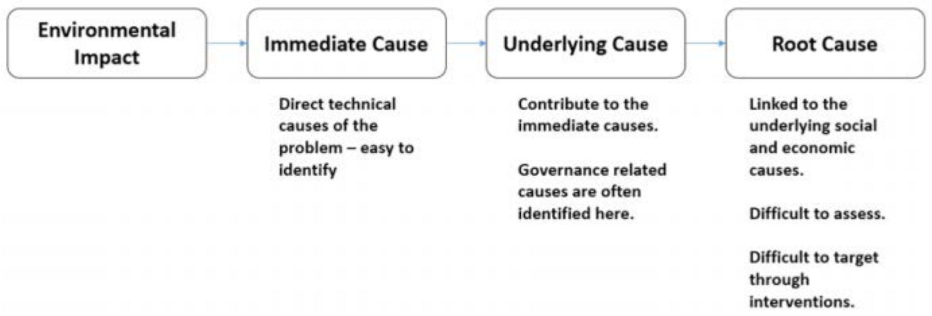

Figure 14. Main components of a Causal Chain Analysis.
Source: http://www.flooddroughtmonitor.com/home

To begin use of the issue analysis tool, users add an environmental issue, such as water quantity and seasonal flows, then characterise this issue. Characterisation of the issue is according to defined parameters including its immediate impact, as well as the immediate, underlying and root causes. The remaining parameters fall into two groups of assessment criteria (see Table 3) and are scored by a numerical value according to the standard definitions from WRIAM. The overall assessment score is calculated by multiplying the results of both groups together. This score relates to an assessment level of the severity of the issue, from no importance to slight, moderate, significant and major negative impact. Figure 15 displays a screenshot of an example of assessment scores for impacts of the environmental issue 'water quantity and seasonal flows'. This assessment can then be used to compare issues and make decisions as to which issues need the most immediate management attention.

Table 3. WRIAM assessment criteria used to score a given issue in the issue analysis application.

Description	Group A Criteria related to the importance of the issue or effect, and which can individually change the score obtained considerably.	Group B Criteria that are of value to the given situation, but individually have a lesser effect on the score obtained.
	Spatial extent (A1) Seriousness of impact (A2)	Permanence (B1) Irreversibility (B2) Cumulative Character (B3)
Group result	At = (A1) x (A2)	Bt = (B1) + (B2) + (B3)
Overall score	At x Bt	

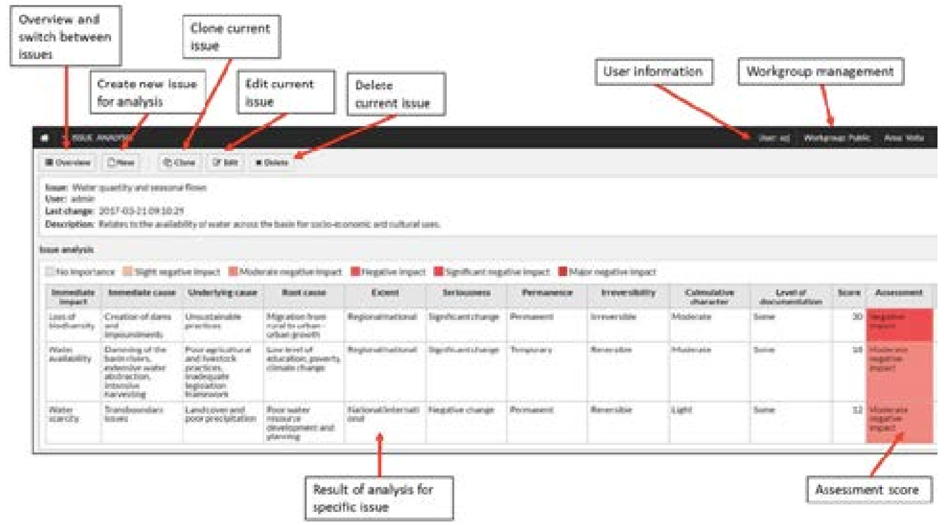

Figure 15. Example of an issue analysis for 'Water quantity and seasonal flows', showing the main functionality within the issue analysis application.
Source: http://www.flooddroughtmonitor.com/home

3.2.4 Water Indicator

The water indicator application can be used to select indicators for measuring the state of specific issues. It is a library of indicators which can also be set with a user defined framework to shape topics with all the data needed for planning. There are several default frameworks with a selection of indicators which can be used to help shape an IWRM plan, or a framework for water utilities needing to monitor upstream risk.

Indicators monitor the current state or the pressure of a specific issue, through providing the status of a parameter. The indicators and platform for displaying this information in the tool help users better understand the current state of water resources in their region, the changes in these resources and whether interventions produce the desired effect.

Overall, the water indicator application is a learning tool for basin or catchment users and provides the following specific support:

- Assists users in selecting relevant indicators based on a specific issue
- Provides a starting point through a default indicator framework that can be adjusted and complemented to match user needs
- Provides an online tool for stakeholders to share their indicator frameworks with others to allow for consistency
- Used as a tool for storing indicator information to support management and planning

The indicators and the indicator framework are the two key ingredients in this application, which holds a library of indicators, each with a detailed description in a pdf metadata sheet. In the tool, when an indicator is selected, an information box provides a description and keywords (see Figure 16), with the metadata sheet which includes the main group category, the purpose of such an indicator, the policy relevance, its usage and interpretation, calculation instructions, data outputs and sources. The tool also allows users to search within the library and add new indicators. As of early 2018, more than 100 indicators have been input into the application. Examples of existing indicators include climate data such as rainfall index, monthly average changes in temperature, groundwater levels, climate moisture index, to social- economic data including social water stress index, mobile phone access and populations served by wastewater services.

It should be noted that the indicator metadata sheets were derived from the River Basin component of the Transboundary Water Assessment Programme, also funded by GEF IW.

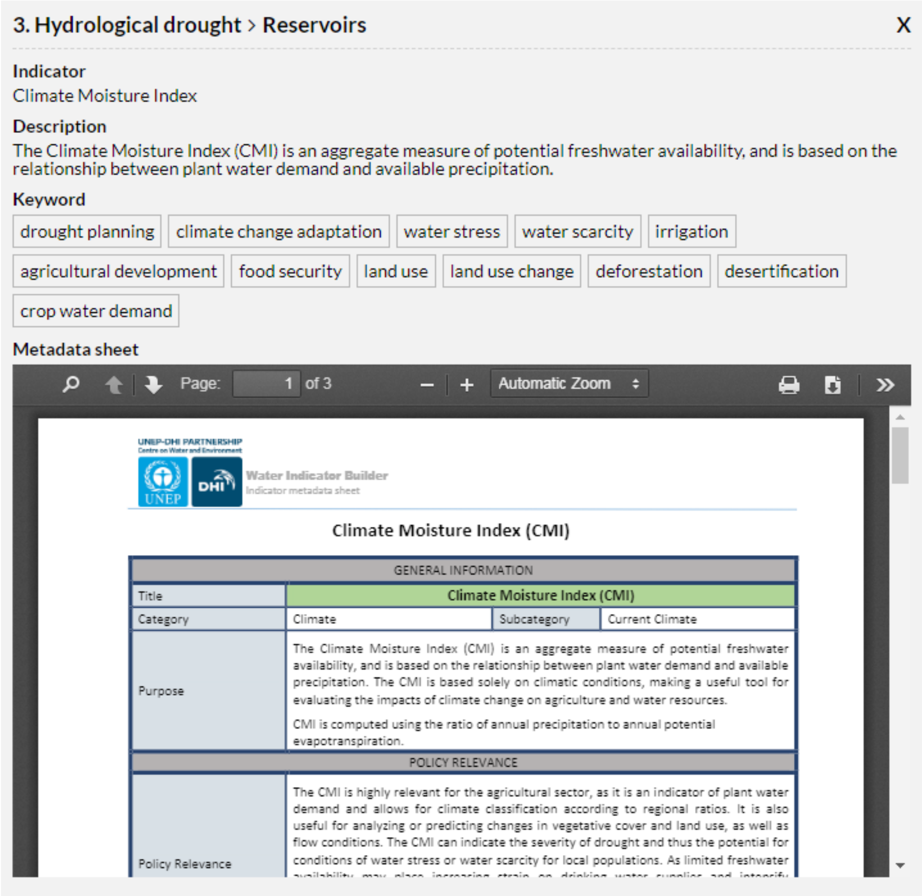

Figure 16. The information box for an example indicator, Climate Moisture Index, within the Water Indicator tool of the Flood and Drought Portal.
Source: http://www.flooddroughtmonitor.com/home

Building on the list of indicators, a framework applies these indicators to monitor the state of specific issues. As mentioned above there are several frameworks targeted at specific topics, with default options of river basin planning, flood, drought and water utility. Each of these frameworks contains grouped indicators, forming a tabular description that depicts the links between the issue and their respective indicators. Once the framework topic is selected in the application, there are main- and sub-group indicators, under which lists of all the indicators that apply to that category are shown. Figure 17 displays an example framework for drought.

Another feature of the water indicator tool is that it is possible to view the various issues and the causes behind these as entered into the issue analysis application. A user can then add indicators from the indicator list or a framework for the immediate impact, immediate cause, underlying cause and root cause.

This water indicator tool provides a template and resource for water managers at the basin and local scale to monitor the most relevant data types for a specific issue, such as floods and droughts.

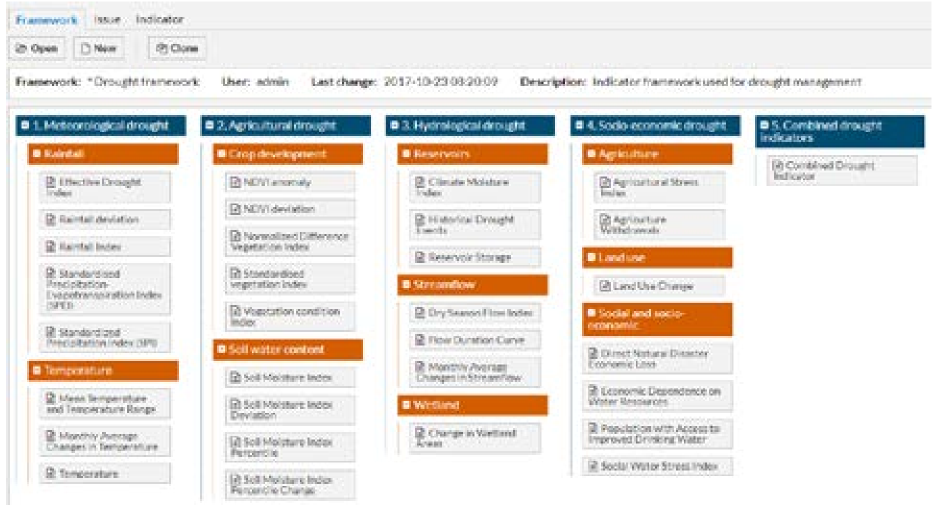

Figure 17. Example of a template Indicator Framework for drought, depicted by a screenshot from the water indicator application. Main indicator groups are numbered in blue, sub-group indicators are in orange and the indicators themselves are listed underneath in grey.
Source: http://www.flooddroughtmonitor.com/home

3.2.5 Basin Planning

The basin planning application uses the refined water resources model and planning tools to support the evaluation of various plans, targeted at decision makers without any modelling expertise. The tool begins by providing a baseline model plan of the specific water basin, previously established in the backend of the Portal. Users can create new plans on top of this baseline using a combination of identified and clearly defined investments and external factors (see Figure 18). Each plan or scenario is represented by a series of these inputs to the model.

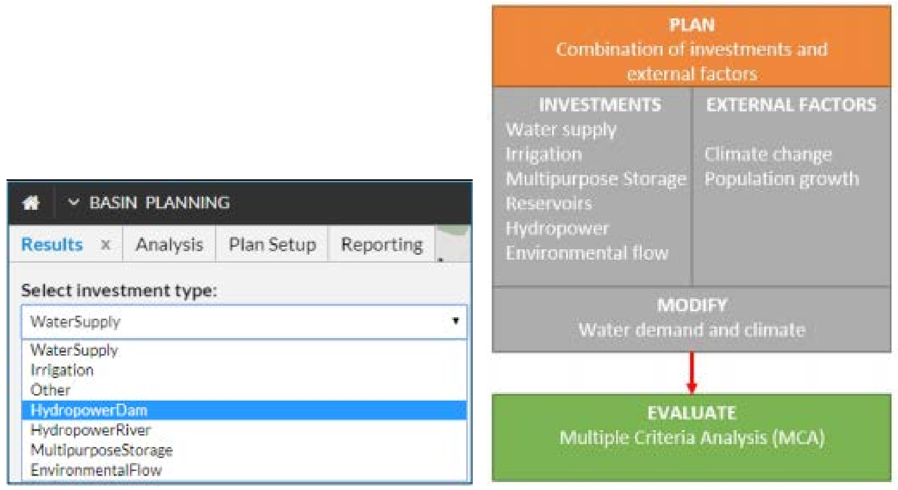

Figure 18. Components and concept of the basin planning application (left) and screenshot of the investment types within the application (right).
Source: http://www.flooddroughtmonitor.com/home

Once the scenario model with the input factors is executed, the available indicators are calculated, the results are stored, and an email is sent to the user when the plan is available. Users can evaluate the resulting outputs of this plan through reviewing the indicator values, presented as tables, charts and on the basin map. Currently available indicators include annual energy production produced by hydropower schemes (GWh), annual reliability of water supply as the magnitude given a certain demand (m^3/s), or as a fraction of demand supplied at a chosen level of probability of exceedance (%), groundwater sustainability index, net present profit value, reservoir status and reservoir status probability. Based on this information, the user is able to create strategies with weighting systems attributed to indicators expressing different policy and strategic focuses. These strategies allow a comprehensive evaluation of the proposed new plan to support informed decision making by users.

Analysis of different plans within the Basin Planning application can be done by comparing key indicator results, as well as by running a simple Multi Criteria Analysis (MCA) and comparing the MCA results. The MCA provides a structured framework for comparison, using a scoring matrix to calculate relative scores based on the weighted strategies previously assigned (see Figure 19). The final result per plan and per strategy, allows a ranking and prioritization of each plan under the weighting scheme carried by each strategy (see Figure 20). The ranked list of plans combines indicator results on the same relative scale, thus reflecting overall plan preference. The plan scoring the highest total relative weighted score can be ranked as the most preferred plan. Moreover, the evaluation can be made into reports that users can export for external use.

Figure 19. Schematic of steps within the analysis of plans in the FDMT basin planning application.
Source: http://www.flooddroughtmonitor.com/home

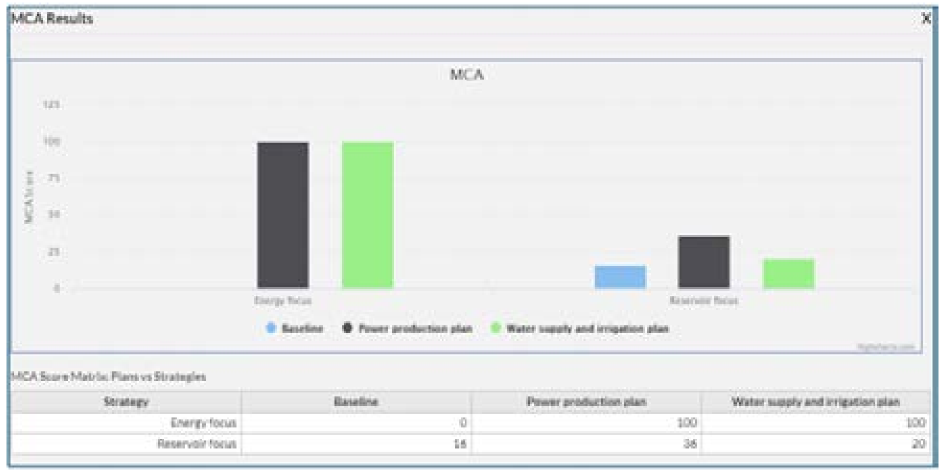

Figure 20. Screenshot of an example MCA result from the basin planning application.
Source: http://www.flooddroughtmonitor.com/home

As of early 2018, the basin planning application was still under development, although it has been tested in the Lake Victoria basin.

3.2.6 Water Safety Planning

It is expected that climactic events such as floods and droughts will have severe impacts on the operations and long term management of water utilities and the quality of drinking water they supply to consumers in their regions, such as in the Chao Phraya, Lake Victoria and Volta basins. Water Safety Planning (WSP) is an approach to protecting drinking water supplies by applying a comprehensive risk assessment and risk management measures along the entire water supply system, from catchment to consumer. Through this approach, WSPs aim to consistently ensure a safe and acceptable supply of drinking water.

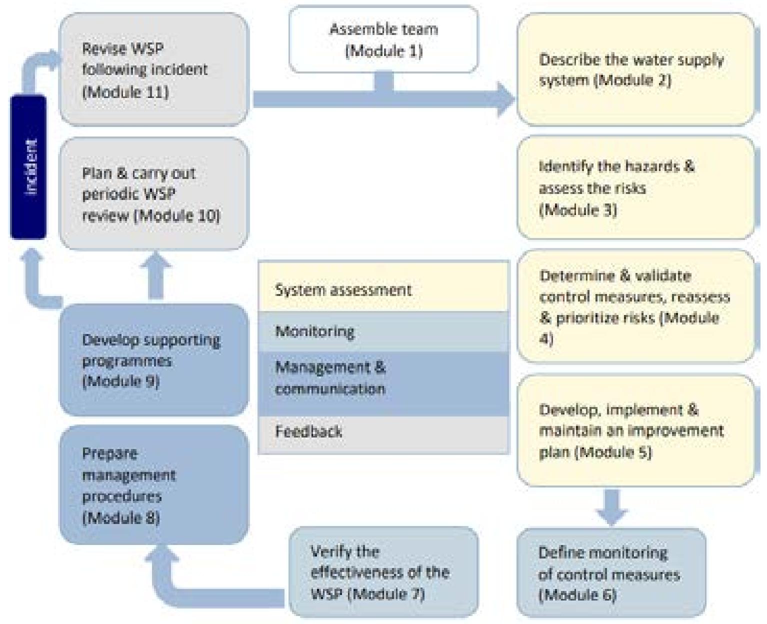

Figure 21. Schematic of the eleven modules making up the Water Safety Planning process.
Source: http://www.flooddroughtmonitor.com/home

The WSP application Portal covers the eleven modules associated with development and implementation of the WSP process (see Figure 21). The application aids in the use of the WSP process through the provision of a user-friendly template to prompt the entry of applicable information for each module. The application has a table of contents with eleven modules as defined in the 2009 WHO/IWA Water Safety Planning Manual. Selecting a module opens its relevant dialogue box, which can be edited to input data (see Figure 22). Through this approach, the application guides users to complete a system assessment of all the steps within the water supply system, determining current and future hazards and risks along this pathway then determining control measures including monitoring of controls for each risk. All of this information can be input by users into the application under specified categories and tables. For the monitoring, management and supporting programmes components of the WSP process, the application provides a space to upload relevant documents in various formats. A form can be filled out for the revision components of module 10 (Plan and Carry out Periodic Review of the WSP) and module 11 (Review the WSP Following an Incident), which prompts the input of information such as changes to the water supply system and management to ensure the WSP is up to date.

Throughout the WSP application functionality, information boxes can be accessed which describe the specific module and its components in more detail, as well as relevant links to the Water Safety Portal (see Figure 23). The Water Safety Portal is an online network focused on the implementation of WSPs. It gives further information on the WSP process and its modules, provides a variety of related resources, such as WSP related news and events and discussion forums to share experiences. Moreover, the Water Safety Portal links to the World Health Organisation/ IWA (2009) Water Safety Plan Manual.

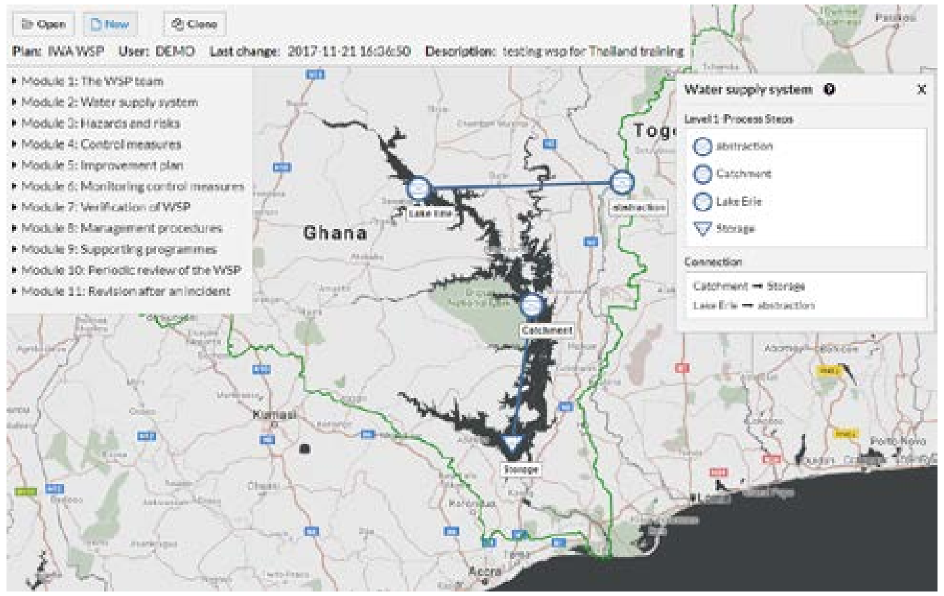

Figure 22. Screenshot of Module 2 dialogue box within the WSP application of FDMT.
Source: http://www.flooddroughtmonitor.com/home

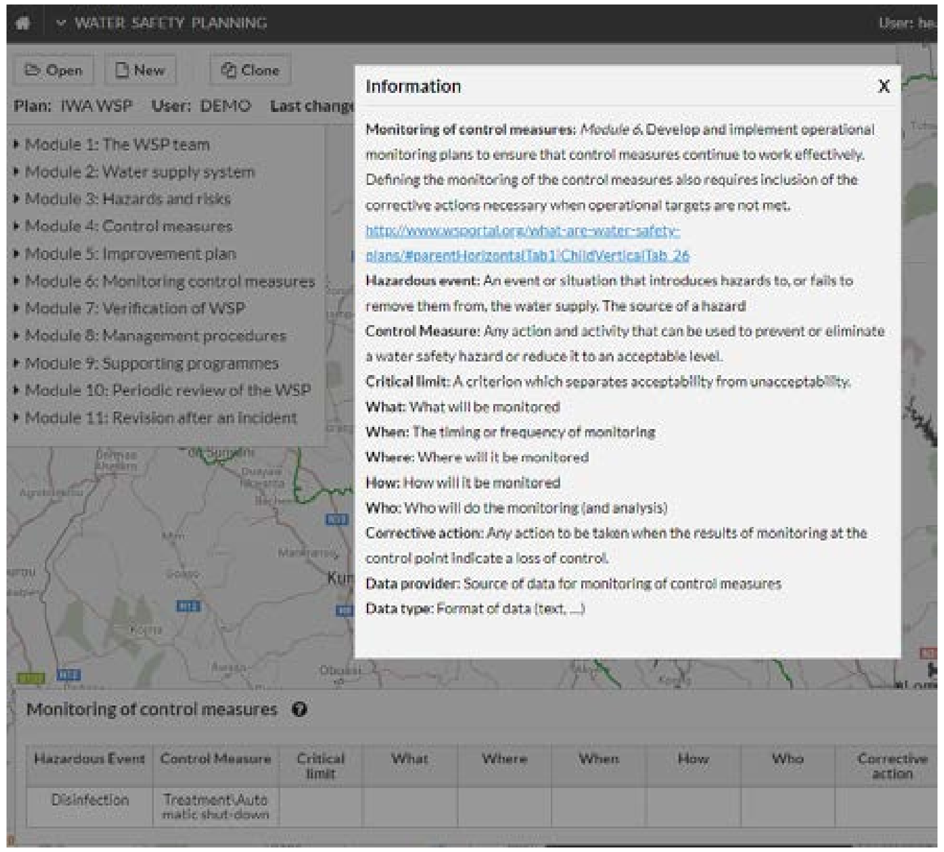

Figure 23. Screenshot of an Information box for Module 6 (Monitoring control measures) in the WSP application.
Source: http://www.flooddroughtmonitor.com/home

3.2.7 Reporting

Tool offered through the Flood and Drought Portal, is the reporting application, aimed at encouraging information dissemination to stakeholders regarding the plans and background of the decision making process. This information can take various formats in reports or bulletins, depending on the audience and the specific content. As such, the reporting application of FDMT is flexible in supplying different reporting templates (Word docx documents) consisting of the overall framework of the report. Each template contains a number of tags, delineated with brackets {}, where the user is prompted to insert content in the form of images, text, chart or tables to replace the tags (see Figure 24). This content links to the other FDMT applications, specifically data and information, so users can input for example charts with the latest climate information, drought hazards or other information from the Flood and Drought Portal. Users can also insert external text files. After users have downloaded the template and input the suggested information, the final report is produced as a pdf or word document (see Figure 25).

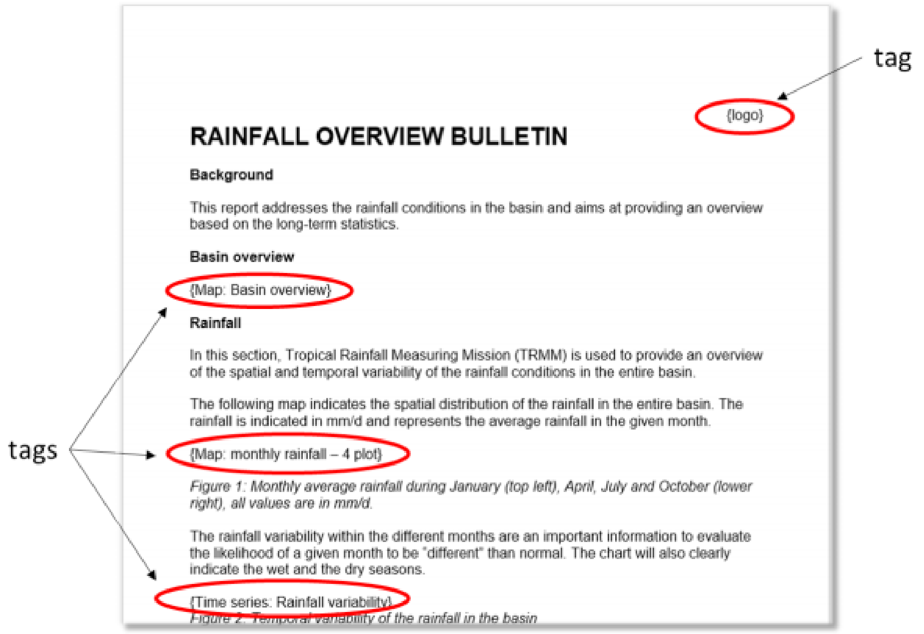

Figure 24. Example report template within the FDMT reporting application, highlighting tags for users to input specific information.
Source: http://www.flooddroughtmonitor.com/home

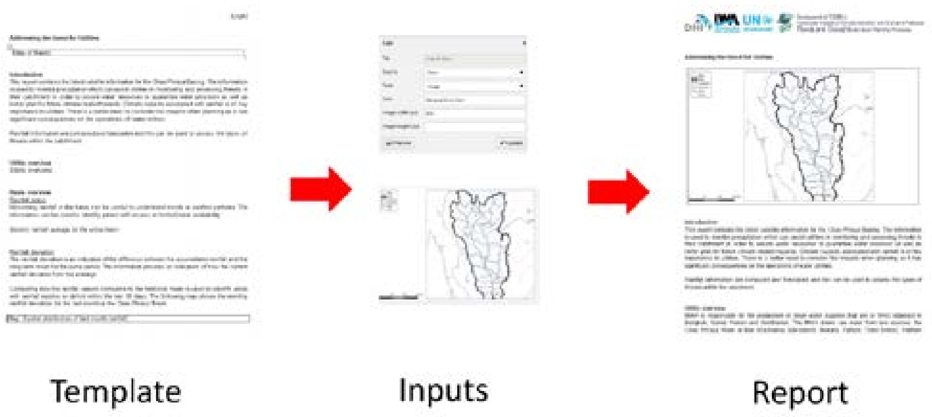

Figure 25. Schematic of the template to final reporting concept within the FDMT reporting application.
Source: Thailand water utility training presentation on Reporting Application (Jessen & Cross, 2017).

In addition, the reporting application provides a space for users to develop their own reports based on their specific requirements. This can be done by making a new report, or cloning a template report to act as a starting point for a user defined report with modified content and tags. To generate a new report, users upload their own docx template, and fill in a short description of the report. The application recognises tags when the new report is uploaded into the system and users then specify the content of each of these tags. The reporting function rounds out the package of data and planning tools in the Flood and Drought Portal by giving a space for users to create output documents based on the other applications.

3.3 Capacity Building and Communications

Communication, information dissemination and capacity building is a strong and significant aspect of the FDMT project. Several channels of communication have been developed between stakeholders and the project coordinators as well as the production of communication outputs for the general public. Involving the potential future users of the tool in the pilot basins from the beginning of the project strengthened the methodology, enabled ongoing feedback on tool development to ensure relevance and also enhanced the capabilities of the users. Additional learning tools and communication outputs, such as the project website, guidance documents, experience notes and workshops and international events are working to disseminate information on the FDMT project to local project partners and beyond.

To further distribute information on the FDMT project on a global scale, project organisers presented the project at several regional and international events. A sampling of events where the FDMT project was represented include:

- International Conference on Drought; Valencia, Spain; March 2015
- 7th World Water Forum; Daegu & Gyeongsangbuk, Korea; April 2015
- European River Symposium; Vienna, Austria; March 2016
- Global Water Safety Conference; Palawan, Philippines; April 2016
- 6th Africa Water Week; Dar es Salaam, Tanzania; July 2016
- Mekong Delta Workshop; Hanoi, Vietnam; October 2016
- 7th IWA ASPIRE Conference; Kuala Lumpur, Malaysia; September 2017
- IWA Development Congress, Buenos Aires, Argentina; November 2017
- International Workshop on Water Scarcity: Taking action in transboundary basins and reducing health impacts; Geneva, Switzerland; December 2017
- IW:LEARN Twinning event – FDMT Technical Training with basin level representatives form GEF projects; Geneva, Switzerland; December 2017
- 8th World Water Forum; Brasilia, Brazil; March 2018
- 3rd Targeted Regional Workshop for GEF IW projects in east Europe and Asia-Pacific; Bangkok, Thailand; April/May 2018

3.3.1 Stakeholder engagement

During the six month initial inception phase of the project in 2014, more than 50 stakeholders from all scales and regions within the three pilot basins were consulted. The series of stakeholder workshops helped shape the methodology of the project and make it relevant to the three regions, while also determining the level of engagement from key stakeholders as the end users of the project. Ultimately these workshops were a key element in determining how the FDMT project could aid in its goals of improving the management and planning for flood and drought events on the ground. The stakeholder consultations gathered data, identified gaps in informed decision-making, and proposed types of information that would be useful to guide both short-term and long-term planning. The key objectives of the consultations included:

- Enhance key stakeholders' understanding and endorse the objectives of the FDMT project
- Understand issues key stakeholders are facing during water planning, focusing on transboundary issues related to climate change, floods and droughts
- Understand the methods and processes which the basin organisations and water utilities go through during planning, and tools they currently use in planning
- Identify other projects or initiatives that could potentially fill issue of data collection and knowledge gaps of the basin
- Gather feedback on the proposed methodology and technical outputs of the FDMT project
- Based on stakeholder input and feedback, refine development of methodology and tools.

More than 200 people were trained through annual training programmes were conducted in each basin to build capacity to use the applications among stakeholders and to further improve the FDMT tools. In order to ensure the online tools could be useful for the local conditions in the pilot basins, which often supported only low bandwidth internet connections, the on-the-ground sessions tested its function in this environment. Separate training sessions were organised for basin-level organisations and water utilities in order to provide more targeted learning. Each session allowed stakeholders to test the tools during the training through guided steps and a series of exercises, and then provide feedback to ensure the tools' relevance and meaningfulness. The annual training sessions helped to improve the FDMT technology, ensure that the tools matched the capabilities of local stakeholders and build capacity of these stakeholders.

3.3.2 Resources & Communication Outputs

A variety of communication materials have been developed for the FDMT project to disseminate information on the project outputs to stakeholders and a wider audience as well as to encourage further learning. The project website (http://fdmt.iwlearn.org) is the hub of all project information and resources. Most material is translated into French and Thai to accommodate the language of key stakeholders in the three pilot basins. The following is a list of the different resources that are available on the project website.

Learning Resources

• User Guidance

Learning resources in the form of informational documents. The online Portal has a step-by-step user guide for each application, outlining how to use each tool. User guides include a quick overview for first time users as well as detailed instructions and explanations of all the functions of the application, with screenshots and diagrams to clearly demonstrate each function.

The user guides do not necessarily explain the practical application of the tools, so the FDMT project is also creating more detailed guidance documents on how to interpret data and how to apply the other applications. The guidance documents are most applicable to water utilities to enhance their capacity to integrate the applications in their daily work to inform decisions and management. To further aid in helping stakeholders understand how to use each tool, tutorial and information videos are being created which will be openly accessible.

• Information sheets

In addition to the guides for the tools themselves, separate factsheets cover many of the other aspects of the project, including the FDMT project overview, pilot basins profiles, as well as water utility, basin, drought and flood informational sheets.

• Communication Strategy and Media Kit

A Communication Strategy and Media Kit were designed to guide stakeholders in the pilot basins in further promoting the FDMT project to its networks. These resources are intended to continue raising awareness of the flood and drought problems and the SWM solution offered through FDMT. The Communication Strategy is a living document, updated on a regular basis, which outlines all the communication products, their purpose and target audience, as well as the key messages of the project. The media kit is a pre-packaged resource of content for blogs, press releases, newsletters and webpages, to provide an overview of the FDMT project for audiences. The kit also includes a social media guide with a project hashtag and a guide to developing blogs as a more digestible communication approach to reach a wider audience.

• Experience notes

International Waters Experience notes have been developed as part of the project to share the successful practices, approaches, strategies, lessons and methodologies that emerged in the context of the project work. The purpose of the experience notes is to facilitate a community of related projects and partners to improve through the replication of its own practical experiences. These are especially focused at the GEF IW projects who are one of the key target groups for uptake of the tools. The project has developed two experiences notes addressing the significance and approach of engagement with stakeholder to develop relevant applications for flood and drought planning and the experience in incorporating climate information into Water Safety Planning to ensure the approach is climate resilient.

From a bottom-up learning approach, a community-based forum has been developed for users within the online Portal, called the Knowledge Exchange Portal (see Figure 26). This forum promotes dialogues between users to share their experiences and self-teach through a discussion board and online course pages. The Knowledge Exchange Portal is embedded within the web-based system and will assist future users in applying the tools, alongside the other guidance materials available on the Flood and Drought Portal and project website.

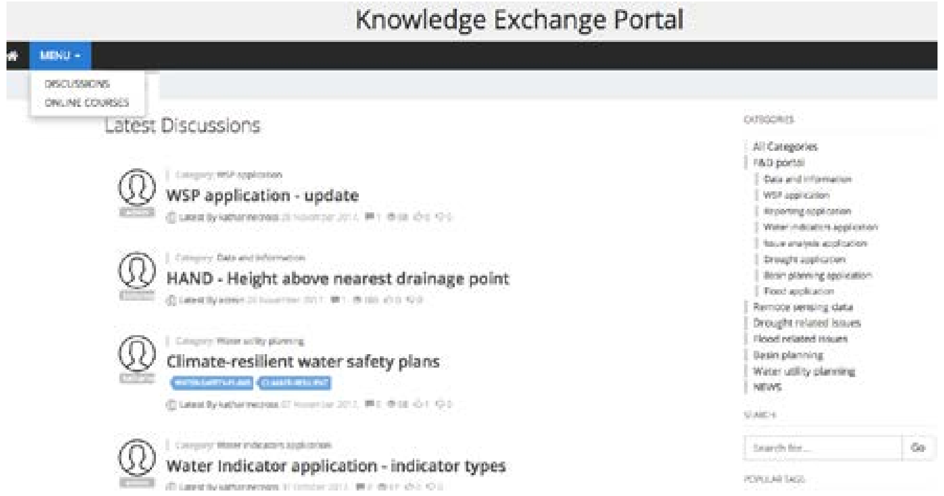

Figure 26. Screen shot of the Knowledge Exchange Portal.
Source: http://www.flooddroughtmonitor.com/hom

To raise awareness of the FDMT project and disseminate project related information to pilot basin partners as well as a wider audience, the following communication outputs were developed by IWA, also hosted on the project website:

Communication Outputs

• FDMT Newsletter

The FDMT newsletter, (with 12 volumes as of April 2018), provides project updates and engages with project stakeholders, communicating their efforts in addressing flood and drought impacts. The 2-4-page newsletter covers not only project updates, but also relevant report and video resources, upcoming and past project related events and flood and drought related news in the pilot basins and beyond.

• Blog

The FDMT blog is an accessible platform for engaging a wider audience in the project, offering a channel for partners to share their knowledge and experience. Around 10 blog posts have been published on the project website, with some of these posts also found on online news sites.

• YouTube Channel

Several social media videos, hosted on YouTube, give a quick introduction to the project and the technical applications available in the Flood and Drought Portal. Each video is 1-3 minutes in length with facts and photos to give an informational overview or guide of different tools and topics related to the project. A series of how-to-videos are also being developed which provide quick tutorials on general functionality of the portal and the available applications.

• Webinars

A series of technical webinars focus on innovative approaches to Flood and Drought planning and management. These are primarily based on the outcomes of the FDMT project, but also include guest presentations from external stakeholders and organisations. Additional webinars address climate resilient Water Safety Planning jointly organised with WHO, how to interpret climate information with EMANTI and a webinar on strategic recommendations for flood and drought management.

- **Infographics (Under development)**
  Representation of different aspects of the project through a blend of illustration and short text, such as displayed in Figure 6. Infographics address transboundary planning, climate resilient water safety planning and flooding and drought.

3.4 Project Stages

The FDMT project implementation process includes five components (see Table 4). After the inception phase in which the project was introduced to stakeholders, initial thoughts on the methodology were developed. Ongoing development and amendments to the methodology have been informed through continued engagement and consultation with stakeholders through planned technical trainings, workshops and events.

Table 4. The five stages of the FDMT project in Lake Victoria, Volta and Chao Phraya basins between 2014-2018.
Source: FDMT Semi-annual progress report, June 2015.

Component Number & Name		Component Description
0	Inception phase	Introducing the project to stakeholders; identifying gaps and needs around flood and drought planning
1	Development of methodologies	Development of six (6) methodologies with tools in a DSS, which increase the understanding of flood and drought dynamics and impacts at transboundary and local levels
2	Validation and testing at basin-wide level	Application of the methodologies in the three pilot basins to provide the opportunity for integration of flood and drought information into basin level planning (basin wide authorities)
3	Validation & testing at local level	Application of the methodologies in the three pilot basins to provide the opportunity for integration of flood and drought information into local level planning (urban water utilities)
4	Capacity building & dissemination	Learning package developed to provide training and information within and beyond the pilot basins; and project outputs communicated and disseminated to inform global dialogue on water security and adaptation to climate variability and change

3.5 Project Inputs

The implementation of this project was made possible due to the financial support of the Global Environment Facility (GEF) trust fund through the UN Environment Programme (UNEP), and the co-financing collected from various stakeholders including the executing agencies, the implementing agency, and local stakeholders in the three basins. The GEF fund provided the core financing of USD 4 million to complete the three pilot basin studies, and the commitments from financial and in kind co-financing among other stakeholders secured more than USD 22 million. In-kind contributions included inputs such as the provision of staff, information, local knowledge and input, development of the technical tools and project support and management. The total budget for the full four-year FDMT project was therefore USD 26 million. The breakdown of funds is provided in Table 5.

Table 5. Summary of main budget components and costs in the FDMT project.
Source: Internal FDMT Semi-annual progress report, June 2015.

UNEP Budget Components	Cost (USD)	
	Budget (GEF)	Co-Financing
Personal Component Project personnel, including PMU cost, Consultants for developing training material, missions travels	3,599,753	14,774,367
Subcontractor Component Supporting agencies/institutions		
Training Component National and regional training courses	288,212	2,533,611
Equipment and Premises Expendable equipment, Non-expendable equipment, Premises costs	10,640	396,055
Miscellaneous Component Operation and maintenance of equipment, Reporting costs (printing and publishing), Communication costs, Project evaluation	151,396	4,760,809
Total Budget	**4,050,000**	**22,464,842**

Most personnel supporting the FDMT project were provided by in-kind support from their respective organisations. To implement the project, two key coordinators with support staff were involved. A facilitator in each basin was selected from existing permanent staff of the executing organisations already located in each of the three pilot basins. These staff were key focal points who built relationships among local stakeholders and ensured that visits and training workshops with the coordinators and support teams were productive. The staff and staff numbers changed over the course of the four-year project on a needs basis.

Several partnerships between international organisations aided in the implementation and execution of the FDMT project (see Figure 27). The UN Environment Programme (UNEP) was the key implementing agency while DHI and the International Water Association (IWA) jointly provided the executive support to cover the overall coordination and operation of the project. It is a novel project management arrangement in that neither DHI nor IWA have taken the lead in management, but share different aspects of project coordination. A project Steering Committee was made up of UNEP, DHI, IWA, as well as the pilot basin authorities (LVBC, VBA and HAII) and key resources persons from UNEP-DHI and the Nile Basin Initiative (NBI). This committee meets at least once a year to review the project budget and work plan then provide feedback and guidance to the executing bodies (DHI, IWA).

gef UN environment DHI IWA the international water association

Figure 27. International organisations involved in the funding, implementation and execution of the FDMT project.

Stakeholders

DHI is an international software development and engineering consultant firm that specialises in knowledge sharing of water-related information through their local teams and unique software (DHI, 2018). They develop advanced technologies to better understand water environments and have global training and knowledge sharing activities to distribute this data. In the FDMT project, DHI acted as the technical coordinator and technical support team. This support team developed the methodology, conducted modelling, collected remote sensing data, tested tools at basin and local level, and created guidelines.

The other coordinating body within the project management unit for project execution, working closely with DHI, was the International Water Association (IWA). IWA is the largest global network of water professionals with more than 10,000 individual and 500 corporate members in 130 different countries. Each year IWA organizes and sponsors over 40 specialized conferences and seminars on a wide variety of topics in water management in locations across the globe including the IWA World Water Congress, IWA Water and Development Congress and Annual Leading-edge conferences. IWA publishes 12 scientific journals and 40+ books per year on water management along with IWA scientific and technical reports, manuals, reports and electronic services. IWA develops leading edge innovations and synthesizes these through the work of the 50 IWA Specialist Groups and a set of global programmes. One of the key communication channels developed by IWA was through designing and operating the project website. Furthermore, IWA led the engagement of stakeholders and capacity building including the organisation of consultation and outreach conferences, workshops, and special events as well as leading the production of dissemination materials and publications. IWA also focused on bringing the project outputs to water utilities in the pilot basins.

In addition, there has been an ongoing collaboration over the duration of the four-year project with the World Health Organisation (WHO) and Global Water Partnership (GWP) in order to gather knowledge and experience for the development of the methodology and tools. The coordination with WHO and GWP were also done to jointly improve WHO and GWP led projects which are aligned on a similar theme as FDMT. The partnership with WHO is on the topic of Water Safety Plans. WHO jointly with IWA produced a manual on WSP which is the basis for the WSP tool within the FDMT. Part of the aim of the WSP tools was to provide support to those using the manual. Similarly, GWP has been conducting a project on integrated drought management and has produced a report on drought indicators. Collaborations with project organisers from both organisations have provided extra information and key learnings that have been used to improve the development of the FDMT project.

Since the TDA/SAP tools are designed to assist transboundary management, the basin organisations, including the Volta Basin Authority (VBA), Lake Victoria Basin Commission (LVBC) and Thai Hydro and Agro Informatics Institute (HAII) are also key stakeholders. Figure 28 gives the list of all regional authorities collaborating on the project. Overall, the FDMT project is a cross agency programme with inputs from international organisations, basin commissions and authorities and water utility agencies. With such a large network, it facilitates bringing together the stakeholders involved in managing the basin and openly share data.

The project has also made use of the experience form the learning basins. Strong collaboration with the Nile Basin Initiative (NBI) and the International Association of Water Supply Companies in the Danube River Catchment Area (IAWD) has helped to shape the development of the methodology and tools. NBI also provided suggestions on how to address high level buy in to the methodology and tools to ensure better uptake of the applications.

FIGURE 28. Regional authorities from the Chao Phraya, Lake Victoria and Volta basins involved in the execution of the FDMT project.

3.6 Enablers

3.6.1 Strong Stakeholder Engagement

Ensuring frequent and inclusive stakeholder engagement throughout the duration of the four year FDMT project helped drive and direct the project. It was especially useful having local and basin organisations' feedback and input during the initiation of the FDMT development, as well as involving them in framing the methodology. This allowed the tools and methodology to be created with direct input as to the needs of users, and further adjustments could be done after annual training sessions with these same stakeholders.

Project partners in Thailand within the Chao Phraya basin were particularly useful in contributing national and local knowledge. Furthermore, these partners had sufficient technical capacity to test and provide critical feedback on the FDMT methodology and tools in order to shape and improve the project outcomes. Stakeholder workshops in the Chao Phraya basin provided project organisers with practical requests for tool adjustment and the Issue Analysis tool was a direct result of feedback from one such workshop. Feedback from trainings in the Volta basin and Lake Victoria basin prompted the switch from a desktop based DSS to an online platform to accommodate the need for a more flexible and user friendly methodology.

The location of the three pilot basins was also considered an enabler for the project, as IWA and DHI already had strong regional knowledge and networks in these locations. DHI had previously implemented information or forecasting systems in the pilot basin regions, so the FDMT project was building on past work, rather than starting from scratch. The established networks with stakeholders allowed a smoother and faster transition to implement FDMT and local knowledge to be available throughout the project. Additionally, as IWA and DHI had staff working in these areas who were familiar with the local agencies, this enabled already developed connections to become stronger as well as stakeholders' trust and engagement to occur from the beginning of the project.

3.6.2 Effective Project Management Approach

A key enabler to this project's progress and success was the project management, planning, implementation and reflection style used throughout the process. The FDMT project involved a detailed planning process, and a defined implementation framework with clear roles for each executing agency. To direct the project implementation, a Project Management Unit (PMU) was created, consisting of the technical and outreach coordinators from the executing agencies. The PMU ran biweekly management meetings and oversaw day-to-day administration of the project.

The Steering Committee oversaw the project's progress and planning stages, helping to guide the direction and ensured detailed reporting. Annual Project Implementation Reviews (PIR), semi-annual reports, consultation reports (including training and workshop reports), blogs and newsletters provided detailed records of the implementation steps and set the tone for the project as it continued. Each semi-annual report had a progress table that covered activities related to each project outcome, and outlined:

- Outcomes and Activities
- Expected Completion Date Status
- Progress
- Issues and Proposed Solutions
- Party Responsible

Table 6 provides a snapshot of part of the progress table from a June 2015 semi-annual report, which includes the above elements. Further to the progress structure, reports regularly assessed performance based on a specific framework. An example of this is shown in Table 7.

Table 6. A sample progress table from the planning stages of the FDMT project. (Note: IP refers to In Progress, state % completed).
Source: FDMT Semi-annual progress report, June 2015.

OUTCOMES & ACTIVITIES	EXPECTED COMPLETION DATE STATUS	PROGRESS Description of progress & achievements during the reporting period	ISSUES & PROPOSED SOLUTIONS Description of problems encountered; issues that need to be addressed; decisions/actions to be taken	PARTY RESPONSIBLE
Component 4 Capacity building and dissemination				
Outcome 4.1 Experience and know how gained through the project is made available within the GEF system and beyond.				
Outcome 4.1.1 Learning package, including technical specifications and training materials for the application of the new methodology with DSS tools, is tested in 2-3 trainings with basin officials, utility and industry management and operational staff, and representatives from civil society with 15-30 people per training.				
Activity 1 – Prepare technical specifications, manuals, guidance and training materials for users in the 3 pilot basins focusing on capacity building in the pilot basins	IP (25%)	Technical workshops are being scheduled. Training material will be developed around these trainings will contribute to this activity.	Information from DSS is needed to further develop the technical specifications, manuals, guidance and training materials. A draft will be ready for training in November 2015, but training material will be developed throughout the project through the iterative training workshops. In addition, the project has established a review group so additional time will be needed for comprehensive peer review.	IWA (with DHI support)

Further to the formal planning process of the FDMT project, the semi-annual reviews ensured the practice of constant reflection at six month intervals throughout the project. These reflections allowed time to determine lessons learnt during the implementation stages, so issues could be solved along the way, rather than only realising problems at the completion of the project.

Table 7. A sample of the Performance Evaluation framework for the FDMT project management, from the June 2015 Semi-annual report.
Source: FDMT Semi-annual progress report, June 2015.

	Component 3 Validation and testing at local level					
	Objectively Verifiable Indicators			Means of Verification	Status 01.01.2015-01.06.2015	Assumptions
	Indicator	Baseline	Target			
Output 3.1 Recommendations for inclusion of flood and drought issues in WSP and other local planning methods in the 3 pilot basins with integration of urban and (agro-) industrial water users' perspectives and realities	Report with recommendations describing the application of the DSS at local level, through the DSS validation on selected application areas, this includes lessons learned from the DSS validation. Report outlining evaluation of the DSS validation at the local level through project review group.	Recommendations for how to incorporate on floods and droughts from a DSS in existing planning methods for water utilities and other utilities at local and urban level are lacking. Baseline: 0	Strategic recommendation for application and the DSS use of information on floods and droughts in existing planning methods at the local level with at least 3 end users (utilities across the 3 pilot basins) Midterm target: Strategic recommendation based on feedback from at least 3 end users (utilities across the 3 pilot basins). End of project target: Strategic recommendation disseminated to a wider range of water utilities.	Reports from application at local scale including: Application of the developed DSS at local level. This includes recommendations and lessons learned for applying the planning methodology Strategic recommendations for inclusion of the DSS in existing planning methods at local level Evaluation of the DSS validation at local level Software package with DSS for application at local level Feedback and comments from stakeholders, project steering committee and project review group	Stakeholder consultations established the working environment for how the DSS should be applied and tested in the pilot basins. The project will work with one water utility within each basin, while other utilities will still benefit from the training. It should be noted that utilities are at different levels with regards to their WSP status (some have already developed and are implementing WSP while others are in the process of initiating the WSP), therefore they will have different uses for the WSP tools being developed. The project is also working closely with WHO to ensure that the tools can potentially be used by utilities beyond the project areas.	Stakeholders recognise the need for use of technical tools in existing planning methods at the local level.

3.6.3 Key Project Inputs

The funding and in-kind support received for the project through the implementing agencies and local stakeholders was also a major enabler for the project. The funds provided by GEF and in-kind co-financing from partner and implementing organisations were significant enough to cover the costs of staffing, detailed project management and implementation across the three pilot basins over a four-year period.

The creation of the online Portal was made possible by several enabling inputs to the project. To develop, implement and update the methodology and tools, it was key to have DHI, a global expert at sharing water data, to create a professional, user-friendly and useful online tool. DHI was able to pool resources from their teams of expert staff, especially their remote sensing team to locate the data to be input into the tool, DHI developers to create the Portal and its back-end and their water resources department to oversee and coordinate these activities. Free and global access to satellite climate data made it possible to share information without the need for the project to generate new methods of data collection in the basins, while meeting a basin requirement for any planning approach.

3.7 Barriers

3.7.1 Implementation Barriers

Completing the FDMT applications was more time intensive than anticipated which created some limitations in terms of application (although the project has been focused on development and testing). As the tools were developed in collaboration with local partners, the process of refining the tools after collecting feedback is lengthy as there are constantly new adjustments required after testing. As the applications cannot be fully used until their production is final, this means there is less time available for actual implementation in each basin. This influenced the decision to extend the project by six months, in order to incorporate the stakeholders' request for more training sessions of longer lengths and further awareness workshops. An adapted schedule for the last stages of the project was created so all online applications would be completed and active by the end of June 2018, only slightly later than originally planned.

Another barrier faced by the FDMT project implementing agencies was that the methodology cannot be tailored to the specific local conditions of every global transboundary basin it targets. This was particularly challenging as the experience in each of the three pilot basins, showed that local stakeholders' priorities vary greatly. While it is not possible to develop a tool with all priorities taken into account, it is acknowledged that basin priorities in other areas of the world may also differ from those within the pilot basins. Therefore, there is a need to bridge the gap between different geographical regions, so that FDMT can be flexible and applied globally while addressing the needs of various stakeholders. Despite this limitation, the pilot and learning basins of FDMT were helpful in identifying specifications that could be applicable in other locations, and the planning tools within FDMT are a means of screening to identify and evaluate the key issues at basin or local level.

3.7.2 Stakeholder Capacity and Interest Level

One of the major challenges encountered in the FDMT project implementation was the limited capacity and data availability among some of the stakeholder partners in the pilot basins. The project was reliant on local stakeholders to implement and apply the tools in a real planning environment, in order for project developers to receive proper feedback and learn from its local use. However, these stakeholders had limited resources to devote to this, especially before the tools were completed. The limited technical capacity of stakeholders was particularly challenging in regards to the Volta and Lake Victoria basins. Because of these limitations in time and capacity, continued support and technical assistance from project organisers were required.

A variety of political influences in the pilot basins at times hampered the engagement of stakeholders for the trainings, workshops and other events. Political unrest in Burkina Faso made it difficult to hold training sessions there. An alternative location in Accra, Ghana was chosen, but due to the greater distance required for stakeholders to travel, attendance was significantly reduced. Limited participation in training events was also seen among Tanzanian stakeholders, as they required permission from their central government to travel to meetings, requiring advance planning time that was not always sufficient.

Another barrier to stakeholder engagement was a wavering level of buy-in and ownership. This project did not provide direct financial investment into a basin organisation, but rather joint learning, which required stakeholders' time and engagement. As the FDMT methodology was developed to involve local stakeholders in the process as much as possible, the varied level of interest among certain partners in the basins made it difficult to incorporate all their ideas into the process. The variance in buy-in and ownership across basins and stakeholders can be attributed to several factors, including voluntary engagement by stakeholders without the provision of extra resources for execution of specific activities, the perception of a top-down approach to implementation, and limited implementation of the tools during the project's timeframe. Without the implementation of the tools to a practical situation demonstrating the value of the methodology and tools, it was difficult to see the extent to which managers would be able to practically apply the methodologies and tools in their work without further training and support.

Furthermore, the FDMT project was highly sensitive to economic fluctuations, social issues and cultural barriers. Of these, language was the main impediment to involvement of stakeholders. The communication materials, online Portal and applications were created in English, which is useful for partners in the Lake Victoria Basin where English is the dominant language, however less useful for the other two basins where English is less commonly used. To address this, key documents and communication materials were translated to French (the dominant language in the Volta basin) and Thai (for the Chao Phraya basin), and as much as possible, translators or staff competent in the required language were present at trainings and workshops. Nonetheless, not all materials are yet translated into these three languages, and translation was not available during all workshop events. The main Portal interface and application tools are still only available in English. Standard webpage translation tools can be applied, however, to enable users to navigate the Portal in a language they are familiar with, and text inputs in any language are accepted when creating the planning templates and frameworks.

3.8 Achievements and Impacts

At the time of writing in early 2018, the FDMT project is still in its last phase, so long-term impacts are yet to be realised. However, the project has already achieved many of its intended outputs and is on track to accomplish its intended outcomes (see Figure 29).

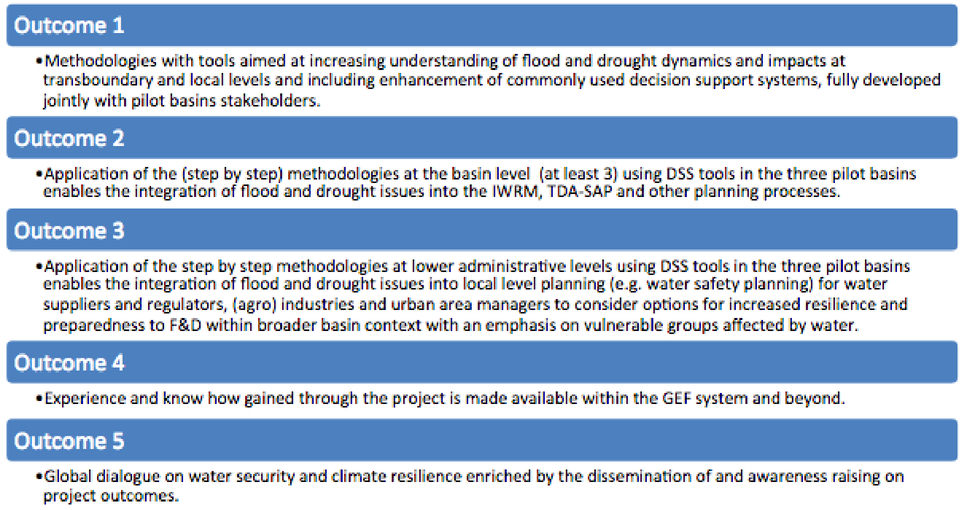

Figure 29. The five key intended outcomes of the FDMT project, as outlined on the project website.
Source: http://fdmt.iwlearn.org/outcomes

3.8.1 FDMT Methodology

As outlined in the first intended outcome above, the project has jointly developed a methodology with pilot basin stakeholders, to better understand flood and drought events and their impacts, and to help local stakeholders plan and make decisions to mitigate these impacts. The methodology will not only assist stakeholders in the pilot basins of Volta, Lake Victoria and Chao Phraya basins, but can also be applied to other global transboundary basins. The increased information and planning capacity provided through the FDMT methodology improves resilience and flood and drought preparations, so water basin authorities and water utilities can be better prepared and equipped for extreme weather events.

3.8.2 Online Portal

A major accomplishment of the FDMT project was the creation of its main output – the DSS software, embodied in an online Portal with a package of technical applications. The Flood and Drought Portal contains a set of tools, which can be used individually or together for supporting activities within flood and drought planning. These tools, as well as information on how they can be applied in practice, are readily accessible to authorities and utilities across transboundary basins. The Portal and its applications fits into the overall tool set available, such as the Global Water Partenership's IWRM ToolBox, which contains knowledge and learning about integrated water resources management. The Flood and Drought Portal and its applications could be considered as one of the "tools" within the IWRM Toolbox.

As of May 2018, 700 users had registered on the Portal. Furthermore, the Portal has registered 286 transboundary basins from around the world. Within the online system, basins are classified as operational if there are registered users for that basin. Most applications in the Portal can be generally applied for planning in any basin, but the Data and Information Application uses satellite data specific to a geographical location. When a user registers for a previously non-operational basin, this triggers the technical coordinators at DHI to process the data for this basin. As of early 2018, a total of 42 transboundary basins were operational with registered users, including basins within Africa, Asia, Central America, Europe, the Near East as well as North and South America.

Intended outcomes 2 and 3 have so far been partially realised, with the creation of applications for flood and drought planning aimed at both basin wide and local levels. While not all applications have been fully completed, the project has made significant progress in designing, implementing and tweaking applications in accordance with stakeholders' input.

In addition to the online Portal, the methodologies for how to apply the tools in a planning context have been developed within the FDMT project. Detailed guidance was created outlining how to use each application, as well as how to interpret data, at a level that stakeholders with various capabilities can understand and utilise for their planning purposes. Such guidance was developed primarily for water utilities.

Another accomplishment from the FDMT project execution was its high degree of efficiency in technical, implementation, and management terms. The creation and development of the online Portal was cost-effective compared with the high cost of developing similar commercial DSS, as it was made as a web-based system and used freely available global datasets. Further efficiencies were obtained through reducing personnel requirements; embedding the project management unit within the executing agencies and having local partners volunteer to test the methodologies and tools.

An example of early successful uptake of FDMT is within the Chao Phraya Basin, where Thai stakeholders are already using the Portal and drought assessment tools to develop a plan for drought. In this region, partners are well equipped with the capacity to use the application and certain organisations have shown interest to register all their staff with the Flood and Drought Portal.

Furthermore, the project is working with the IW: Learn[1] to promote the Portal and its applications to transboundary basins involved in the TDA/SAP process, which is what the project was originally designed to support.

3.8.3 Capacity Building and Information Dissemination

Capacity building across the three pilot basins has largely met the project's desired outcomes. To share the experiences gained throughout the project, project updates and details are widely available online and further distributed through other activities and mediums, such as events. In addition, a large volume of communication materials and training documents have been produced over the course of the FDMT project. In accordance with the fifth intended project outcome, these materials are widely distributed at a local, regional and international scale, with most accessible online, on the project website and the online Portal.

Consultations, technical training sessions and workshops, information dissemination and awareness raising activities for stakeholders have improved stakeholder knowledge, such as regarding remote sensing knowledge, and increased awareness of the issues and tools now available through FDMT to better plan for flood and droughts. Additionally, there has been a significant increase in stakeholder access to information, tools and knowledge of how to apply the data and tools provided in the FDMT project. The improvement of data access and planning abilities across users in the Volta, Chao Phraya and Lake Victoria basins means that planning authorities and water utilities can be better equipped to address the impacts of floods and droughts. The core project objective to enhance the ability of managers in the pilot basins to recognise and address climate change impacts on floods and droughts has been partially realised in the short-term. Progress still needs to be made to continue strengthening capacity across different stakeholders in the basins, to ensure that they are all able to apply the tools and knowledge gained is applied in operational and strategic planning. IWA and DHI have existing projects and proposals that aim to enable further implementation.

1. IW:LEARN is the Global Environment Facility's (GEF) International Waters Learning Exchange and Resource Network. The IW:LEARN project was established to strengthen transboundary water management around the globe by collecting and sharing best practices, lessons learned, and innovative solutions to common problems across the GEF International Waters portfolio. It promotes learning among project managers, country official, implementing agencies, and other partners (IW:LEARN 2018).

4. Links to the SDGs

The FDMT project is linked to sustainable goals 6 (clean water and sanitation), 11 (sustainable cities and communities), 13 (climate action), 15 (life on land) and 17 (partnerships for the goals). Table 8 lists the specific targets within these SDGs that are addressed by aspects of the FDMT project.

Table 8. A list of the SDGs and their specific targets that relate to the FDMT project.

Sustainable Development Goals and Targets	
SDG 6: Clean water & sanitation **Ensure availability and sustainable management of water and sanitation for all**	
6.4	By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity
6.5	By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate
6.B	Support and strengthen the participation of local communities in improving water and sanitation management
SDG 11: Sustainable cities and communities **Make cities and human settlements inclusive, safe, resilient and sustainable**	
11.4	Strengthen efforts to protect and safeguard the world's cultural and natural heritage
11.5	By 2030, significantly reduce the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations
11.A	Support positive economic, social and environmental links between urban, per-urban and rural areas by strengthening national and regional development planning
11.B	By 2020, substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change, resilience to disasters, and develop and implement, in line with the Sendai Framework for Disaster Risk Reduction 2015-2030, holistic disaster risk management at all levels
SDG 13: Climate Action **Take urgent action to combat climate change and its impacts**	
13.1	Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries
13.2	Integrate climate change measures into national policies, strategies and planning
13.3	Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning
13.B	Promote mechanisms for raising capacity for effective climate change-related planning and management in least developed countries and small island developing States, including focusing on women, youth and local and marginalized communities
SDG 15: Life on Land **Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss**	
15.3	By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world
SDG17: Partnerships for the Goals **Strengthen the means of implementation and revitalize the global partnership for sustainable development**	
17.7	Promote the development, transfer, dissemination and diffusion of environmentally sound technologies to developing countries on favourable terms, including on concessional and preferential terms, as mutually agreed

The data and planning capabilities of FDMT contribute to ensuring clean water and sanitation for all, SDG 6. Equipping basin authorities, water utilities and decision makers with the information and tools to complete comprehensive assessments and plans of water resources in their regions supports their ability to more effectively prepare for disasters and properly allocate water to reduce water scarcity (target 6.4). Integrated Water Resources Management is one of the key management processes incorporated into the FDMT applications, including for transboundary basins, thus increasing the proportion of transboundary basin areas with an operational arrangement for water cooperation (indicator 6.5.2). Not only does the FDMT project target transboundary level cooperation, but it also empowers local organisations and stakeholders such as water utilities to be better informed to manage their water resources (target 6.B). This empowerment was not only through tools targeted at these groups, but also a high level of stakeholder engagement with local organisations during the FDMT project.

The technical applications developed in FDMT also strengthen the safety and resilience of cities and human settlements under SDG 11. The aim for the improved forecasting and warning capabilities that FDMT promotes is to support the creation of mitigation measures and strategies that would then protect natural and cultural heritage sites (target 11.4), and reduce the number of deaths and economic losses caused by flood and drought. These protection measures could also protect land that would otherwise become degraded by the effects of such disasters, simultaneously addressing SDG 15, target 15.3. Protection of human settlements is supported at various scales within the FDMT project, addressing target 11.A in strengthening national and regional development planning and target 11.B in increasing the number of countries with national and local disaster risk reduction strategies.

As flood and drought events are a consequence of global climate change, FDMT contributes to SDG 13 in strengthening resilience against the impacts of climate related hazards and natural disasters (target 13.1). The planning tools available through FDMT, encourage improved preparations and effective decision-making based on climate data and forecasting of hazards to be incorporated into national plans (target 13.2), especially in least developed countries such as those in the Volta and Lake Victoria pilot basins (target 13.B). Furthermore, the stakeholder training and information dissemination conducted throughout the FDMT project contribute to target 13.3 in improving human and institutional capacity to handle climate change impacts.

Finally, FDMT addresses SDG 17 in strengthening global partnerships for sustainable development. This is demonstrated not only by the broad number of international and local organisations involved in the development and implementation of FDMT, but also by the promotion and dissemination of the project on a global scale, especially targeted at transboundary basins in developing countries (target 17.7).

5. Lessons learned

Over the course of the four-year FDMT project implementation, several key lessons were learned by the project coordinators. The following section provides an overview of the insights gained from the beginning of the project up until early 2018.

Available Data

As the development of the DSS requires climate and water data relevant for planning from the geographical regions, a barrier to the development in the Volta and Lake Victoria basins was the lack of accessible data. Monitoring stations are sparse in the African basins, the data that is available may be unreliable, and there is limited willingness to share the information that is available. These limitations resulted in the use of freely available global satellite data, and a stronger focus on tools for using remote sensing information.

A further element identified throughout the project was the need to include gender related data and indicators to technical applications. At stakeholder workshops and trainings in the three pilot basins, a great majority of participants were male as the operational level for water utilities is highly male dominant, and retrieving data on gender related topics was not possible. While the FDMT project was mindful of gender issues in the water sector, it is clear that more attention should be aimed at inclusive gender planning in the future, in order to overcome the challenge of a sector which predominately employs men in the workforce. Within the project tools, gender indicators have been identified and integrated in the water indicator application. These include: Estimated Female Earned Income Over Male Value (Ratio); Global Gender Gap Index; Rate of Out of School Children of Primary School Age, Female, Time Spent on Collecting Water; and Water and Sanitation Charges. Such indicators can be useful to inform governance and regulatory practices, for example.

Program Usability

As the FDMT project aimed to empower local stakeholders with tools to forecast and plan for flood and drought events, a key consideration was the usability of the DSS programs. Identifying the right people and organisations to work with at the basin, national and local level, including technical staff and policy and decision makers was important for effective engagement.

Early in the project water utilities were not clear how outputs would support planning. However, once the WSP tool came online, it was apparent that this was the entry point (as anticipated) to support planning and introduce climate information. Furthermore, efforts were made to provide utilities with continuous updates and training to overcome the lack of clarity, including a focus on improving their technical capacity to use and interpret information from the tools, then integrate this into their planning.

These frequent stakeholder consultations had further benefits that were helpful to improve the project. First, while the originally proposed DSS had impressive capabilities and outputs, there were concerns that it would be too complex for stakeholders with limited technical capabilities to use and understand. This DSS was a comprehensive desktop-based software, enabling users to tailor a planning process based on functionality and user developed scripts. Feedback from technical workshops and training sessions with local stakeholders encouraged a shift to online tools rather than the original desktop-based software which had required users work in the back-end of the system to receive the functions in the front-end. As such, the project adapted with these modifications to create a more simplified online system to host the tools which can be used individually or together in a single workflow. A further benefit to the online DSS compared to the originally proposed desktop-based software, is its ability to be used by anybody with access to at least low bandwidth internet. This makes it much more accessible on a global scale, and encouraged the use of the tools by stakeholders outside of training sessions.

Another lesson from the consultations was that while the tools from the FDMT project could be useful, they needed to be incorporated into the stakeholders' current workflows to ensure that they would be actively used after the project end date. Several previous donor funded projects that occurred in some of the pilot regions found that formalised planning methods (i.e. IWRM, TDA/SAP) are often carried out by external consultants, and not used frequently during the day-to-day work in basin organisations. This identified the need to ensure data and outputs from formal planning within the applications can be incorporated into operational planning by the stakeholders. The FDMT project organisers then worked on creating more tools and manuals to guide stakeholders on how to use the information from the tools in decision-making on flood and drought planning, as well as holding awareness workshops on this topic.

A further finding was that long-term climate change modelling is not of as much interest to water utilities in the basin as seasonal forecasting. This is a useful lesson in that more training and focus could be placed on improving the applications for seasonal forecasting for organisations and utilities dealing with operational planning from months to season. While long-term climate planning was not of as much interest to certain users, it was still important for organisations to have the tools to develop long-term strategies and guidelines. Additionally, raising awareness of the importance of long term climate change modelling could help engage local partners to think about its use in their environments. Associated with this lesson is the need to understand and manage stakeholders' expectations while also finding a balance that aligns with the project's aims.

Communication

Special attention to language considerations was found to be important to ensure communication channels could flow freely between stakeholders and project coordinators. As the local language differs across the three basins, it was critical to have sufficient translators throughout the process. While English is common in the Lake Victoria basin, French is the predominant language in the Volta basin and Thai in Chao Phraya basin. Not only do translators need to provide communication material to stakeholders on the project, but there also needs to be a means for the project coordinators to receive feedback and input from French and Thai speaking local stakeholders. Having members of the project staff team fluent in Thai and French was important to allow this translation.

Beyond language, stakeholders had to be informed of all the benefits of each tool, in order to encourage them to engage with all planning tools. It was found that when stakeholders had a deep understanding of the benefits and functionality of a tool, they were more enthusiastic about using it. This depended on how the benefits were explained to stakeholders, including the approach and languages used. Awareness workshops and technical trainings for stakeholders provided a good opportunity to share with them the benefits and demonstrate the value of each tool.

Sustainability

Many local stakeholders have constrained financial budgets, and lack capacity in some areas, such as human resources, to carry out key activities after the international partners leave. This is an imperative consideration in ensuring the methodology and tools have long-term sustainability and continue functioning in the basins after the closure of the project. This was addressed by attempts to more effectively communicate benefits of FDMT to encourage its use, strong emphasis on trainings for improved capacity building, as well as planning a follow-up phase after implementation.

6. Conclusion, next steps

The Flood and Drought Management Tools project has developed a global approach to help water managers and other relevant partners better prepare for the effects of climate change in transboundary basins using a SWM approach. This has involved the creation of an online Portal with a package of applications or tools that are freely accessible and user-friendly, providing access to satellite data to display relevant climate and water information in operational basins and a number of other relevant tools to support management and planning of water resources. This was made possible through the joint effort of GEF, UNEP, IWA and DHI, as well as basin and local stakeholders in the Volta, Lake Victoria and Chao Phraya basins who were regularly consulted and trained. Active stakeholder involvement, including learning from their knowledge, was essential for the development of the tools as well as for increasing their awareness and capacity to plan and make informed decisions to address the impacts of floods and droughts in their regions.

Furthermore, as the methodology and most applications are flexible with the aim of a global scope, the Portal is currently accessible to all GEF IW transboundary basins.

6.1 Future of the Project

The FDMT project will continue within the three pilot basins until the end of 2018, at which time it is anticipated that the Portal and technical applications developed out of the project will be fully functional. The training of stakeholders, fine tuning of tools and a further upcoming crop application will round out the final work on the project in 2018. The crop application includes a crop calendar module and a crop analysis tool to estimate the crop yield or the crop water demand under given environmental conditions based on AquaCrop, a crop water productivity model developed by the Land and Water Division of FAO. DHI, who is responsible for the development of the technical applications, will ensure that the web based portal is maintained and functional for a period of three years following the project completion. This does not include technical support or training, but efforts are being made to identify additional funding to cover these areas.

To assist with the project sustainability following the end of the pilot projects, learning packages with all the essential information for understanding the project and tools are being developed for the stakeholders in each basin. While project organisers will not be as active in communication with basin partners following 2018, several measures are in place to continue the dialogue on the FDMT project. The executing organisations have a presence in each of the basins (Ghana, Kenya and Bangkok) where they can assist stakeholders and may be able to hold follow-up training sessions after the official project closure. Furthermore, the online Knowledge Exchange Portal provides a bottom-up living learning resource for future users to discuss among themselves in how to best use and apply FDMT.

While the pilot and learning basin work is wrapping up in 2018, several external projects are being conducted by DHI and IWA that build on the FDMT project. DHI is actively pursuing other projects that will use the Portal and technical tools developed from the FDMT project, in order to further refine them and strengthen the technical components of the tool. Specifically, the use of FDMT applications in other projects are further developing and validating data for seasonal climate and drought assessments, enhancing reporting facilities, improving indicators of tools and validating hazard and risk maps. Table 9 outlines the details of projects DHI is currently collaborating on for these objectives. In addition, the use of the tools within these projects will enhance the sustainability efforts of FDMT and help make its use more widespread.

Table 9. External DHI projects which build on the applications from the FDMT project

Project Name	Collaborators	Location	Timeline
Operational Decision Support System	World Bank	Malawi	2014-2018
Zambezi water resources information system, Enhancement 3: Hydro-meteorological database and decision support system	World Bank	Zimbabwe	2016-2018
Improving resiliency of crops to drought through strengthened early warning within Ghana	Climate Technology Centre and Network (CTCN)	Ghana	2016-2017
Adaptation to climate change through improved information and planning tools for Lake Victoria	Climate Technology Centre and Network (CTCN)	Lake Victoria Basin	2017-2018
Development of the Ayeyarwady Decision Support System and Basin Master Plan	World Bank	Myanmar	2017-2019
Earth Observations for Sustainable Development	ESA	Myanmar	2016-2019
Various DHI projects in South East Asia		Malaysia, Thailand, Vietnam, Myanmar	ongoing

In addition to the projects DHI is involved in, IWA is also pursuing projects where the applications from the FDMT project can be used. They are working to identify possible areas of collaboration with the World Health Organisation (WHO) to incorporate relevant tools into their projects. The OPEC Fund for International Development (OFID) is funding a *Climate Resilient Water Safety Project* in East and West Africa that will incorporate elements of the FDMT project. On top of this, several proposals have been developed that integrate the Flood and Drought Portal.

After the successful development and implementation of the FDMT methodology and tools in the Chao Phraya, Lake Victoria and Volta basins, the project is scaling up. Project organisers are promoting FDMT on a global platform to encourage its use in other transboundary basins, with the aim of improving data sharing and informed planning for floods and drought across the world.

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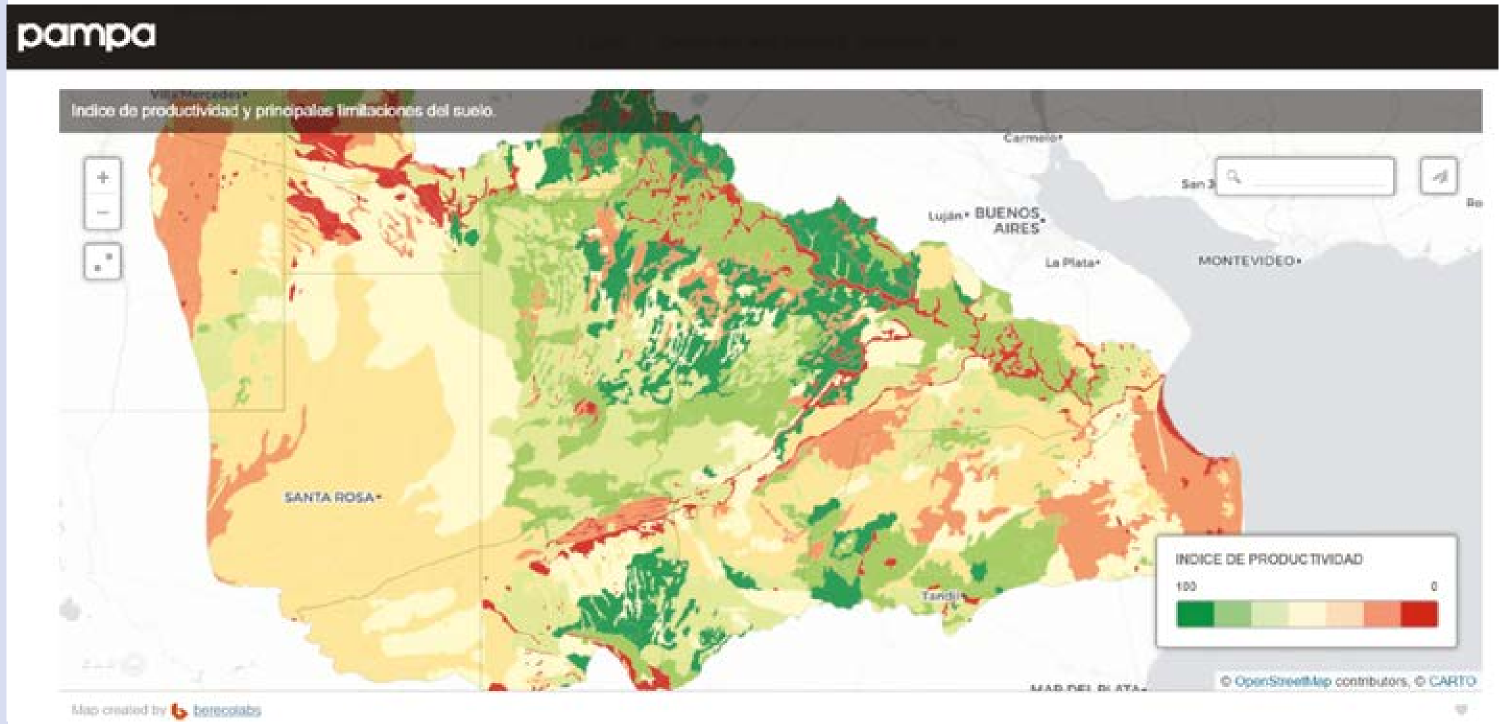
“Pampa Inteligente“; A new way of managing the Salado river basin in Argentina as a Smart Territory

Country: Argentina
City/region where project is based: Salado river basin
Population (of area where the project is based): 1,300,000
Key organisations /stakeholders involved in the project: BerecoLabs (Leader and General manager of the project, system design and mathematical modelling), Tecmes SRL (IoT hardware company), La Plata National University (Research on territory aspects), Northwest Buenos Aires National University (Research on economic and social issues).

Authors: Pablo Bereciartua*, Ariel Cohen*
*BerecoLabs



Water challenge

Periodic and recurring floods and droughts are generating growing losses in the productive system of the Salado River Basin at both the environmental and social dimensions, increasing population and economic vulnerability in the area. In addition to this, unlike most other rivers, the landscape topography of the region that the Salado river flows through is extremely flat (endorreic watershed) and the agricultural production has had a net impact increasing the water table level. This creates a unique challenge for the Salado river as traditional mitigating hydraulic infrastructure such as dams rely on elevation gradients. A flat terrain reduces the options for conventional water management in the Salado.

Project approach

To address these challenges, a mobile phone app (application) has been designed, for the farmers and the citizens in the Salado river basin. The App, which includes a map feature, allows users to access key hydrological variables such as ground humidity, precipitation, groundwater level, and road conditions. It embodies the concept “Past, Present and Future”, making it possible for users to see the evolution of these variables through the past and receive a prediction about the future using adaptive local algorithms. Furthermore, by providing hydrological and meteorological variables at a local level, the app aids users in choosing the best path to take when an extreme event is presented (based on rural transportation routes and flood pathways) and to schedule farming tasks accordingly.

By assessing the groundwater level, the application allows users to determine when it is likely to be available for irrigation (1-2 m below the surface) or when it is elevated above the ground surface, representing a threat of flooding. The App explains the risks of an elevated water table. It also allows assessment of flooding impacts on rural population and roads.

The app provides the representation of certain hydrological variables plotted on a map, as well as user alerts about related issues like blocked transport routes.

In order to provide the hydrological and meteorological information within the App, the project uses Internet of Things (IoT) from hydrometeorological stations, satellite imagery combined with learning adaptive algorithms to predict the future, to elevate the resilience of the area and the regional economy towards climate variability and change (i.e. through user and algorithmics based alerts, early warnings and progressively further wheatear related optimal decision making).

Results and next steps

As of July 2018, the project has successfully developed the App with a library of reliable hydrological and climate data for the Salado river basin. In this beta phase, around 100 people have tested the App and send BerecoLabs their feedback and reviews that are being used to improve it.

The proposed next steps for the projects are:

- Improve the forecasting model with AI techniques.
- Communicate the potential of this tool to the concerned population.
- Scale up the tool with more sensors in the region.
- Replicate in other basins or countries.

More info at: http://pampainteligente.com
and http://berecolabs.com

SWM solution and scaling

This project is based 100% on smart technologies using ICT data in real-time, satellite information and local IoT sensors. It has a collaborative platform where its performance increases as the users interact on the App by sending alerts (for example, when a rural route is blocked or in a bad condition) and early warnings. This collective intelligence results in a smart way to reduce vulnerability to extreme weather conditions, helping populations adapt to climate variability and climate change.

Future improvements could be made by scaling up the number of meteorological stations in the region enabling an increase in information and accuracy. The main constraint to scaling up the project at this stage is the lack of adequate financial support, which will be required to install more smart technology hardware on terrain.

SWM technology for efficient water management in universities: the case of PUMAGUA, UNAM, Mexico City

Fernando González Villarreal[1], Cecilia Lartigue[2] ,Josué Hidalgo[3] , Berenice Hernández[4] , Stephanie Espinosa[5].

1. Director, PUMAGUA - 2. Executive coordinator, PUMAGUA - 3. Responsible for Water Quantity Area, PUMAGUA - 4. Responsible for Social Participation Area, PUMAGUA - 5. Responsible for Water Quality Area, PUMAGUA

Summary

Mexico faces a number of water challenges including water quality, access and inefficient management of water. On a smaller scale, Mexico's largest university (and indeed the largest university in Latin America), the National Autonomous University of Mexico (UNAM) also faces these challenges in its campuses. To address these challenges, UNAM launched the Program for Management, Use, and Reuse of Water (PUMAGUA) in 2008 with the aim of implementing the efficient management of water at the campuses of UNAM. The three key objectives of PUMAGUA were to: 1) reduce potable water consumption by 50% through improved practices and leak detection, 2) improve the quality of drinking water and treated wastewater in accordance to Mexican regulations and 3) promote participation of the entire UNAM community in the efficient use of water. Prior to PUMAGUA, UNAM faced up to 50% water loss through leakages in the university pipelines, irregularities in drinking water disinfection, treated wastewater did not comply with regulation, and there were no continuous capacity development activities or communication campaigns to save and conserve water.

Since PUMAGUA was initiated in 2008, it has achieved a reduction of 25% in water supply in the University City campus (CU), despite a population increase of more than 37% from 2008 to 2018. Drinking water and treated wastewater are now both of excellent quality. PUMAGUA has also enhanced the responsible use of water by key actors, as well as the participation of students and lecturers in generating proposals to solve water problems. In addition, it has carried out workshops addressed to maintenance staff and gardeners to enhance water saving actions.

In order to produce these results, PUMAGUA has made use of Smart Water Management (SWM) technology, in particular, remote water consumption measurement and water quality assessment tools. The Program created UNAM's Observatory of Water, a digital real-time platform that includes water quantity and quality data, and social participation, in order to respond promptly to any eventuality and to actively interact with the university community. In addition to the implementation of the program at UNAM, PUMAGUA has extended its activities to trial smart water projects in other university campuses and also in low-income housing in Mexico City.

Throughout the PUMAGUA program we have learned several lessons, including 1) smart water management can build trust in water users (in our case, in the university community); 2) smart technology still requires a lot of time and effort to manage and maintain, especially in the beginning stages of a project; and 3) as technology changes so quickly, it is essential to have the financial resources to afford the acquisition of technology upgrades, as well as the human capabilities to manage the updates. As a result of sharing our results and lessons from the PUMAGUA program we hope that other programs will be able to leapfrog some of the challenges we have faced, and also can achieve some of the successes we have accomplished.

Moving forward, our intentions are to update the SWM technology, particularly, regarding water consumption measurement. We will also try to use this kind of technology for other purposes, such as measuring soil moisture, in order to determine the need for watering gardens.

PUMAGUA has become a model for water management and use and has been extended to other universities, institutions, and localities. The use of SWM technology has been of the utmost importance to achieve this.

1. Background

This section highlights some of the challenges Mexico, and on a smaller scale UNAM, faces in regards to water management to provide the context for the PUMAGUA case study.

Water resources in Mexico

Country: Mexico
Population: 128,000,000
Annual rainfall: 1,500 billion cubic meters; 779 mm per year
Renewable water resource: 470 million cubic meters (3.67 m^3/annum/capita, one of the lowest in Latin America)
Climate: Highly varied (includes tropical, semi-arid, desert, temperate, humid subtropical and Mediterranean)

1.1 Water challenges in Mexico

To understand PUMAGUA, it is necessary to review the challenges that confront Mexico as a whole. Mexico's annual rainfall varies greatly across regions and seasons, with heavy rainfall occurring in summer (from May to October), while the rest of the year is relatively dry (CONAGUA, 2014). There are two distinct regions in Mexico: 1) the centre and the north region (which when combined occupy two thirds of the country), is very dry with rainfalls ranging from 200mm/year in Baja California to 600-1000mm/year at the south of the Altiplano Central; and 2) the southeast region, which is very humid with rainfall of over 3,500 mm/year. On average each year, Mexico receives 1.5 billion cubic meters of rainfall. Despite this, approximately 72% of rainfall is lost through evapotranspiration, with only 22% flowing into rivers and 6% infiltrating into and recharging aquifers. Considering the exports to and imports from neighbouring countries, Mexico receives an annual average of approximately 470 million cubic metres of renewable water resources (CONAGUA, 2014), making it a country with low natural water availability, one of the lowest in Latin America (SEMARNAT, 2012). In addition, high population density in some parts of the country causes an intense pressure on water resources. Such is the case of the region where Mexico City and the University City of UNAM are located (Figure 1).

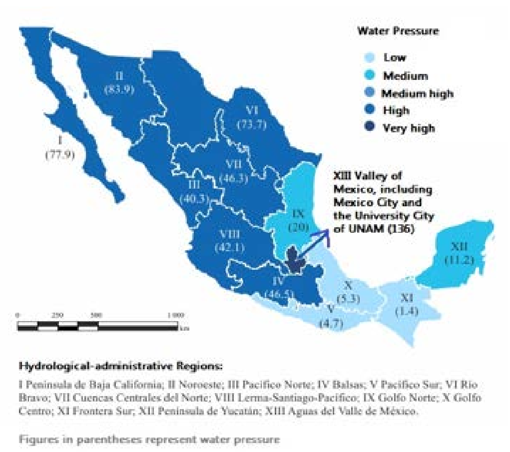


Figure 1. Water pressure map for the thirteen hydrological administrative regions of Mexico, showing Mexico City as one of the regions with the highest water pressure in Mexico.
Source: CONAGUA. Atlas del Agua, 2016

CASE STUDIES
SWM TECHNOLOGY FOR EFFICIENT WATER MANAGEMENT IN UNIVERSITIES:
THE CASE OF PUMAGUA, UNAM, MEXICO CITY

1.1.1 Drinking water services in Mexico

According to the National Commission of Water (CONAGUA) in 2015, 92% of the population of Mexico had access to drinking water (96% in urban areas and 82% in rural areas). Nonetheless, Mexicans have become the leading per capita consumers of bottled water in the world, each using between 215 and 234 litres of bottled water per year (Pacheco-Vega, 2017). Approximately 80% consume bottled water instead of tap water paying considerably more per litre than if they were to drink potable tap water. With water utilities providing more than 200 times the water in volume than that provided by purchased bottled water, for a lower cost. Low-income households spend more money on bottled water due to the water access being lower in poorer areas[1] (Torregrosa, 2012).

One of the main issues for water utilities in Mexico is the inefficiency of network operations. González Villarreal et al. (2015) found that at least one quarter of households do not receive water daily. Between 30 and 50% of water is lost through leaks in Mexican cities (Capella, 2015).

In 2008, per capita average piped water consumption volume of water in Mexico City was measured by Capella-Vizcaino et al. (2008) who showed that while average water consumption is 184 litres/person per day, consumption volumes in different areas of the city range from less than 125 litres to over 475 litres/person per day (see Figure 2).

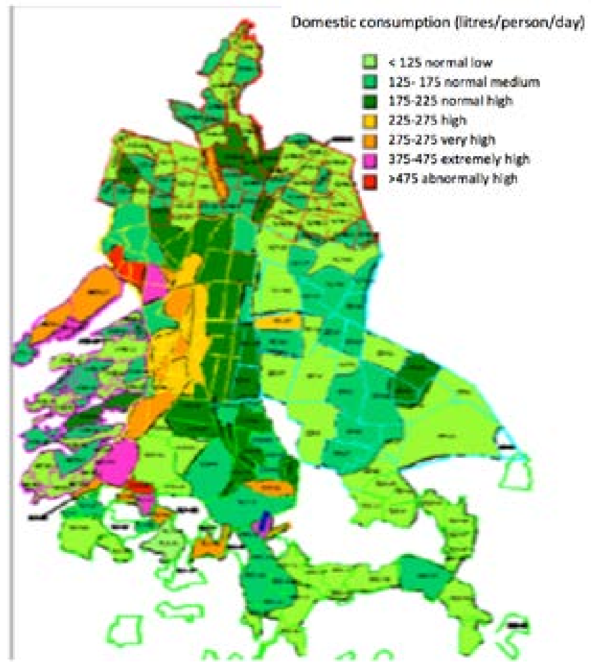


Figure 2. Water consumption volumes in Mexico City.
Source: Capella-Vizcaino et. al, 2008

1.1.2 Water quality in Mexico

With regards to drinking water quality, in 2008 Mexico ranked 59th out of 92 countries, below countries such as Bangladesh, Egypt, and Kenya (Carr and Rickwood, 2008). While the water utility of Mexico City states that tap water complies with regulation in most of the city, Romero Sanchez (2015) has shown that 12% of inhabitants (approximately 1 million people) do not receive good quality water. According to Romero-Lankao (2010) even when water quality is allegedly monitored on a continuous basis, it is doubtful that this monitoring is effective,

1 Some areas in Mexico have limited access to tap water due to the rationing of water by the water utilities

particularly in central areas of the lake system and in some areas of its aquifers. This is because aquifers are polluted with bacteria, faecal matter and sulfates, among others, due to over-exploitation, subsidence, fractures, lack of access to sanitation by some sectors, and lack of maintenance of domestic installations, such as water tanks. There are no accurate data on the health implications of poor water quality in some areas of the Metropolitan Area of Mexico City. Nevertheless, 30% of intestinal related diseases in Mexico are related to the quality of water, and diarrhoeal diseases are the fourth most common cause of child mortality in Mexico City.

Bottled water use in Mexico

According to González Villarreal et al. (2015), Mexicans buy bottled water mostly due to the belief that tap water is not safe. A study by the Interamerican Development Bank (2011) in Mexico City found that the reason 81% of interviewees buy bottled water is a lack of trust in tap water, despite 88% of them stating they had never fallen ill after drinking it.

With the purpose of encouraging tap water consumption whilst reducing bottled water and consumption, in 2013, the Legislative Assembly of Mexico City modified the Law of Education of Mexico City to require the government to install water fountains in primary and secondary schools (ALDF, 2013). At the national level, in 2016 the Ministry of Public Education modified the Law of Physical Educative Infrastructure in order to obligate public schools to provide sufficient drinking water for students, and to install water fountains, according to guidelines established by the Ministry of Health in collaboration with the Ministry of Education (DOF, 2016).

Water uses in Mexico

Irrigated agriculture is by far the main water user in Mexico, consuming about 76% of this resource in a very inefficient way (CONAGUA, 2016b). According to Almazan Cisneros (2003), about 38% is lost in piping and 40% in application. Around 65% of water for agriculture comes from surface bodies and 35% from aquifers (CONAGUA, 2016a).
Domestic use is the second water consumer in Mexico, using 14.5% of water for consumptive uses. About 64% of it comes from surface bodies, and 36% from aquifers. From 2005 to 2014 there was an increase of over 12% in the volume of water allocated to this use (CONAGUA, 2016a).
While the national average pressure for water is 19% (more than 40% is considered as high), in the southern states of the country, water pressure for water is low, while in the northern ones it is high. The administrative hydrological region (a division established by CONAGUA) where Mexico City is located, pressure for water is the highest in the country (nearly 140%, Figure 2) (CONAGUA, 2016b).

1.2 PUMAGUA at the University City, UNAM

University City (CU), UNAM, Mexico City

Population: 185,000 people
Land size: 700 hectares
• 240 ha 'Pedregal de San Angel' Ecological Reserve
• 150 ha of gardens
• 300 ha covered by ~400 buildings
Water supply in 2008: 100 litres/second (8,640m^3/day)

The National Autonomous University of Mexico (UNAM) in Mexico City is the largest university in Mexico and Latin America (see Figure 3). Its main purpose is to serve the country, to train professionals, to organize and carry out research, with the key focus on national conditions and problems and in disseminating the benefits to the country (National Autonomous University of Mexico, 2017). After the IV World Water Forum in Mexico City in 2006, the University created the Water Network of UNAM, with the participation of 26 schools and institutes of UNAM. Yet while UNAM was conducting research on water quality challenges elsewhere throughout Mexico, they did not have a water management system in place for their own university premises. As the main campus, City University (CU), alone houses 185,000 students, academics and other staff and is 700 hectares in size. The 'Program for Management, Use, and Reuse of Water at UNAM' (PUMAGUA) was established, in 2008 with an interdisciplinary team assembled to implement an integral program of management, use and reuse in UNAM's campuses, with the participation of the community.

The autonomy of UNAM with regards to the Mexican government gives it the faculties of (1) self-regulation, that is, to regulate its internal relationships; (2) self-academic organization, which means that it decides its academic, research and culture dissemination plans and programs; (3) administrative self-management, in other words, to freely administrate the economic resources assigned by the legislative power (González-Pérez and Guadarrama-López, 2009).

1.2.1 Water supply at University City (CU), UNAM

The Directorate of Works at UNAM is responsible for operating the water services within UNAM's campuses, in the case of CU. UNAM has a concession of the three wells by the National Commission of Water, and as a result of this concession, UNAM is not required to pay for the supply and use of water. This is of particular importance, as unlike many other smart water management projects recovered costs via reduced water consumption was not feasible in this project.

Figure 3. Location of the University City (CU for its acronym in Spanish) in Mexico City.
Source: PUMAGUA, 2012

Mexican water regulations relevant to PUMAGUA, UNAM

The following regulations were set out by the Mexican government to improve water quality in Mexico:
• Official Mexican Norms (NOM): NOM-127-SSA1-1994 (2000) for drinking water quality
• NOM-003-SEMARNAT-1997 for quality of treated wastewater
• NOM-230-SSA1-2002 for water sampling procedures
• NOM-179-SSA1-1998 for sample size requirements and sampling frequency

1.3 Water conditions at the CU when PUMAGUA was launched

Soon after PUMAGUA was launched, the team realized that, in addition to calculating the water balance, it was fundamental to assess drinking water and treated wastewater quality in order to determine compliance with Mexican regulations and to improve water safety. In addition, community participation was believed to be of the utmost importance, as the team understood that technical improvements both in water quality and in water saving would need the community's support in order to be lasting. Therefore PUMAGUA was organised into three main areas: Water Balance, Water Quality, and Communication and Participation, with three key objectives.

1.3.1 PUMAGUA's objectives:

1. To reduce potable water consumption by 50% through improved practices and leak detection;
2. To improve the quality of drinking water and treated wastewater in accordance to Mexican regulations; and
3. To promote participation of the entire UNAM community in the efficient use of water.

PUMAGUA started in the main CU campus as a pilot case in order to create a model of water management that could be exported to other campuses of UNAM, to other universities, and to other localities in the country. UNAM has six campuses throughout the country, seventeen schools in the Metropolitan Area in Mexico City, as well as research institutes and schools in 20 states of Mexico, the United States, Canada, Spain and China. In addition to the pilot case, some SWM were also implemented in other campuses of UNAM[2].

1.3.2 PUMAGUA Management

PUMAGUA comprises different members of the University: (1) The interdisciplinary team; (2) the staff of the Direction of Works; and (3) the authorities of each institute, school, and administrative office.

1. The team has had a different number of participants in the lifetime of PUMAGUA. For instance, in 2010, there were 50 participants (see organisation chart, Figure 4), while in 2017, the group is made up of 10 persons, due to budget restrictions.
   The mission of the team is to assess water management conditions (water quality, water quantity and social participation) and to issue recommendations to improve them.

2 In addition to the pilot program, water meters were placed in Facultad de Estudios Superiores Aragón (Mexico City) and in Juriquilla campus (in the State of Querétaro). Other actions not related with SWM included installing drinking water disinfection system in Facultad de Estudios Superiores Acatlán (State of Mexico) and a toilet infrastructure upgrade in Facultad de Estudios Superiores Iztacala, and Zaragoza (both in Mexico City).

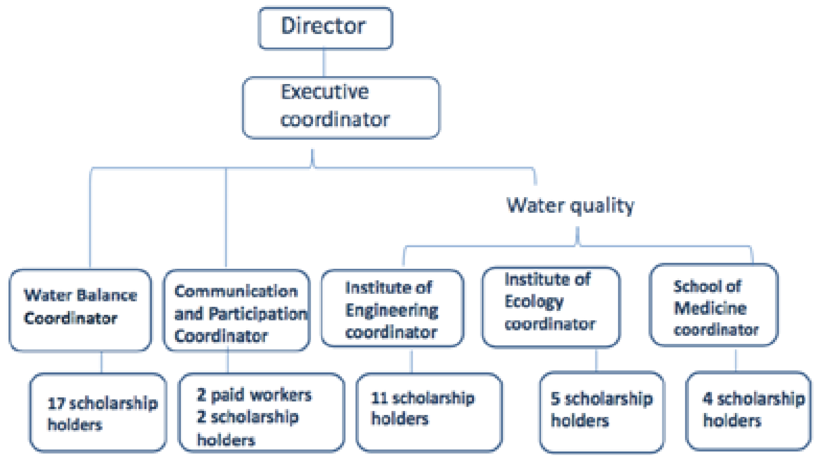


Figure 4. Organisation chart of interdisciplinary permanent group of PUMAGUA in 2010

2. Separate from the PUMAGUA group, the Direction of Works is responsible for planning and undertaking construction at UNAM, as well as operating, refurbishing, maintaining, and conserving all buildings, gardens, equipment and electromechanical installations. The area of Conservation of this office collaborates with PUMAGUA with the purpose of operating the distribution network more efficiently and particularly to detect and repair leaks. It also operates the drinking water disinfection system (Sodium Hypochlorite 13%), as well as the wastewater treatment plant.

3. The authorities of institutes, schools, and administrative offices participate in PUMAGUA by implementing actions suggested by the Program: installation of real-time water meters, drinking water fountains, and of bathroom water saving appliances (i.e. taps, toilets and shower heads); leak detection and repairing, substitution of high water consumption gardens for low consumption native vegetation, dissemination of water saving information, attendance to PUMAGUA's workshops.

2. Water challenge

Prior to the PUMAGUA program, there was not a clear understanding of the water problems at UNAM, as previously no diagnosis had been conducted. Thus there was a need to better understand the water system and the initial PUMAGUA diagnosis revealed the depth of the challenge, as outlined below. The first activity of PUMAGUA, in 2008, was a diagnosis of the water system at the University City focusing on three core issues: water quantity, water quality, and social participation.
A summary of the findings is listed below, and this section explains it in more detail.

- Absence of updated hydro-sanitary information
- Absence of water consumption measurement in buildings
- Water losses in distribution network above 50%
- Noncompliance of Mexican standards of quality of drinking water and treated wastewater
- Three treatment plants needing refurbishment
- 26 integrated anaerobic bio-reactor plants needing removal

- Absence of a program that incited participation of university schools, institutes, and offices in responsible water management and use
- Lack of knowledge about the water management system among CU's community
- Reluctance of academics for water conservation measures that could imply some level of compromise
- Highest willingness to participate found among students
- No specific irrigation method and water saving was not found as an objective of this activity.

2.1 Water quantity

To assess the volume of water used on site, the Directorate of Works analysed the information available on the hydro-sanitary infrastructure (i.e. the water distribution and wastewater collection networks), and measured drinking water supply and leaks using water meters.

A lack of hydro-sanitary information was immediately detected, including the layout of the distribution network. The only blueprints available were on paper as there was no online system available to upload them to (see Figure 5). Consequently surveys took place in order to determine the pipeline routes and to draft and digitalize hydro-sanitary blueprints. A total of 54 km of drinking water pipelines were identified. It was also found that there was no water consumption measurement within the buildings. None of the water meters installed in the past were working when the diagnosis took place.

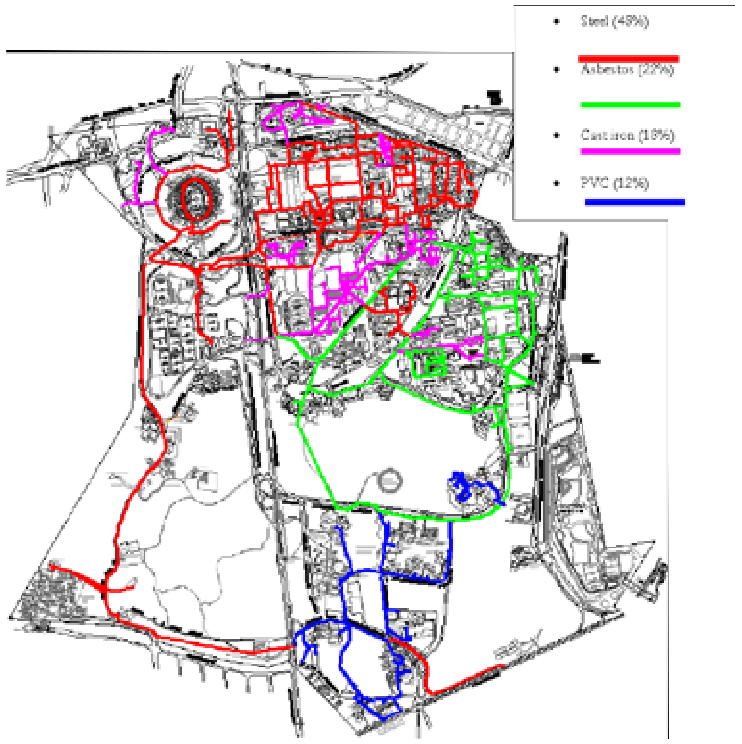


Figure 5. Digitalized water supply network of the University City of UNAM. Pipeline colours correspond to different materials: steel, asbestos, cast iron, and PVC.
Source: PUMAGUA, 2012

Thirty percent of a sample of toilets and faucets were not working properly. After the assessment, a full inventory of infrastructure was created. The water system identified is briefly described below in Box 5.

Water infrastructure prior to SWM implementation

Drinking water infrastructure:
- 3 wells, with an average extraction of 100 l/s
- 3 storage tanks with a capacity of 12,000 m^3
- 54 km of pipelines

Wastewater infrastructure:
- 18 km of sewage pipelines
- 1.8 km of rainwater drainage
- 3 treatment plants and 26 small, integrated anaerobic bio-reactor plants.
- 13 cisterns of treated wastewater for irrigation of the university gardens

Pressure modelling and sectorisation:
Pressures in the distribution network were modelled using the software EPANET, and five hydraulic sectors were defined in order to facilitate leak detection (Figure 6).

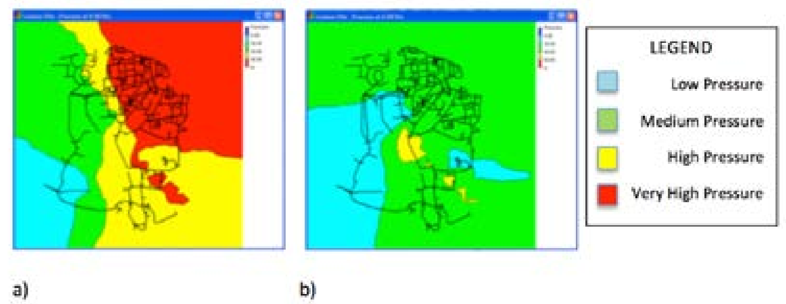


Figure 6. Simulation of the distribution network of the University City of UNAM a) without pressure control, and b) with pressure control
(PUMAGUA, 2012)

According to measurements performed by PUMAGUA, over 50% of water extracted from the wells was lost through leaks and operation wastes (for instance, 5000 liters were lost per day in a laboratory that did not have water recirculation or cooling). Figure 7 shows the water balance in 2008.

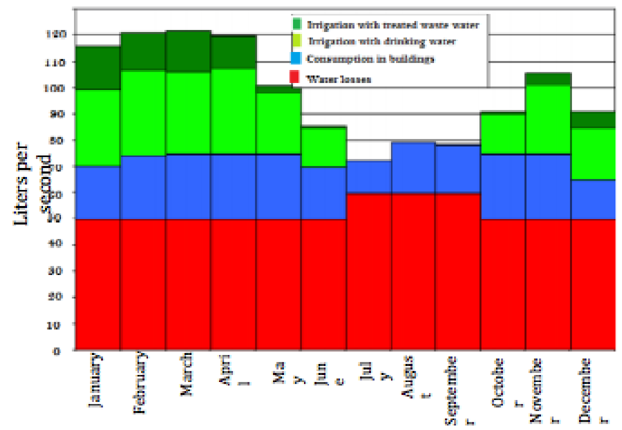


Figure 7. Water uses of University City, in 2008, according to which water losses were over 50% of water supply.
Source PUMAGUA, 2008

2.2 Water quality

Water quality at CU was analyzed both before and after disinfection in order to (1) determine if there were pollution threats in the groundwater and (2) to determine if the disinfection system worked properly. Periodical sampling of ground water was performed from 2008 to 2010. This allowed the identification of potential health hazards, such as the sporadic occurrence of Total Coliforms and Faecal Coliforms. The water quality analysis showed nitrate levels were close to the established limits in national regulations (NOM-127-SSA1-2000: 10 mg/L nitrates).

Water quality after disinfection with chlorine was also determined. Samples were sent to an external certified laboratory for the analysis of the 41 parameters comprised in the Mexican drinking water standard. All parameters complied with the standard, except for free residual chlorine (FRC), which is fundamental to prevent the growth of microbiological organisms. FRC was found to be below its minimum ´permissible' limits Figure 8 shows free residual chlorine concentration in one of UNAM's buildings.

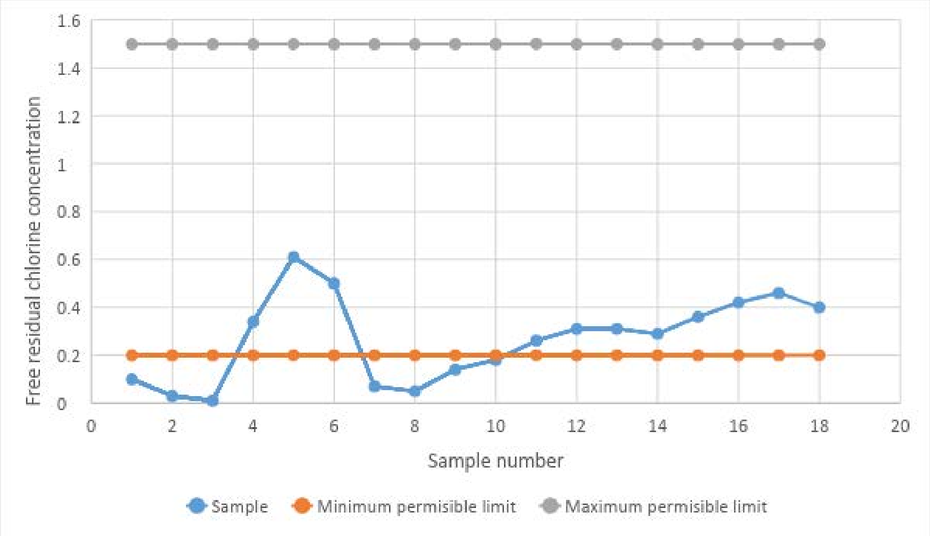


Figure 8. Concentration of free residual chlorine in 18 samples of disinfected water at Universum Museum, University City, UNAM, in 2008.
Source: PUMAGUA, 2008

To assess the water quality on site, an in-situ water sampling program was also carried out, assessing the water quality in the water wells, the distribution system, and the drinking water tanks (Orta de Velásquez et al. 2013). The sampling points were selected based on Mexican Standards, empirical criteria and the application of probabilistic systematic sampling. Initially 20 sampling sites were established to cover the five hydraulic regions; and testing was performed monthly. Concentrations of FC, TC, and free residual chlorine (FRC) in water were assessed. Figure 9 shows the FRC and coliform bacterial densities obtained in 2012.

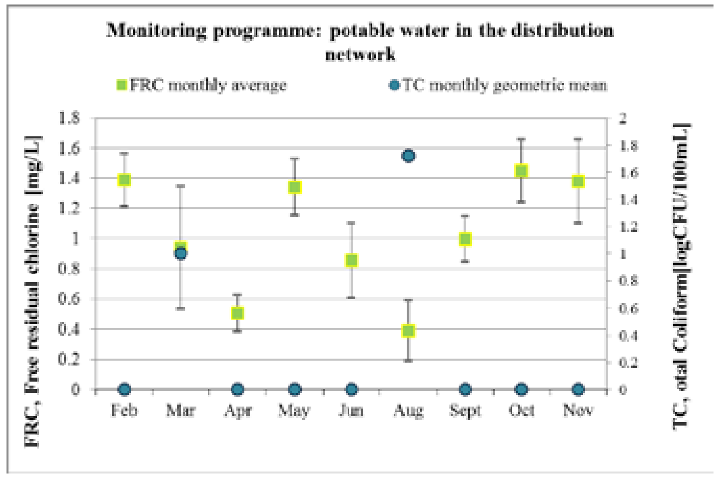


Figure 9. Free residual chlorine concentration and coliform bacterial densities in different points of the water supply network of the University City of UNAM throughout the year. Results display FRC intervals with a 95% confidence level.
Source: Orta de Velásquez et al. 2013

The main treatment plants and their effluents were also evaluated (Figure 10). The Direction of Works operates three wastewater treatment plants (WWTP) distributed around the campus. The team determined that water quality from the three plants did not comply with Mexican regulations. Consequently, the team recommended refurbishment of the three plants (PUMAGUA, 2008).

In 2008, there were also 26 small Integrated Anaerobic Bio-Reactor Plants (BRAIN, for its acronym in Spanish) spread throughout the campus. Due to lack of maintenance, water quality within BRAIN did not comply with Mexican regulations. Therefore, PUMAGUA suggested to close the 26 plants.

Figure 10. "Cerro del Agua", main Wastewater treatment plant of the University City, in 2008. It comprised:
a) Pre treatment: sand traps and screens for elimination of large solid particles; b) Flow meters: three flow meters parallel to each other; c) Secondary treatment: Activated sludge treatment, rotatory biological discs, and spray filter (all used within the same WWTP); d) Tertiary treatment: sand traps (filters) and disinfection.
(PUMAGUA 2012)

The distribution system of treated wastewater was also analysed. Within the campus water distribution system, treated water is pumped to cisterns from where water is distributed for the irrigation of gardens. Since 2008, the effluent's water quality has been analyzed every month with regards to FC, helminth eggs, fats, oil and greases, Biochemical Oxygen Demand, Chemical Oxygen Demand, and Total Suspended Solids. The PUMAGUA team assessed the physical and operative conditions of the plants and concluded that they were operating below design capacity, did not have adequate physical conditions and their effluent quality did not comply with Mexican regulations (Orta Velásquez et al. 2013).

Likewise, inspections of the storage cisterns revealed that most of them had inadequate physical conditions (lack of lid, leaks, rusted metal parts, etc.), as shown in Figure 11. It was deemed that the water stored in the cisterns did not comply with local regulations (Orta Velásquez et al. 2013).

Figure 11. Inadequate conditions of some storage cisterns located at the University City. (PUMAGUA, 2012)

2.3 Social participation

The initial PUMAGUA diagnosis of the water system at UNAM CU also revealed that there was no program within the University to encourage authorities of schools, institutes or administrative offices to implement actions to lower water consumption or water pollution inside buildings.

A stratified survey was developed in 2009 by the PUMAGUA team, in order to establish a baseline of CU's community who participate in responsible water management and use. The variables assessed were knowledge, beliefs, attitudes, practices, and preferred means of communication. The team believed that communication and training activities could be better designed if these variables were determined.

Face to face interviews were carried out applying a questionnaire to a sample of 1,480 people of different sectors (academics, students, administrative workers, laboratory staff, housing residents, and visitors), and special workshops took place for gardeners in order to determine their watering methods.

These were the main findings of these activities:

- There was limited knowledge of the water management system among all sectors.
- Less than half of interviewees noticed water waste in the campus.
- A significant portion of the participants (over 40%, particularly administrative staff) believed that UNAM's authorities did not care about water waste.
- Students were the only sector that specifically recognised their own responsibility in water waste.
- Academics were the sector with the least willingness to accept measures for water conservation that would require some level of compromise.
- Only one third of academics had been trained to adequately dispose of chemical residues in laboratories.
- Very few maintenance workers had received any sort of training regarding responsible water management.

- Multiple watering methods were used, without detectable criteria and without the purpose of saving water. Each gardener did as they thought best, in terms of frequency and duration of watering, to keep gardens green.
- Bottled water use at UNAM was high, with 80% of those surveyed at UNAM drinking bottled water instead of tap water.

The results of this questionnaire display the low engagement of the UNAM population with the importance of water conservation.

Bottled water versus tap water consumption in CU, UNAM, in 2012

According to Espinosa et al. (2014), in 2012, only 14% of the university community consumed tap water exclusively, while 75% consumed bottled water, and 11% consumed both. Bottled water was preferred mainly for organoleptic reasons (taste, colour, turbidity, odour), as 54% of respondents pointed out this reason, while health was the second reason (26% of respondents).

3. Smart water management solutions

The smart solutions integrated into PUMAGUA are organised in three main areas (as shown in Table 1):

- Water quality solutions
- Water quantity solutions
- Participatory community solutions

Table 1. Smart Water Management solutions

	Water Problem Addressed		
SWM TOOL	Water Quality	Water Quantity	Participatory Community
Water Observatory	X	X	X
Real-time monitoring sensors	X	X	
Telemetry system		X	
Outreach activities			X

3.1 Water Quality Solutions

3.1.1 Operation of real-time water quality monitoring system

In order to have reliable and constant information about water quality, a real time monitoring system was installed in the Institute of Engineering, where one of the researchers responsible for the Water Quality area of PUMAGUA, Doctora. Teresa Orta, is based. Real time monitoring was implemented by means of a data collection sensor system, located in one of the buildings of the Institute of Engineering of UNAM. Due to economic reasons, only one of these systems could be installed. The sensors measure six physicochemical parameters: free residual chlorine, conductivity, nitrates, pH, turbidity and temperature, through a constant water flow from the distribution network. The system collects measurements of the aforementioned parameters every five minutes and sends them through a local area network to a web site provided by the manufacturer (Figure 12).

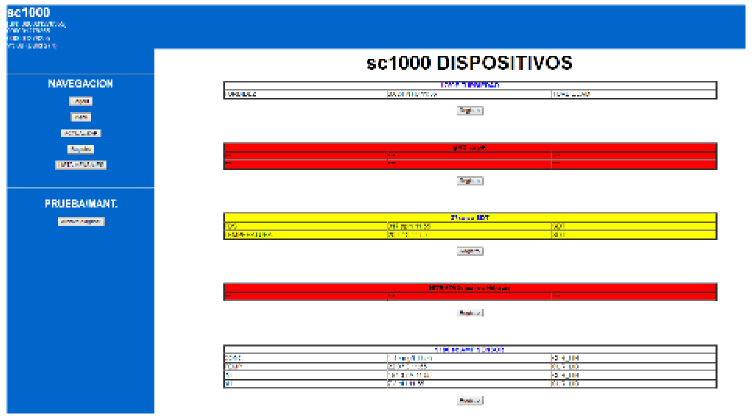


Figure 12. Download platform of the real time water quality monitoring system.
Source: http://132.248.156.11

The sensor system consists of a controller and four sensors (Figure 13), one for each physicochemical parameter, with the exception of pH (measured by the chlorine sensor) and temperature (measured by the conductivity sensor). Water from the distribution network is fed to each sensor from a tap connected to PVC pipes (Figure 14).

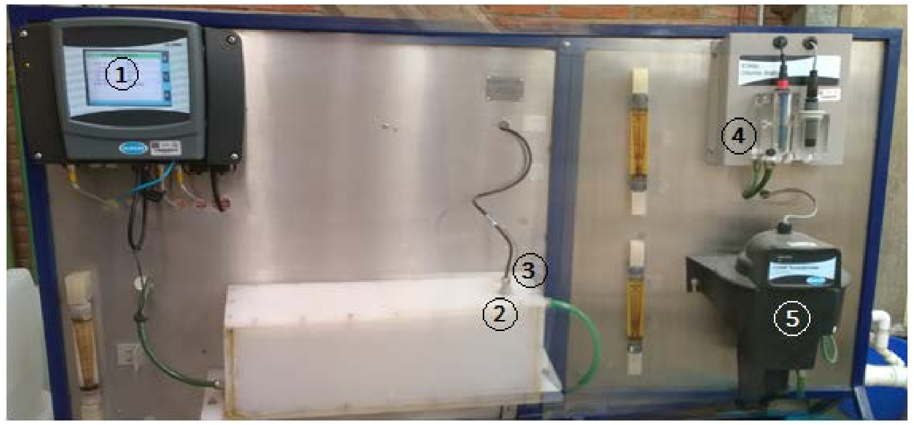


Figure 13. Real time water quality monitoring system, located at the Institute of Engineering, UNAM: (1) Controller, (2) Conductivity sensor, (3) nitrate sensor, (4) chlorine and pH sensor, and (5) turbidity sensor.
Source: HACH Company, 2006

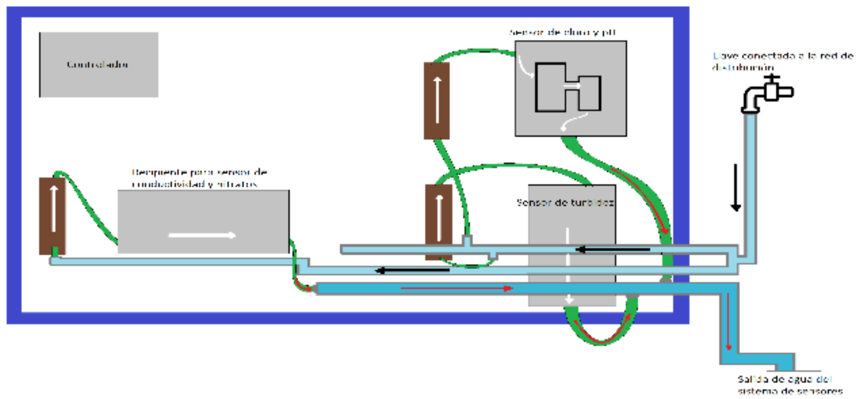


Figure 14. Water inflows and outflows in the real time water quality monitoring system. Water from the distribution network feeds this system. Black arrows represent water flowing into a sensor, while red arrows represent water flowing out of the system.

Conductivity and temperature sensor

This sensor generates a low current whose intensity is then measured by a detector. The intensity of the current corresponds to the conductivity of the volume of water in which the sensor is submerged (Figure 15). This sensor also has a resistance temperature detector.

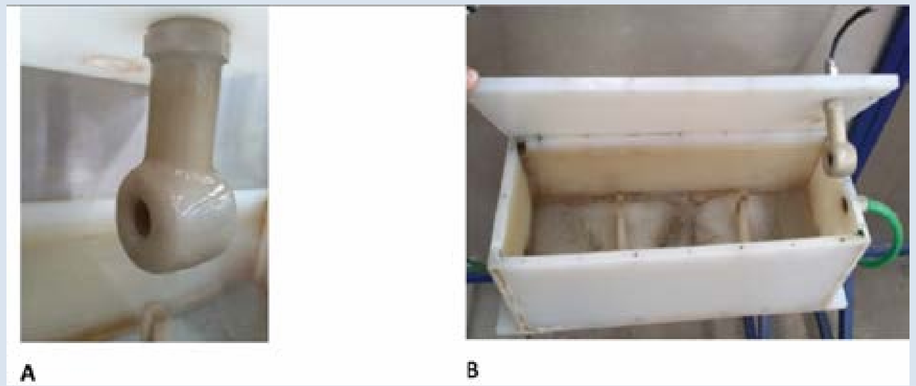


FIGURE 15. (A) Conductivity sensor of the real time water quality monitoring system; (B) a container was built to allow constant water flow. Source: Stephanie Espinosa, 2016.

Nitrates sensor

The Nitrate sensor measures photometrically the concentration of nitrates diluted in water. Similarly to the conductivity sensor, the nitrate sensor must always be submerged in water (Figure 15-B) so that it can emit ultraviolet light. Two receptors then measure absorbance (Figure 16): one of them works as a control element, while the other functions as a measurement element. The measured absorbance corresponds to the difference between the emitted light and the receiving light after its interaction with diluted nitrates.

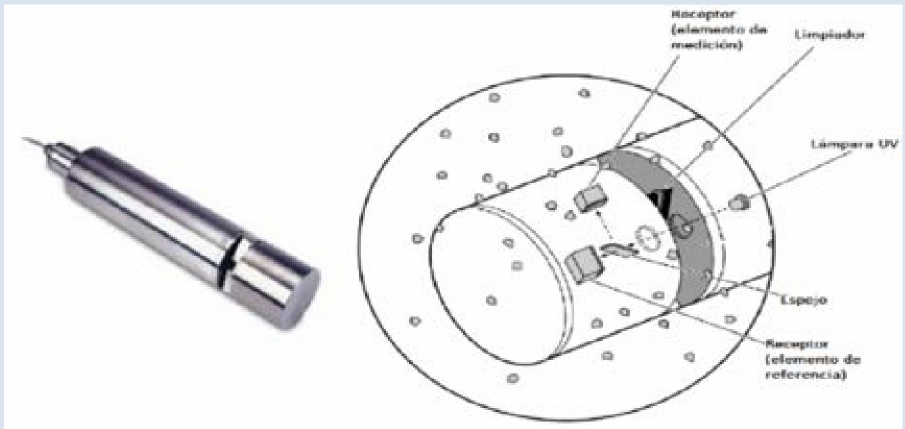


FIGURE 16. Components of the nitrate sensor. From top to bottom: Receptor (measurement element), cleaner, UV lamp, mirror and receptor (reference element). Source: HACH Company, 2006

Free residual chlorine and pH sensor

The free residual chlorine and pH sensor measure the concentration of free residual chlorine in water. This compound is made of diluted chlorine (in low pH conditions), hypochloric acid gas and hypochlorite ions. The concentration of each of these elements depends on pH and temperature. As the concentration of hypochlorite ions depends on pH, this sensor has a potentiometer (Figure 17).

The sensor comprises a gold electrode, a counter electrode made of silver, an electrolyte (potassium chloride solution), and a micropore membrane, which is selective to hypochloric acid (HOCl) (Figure 17).

When the water sample is in contact with the membrane, HOCl molecules disseminate into a narrow area between the membrane and the cathode, which contains chloride potassium. At this point, a constant potential is applied to the cathode and the HOCl consequently decomposes in chlorine ions and water. The system calculates free residual chlorine by using the dissociation curves of HOCl.

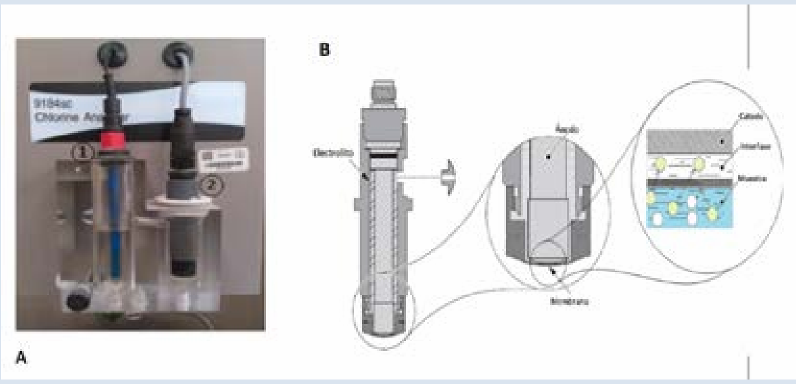


FIGURE 17. (A) pH sensor (1) and free residual chlorine sensor (2); (B) The free residual chlorine sensor consists of an anode, a cathode, and electrolyte solution and a membrane, which is selective to HOCl. From left to right, and top to bottom: Electrolyte, anode, membrane, cathode, interphase, sample. Source: HACH Company, 2006

Turbidity sensor

The turbidity sensor measures water turbidity as follows: 1) it emits a beam of light that passes through the water sample, 2) a submerged photocell then detects the light disseminated by the particles at an angle of 90º with respect to the central line of emitted light. Consequently, the greater the amount of suspended particles, the greater the amount of light disseminated towards the photocell and the higher the turbidity of the sample (Figure 18).

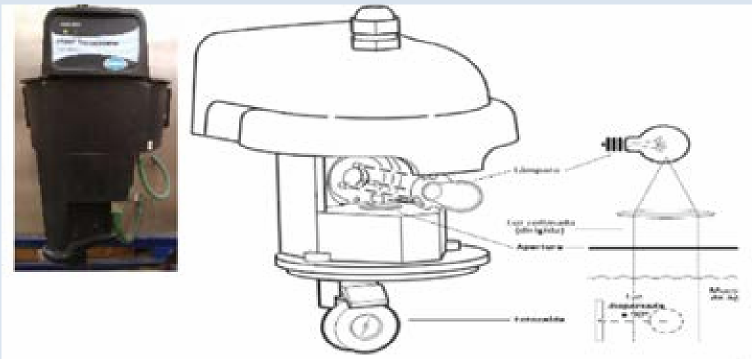


FIGURE 18. The turbidity sensor and its components. Source: HACH Company, 2006

3.1.2 Water Quality in the online Water Observatory of UNAM

The Water Observatory platform (shown in Figure 19) is an online platform that hosts the real-time data for the water users at UNAM. It has two modes, 1) administrator (which is accessible only by the staff at PUMAGUA) and 2) user (which is accessible to anyone with access to the internet). The two modes were designed to enable PUMAGUA to store all of the data in one location, while providing relevant information to the community. The decision to provide different access levels to information for the administrator and the user mode was made as a result of the abundant volume of data provided to the platform, and the need to allow the regular user to quickly access information. In addition to this, much of the technical information may be difficult for the general public to understand and might cause unnecessary alarm, while it is of the utmost importance for PUMAGUA to be aware of this data, in order to take action in case of eventualities.

The Water Observatory summarises the results obtained from the water quality analysis. Drinking water results are displayed based on three types of monitoring approaches: real-time information from sensors, on-site sampling carried out by PUMAGUA, and on-site sampling carried out by an external certified laboratory. It also hosts treated wastewater results from the on-site sampling in the Wastewater Treatment Plant of “Cerro del Agua” and six wastewater storage tanks.

On the left side of the main screen, a map of the main campus of UNAM is displayed, in which the items of interest are depicted. Information about the date of monitoring, type of water, and the water source is linked to each element displayed in the map.

The right side of the map provides an option menu. In the administrator mode, the option menu consists of eleven search criteria in order to be able to select specific consultations for each site (Figure 19).

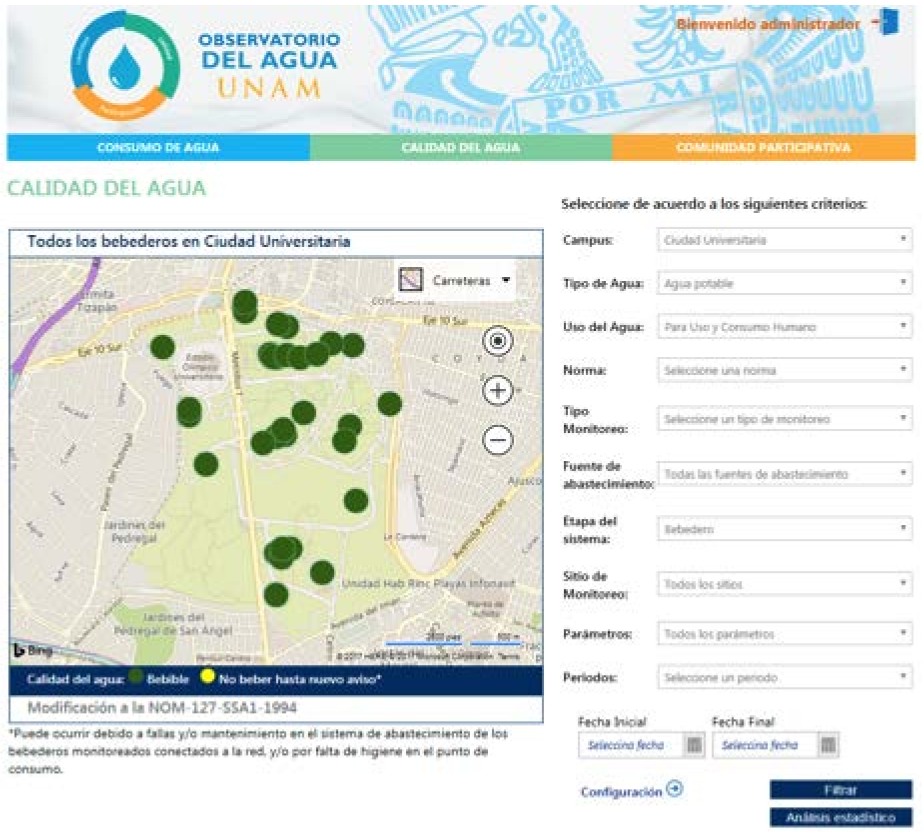


Figure 19. Screenshot of the online Water Observatory, shown in the administrator mode in Spanish.
Source: www.observatoriodelagua.unam.mx

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The list below details the functions available in the option menu of the Water Observatory platform:

(1) Campus: Currently the information comes from the main campus only but in the future other campuses can be included.
(2) Type of water: drinking water or treated wastewater.
(3) Use of water: human use and consumption (for drinking water only), reuse in gardens (for treated wastewater only). In the future, reuse in toilets may be added.
(4) Applicable regulation: there are three reference standards: (1) drinking water quality, (2) treated wastewater quality (3) conditions of storage tanks.
(5) Type of monitoring: real-time or in-situ sampling.
(6) Water source: specific well, in the case of drinking water; and specific treatment plant, in the case of treated wastewater.
(7) Monitored element: drinking fountain, distribution network, intake, storage tank, regulation tank.
(8) Location of monitored element: school, institute, or administrative office.
(9) Parameter: This option includes the five parameters measured in real time, the three parameters monitored in-situ by PUMAGUA, and the 41 parameters analyzed by the external laboratory.
(10) Period: Regarding the real time sensors, the platform can show daily information, as well as data from several days, months or years.

A graph of the information presented within the platform can also be obtained.
In the user mode, only five options are shown, all related to drinking water:

(1) Campus
(2) Type of water: drinking water
(3) Type of monitoring: real-time or in-situ sampling
(4) Monitored element: drinking fountain, distribution network
(5) Location of monitored element

The site map is useful for users as it shows the real-time water quality of each element (e.g. drinking fountain, intake, or distribution network) on the campus. When the water quality of an element complies with the national Mexican water regulations, it is depicted in green on the map. When it does not, it is depicted in yellow. A pie graph showing the percentage of total data complying with Mexican water quality regulations is shown in Figure 20.

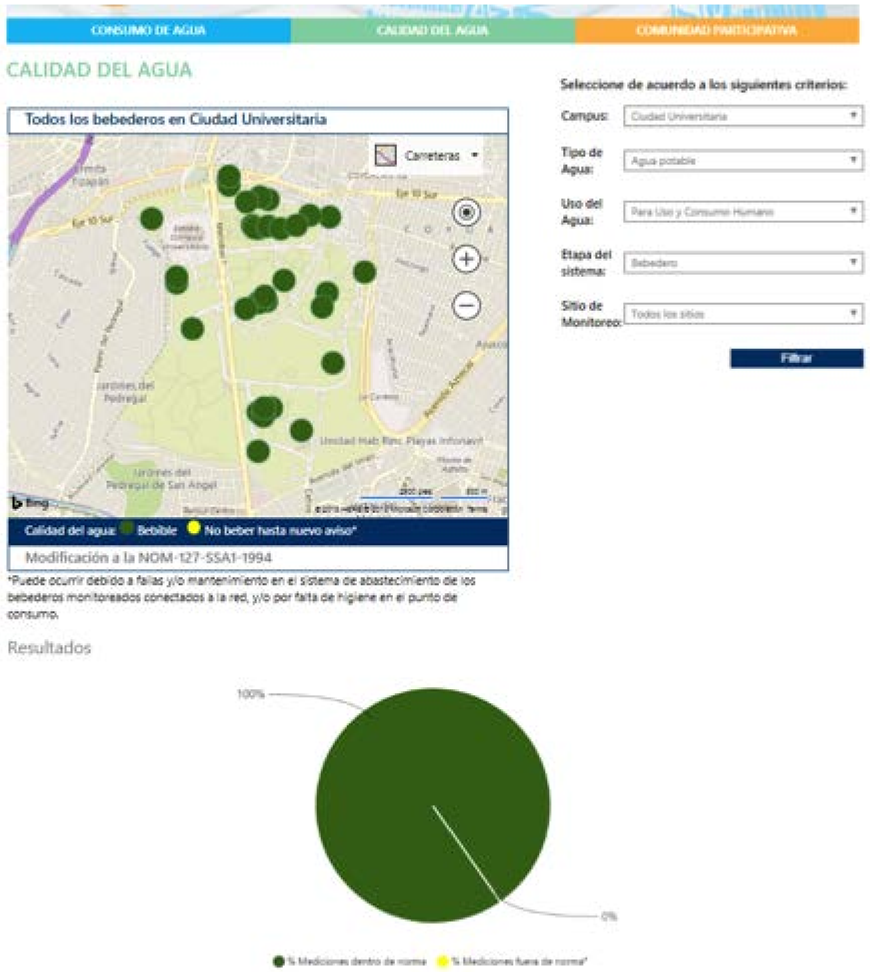

Figure 20. Information provided to a regular user by the Water Observatory of UNAM. This example shows the drinking devices whose water complies with regulation, i.e. potable water (green dots), and the water that is not to be consumed until advised due to bacteria contamination (yellow dots). The pie chart shows the percentage of compliance (100% green).
Source: http://www.observatoriodelagua.unam.mx/CalidadAgua/CalidadIndex

Statistical analysis can be performed with all the information stored in the database, since 2013. Correlations and variance analysis can also be carried out using the real-time data (Figure 21).

Figure 21. Example of statistical analysis performed by the Water Observatory of UNAM, regarding the concentration of free residual chlorine in January 2014.
Source: http://www.observatoriodelagua.unam.mx/CalidadAgua/AnalisisCalidad

3.2 Water Quantity Solution

3.2.1 Water consumption measurement points

Measurement points to assess water consumption were selected according to criteria established in various handbooks, such as the (Mexican) Handbook of Drinking Water and Sanitation (MAPAS for its acronym in Spanish) and the handbook of the National Water Commission. Electromagnetic water meters were used for macro measurement (wells, tanks, hydraulic sectors), while for water intakes of buildings (micro measurement) volumetric meters were installed (see Figure 22).

Figure 22. Electromagnetic water meters (left) and volumetric meters (right).
Source: PUMAGUA, 2012

PUMAGUA has installed 9 macro meters across the UNAM CU distribution system, one in each well, in the supply points of each hydraulic sector, and one for repumping from one tank to another. There are also 210 micro water meters in the water intakes of buildings.

3.2.2 Remote measurement

For the remote measurement system, a protocol of communication through radio frequency was selected, using a range of 900 and 920 MHz. For this kind of transmission, it is necessary to install Gateway antennas that receive data from radios of water meters every five minutes. At this point, analogous information is converted to digital information. Antennas have a radius coverage of one kilometre with line of sight. Seven antennas were installed in different parts of the campus to provide decent coverage (see Figure 23). To enable communication between antennas and water meters, it was also necessary to install 30 repeaters or boosters (used to receive the signal and send it to another receptor) throughout the campus.

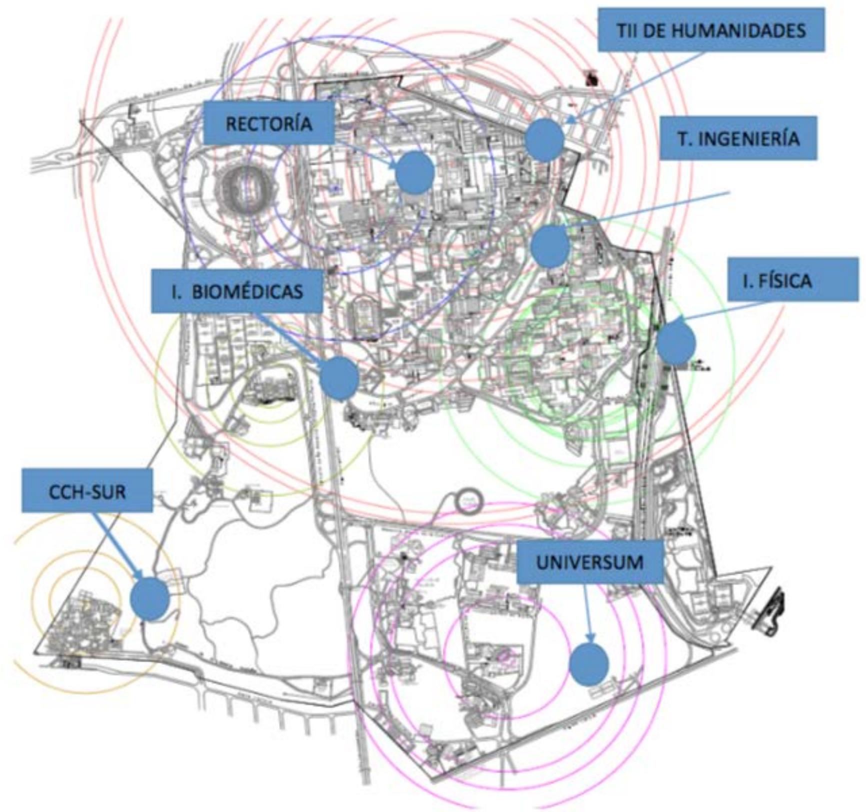

Figure 23. Location of antennas, as part of the real-time monitoring system in the main campus of UNAM. Labels represent the building names where the monitoring systems are implemented.
Source: PUMAGUA, 2012

3.2.3 Architecture of the Telemetry System

Measurement points, data transmission, data collection, as well as the presentation interface are all part of the telemetry system installed in the main campus of UNAM (Figure 24). For the whole system to be reliable, it is of the utmost importance that each one of these elements works properly.

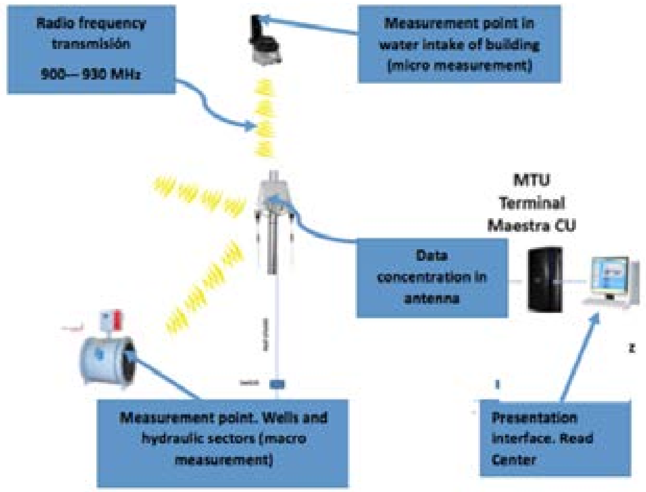

Figure 24. Telemetry system installed in the main campus of UNAM, including macro and micro meters, an antenna and the server where information is displayed and analyzed.
Source: PUMAGUA 2012

Information from water meters linked to the remote lecture system is processed, analysed and displayed using the software Read Center (from Badgermeter). Read Centre is a reading data management software application that provides a central location for performing various meter-reading tasks. It allows data sharing across meter reading solutions offered by this company.

The software is made up of three components (see Figure 25):

- A server (Monitor) that handles communication with the Gateways.
- A client (Control) that defines reading schedules, performs system management, and runs reports.
- A database server that stores information.

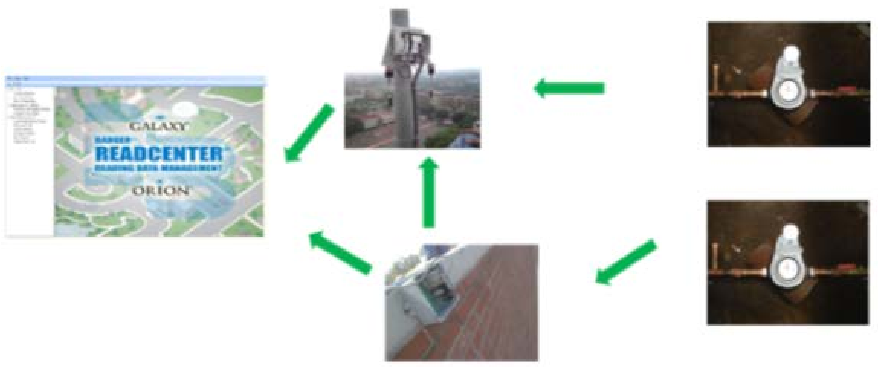

Figure 25. Direct and indirect transmission of water consumption information in the main campus of UNAM.
Source: PUMAGUA, 2016

For the water meters that have not yet been linked to the system, PUMAGUA's staff make regular trips to collect the data with a portable computer called Ranger Trimble. This is possible as the water meters have a data logger that stores information every hour. The collected data is later processed manually in Microsoft Excel.

3.2.4 Water Quantity in the Water Observatory of UNAM

In order to link the database of Read Center with the database of PUMAGUA, additional software was developed for PUMAGUA. This software collects information from the Read Centre database, replicates the information and modifies its structure in order to make it compatible with the Water Observatory database. The latter database is administered and operated with the SQL Server software. The water consumption measurements collected with the portable computer are also stored in this database (Figure 26).

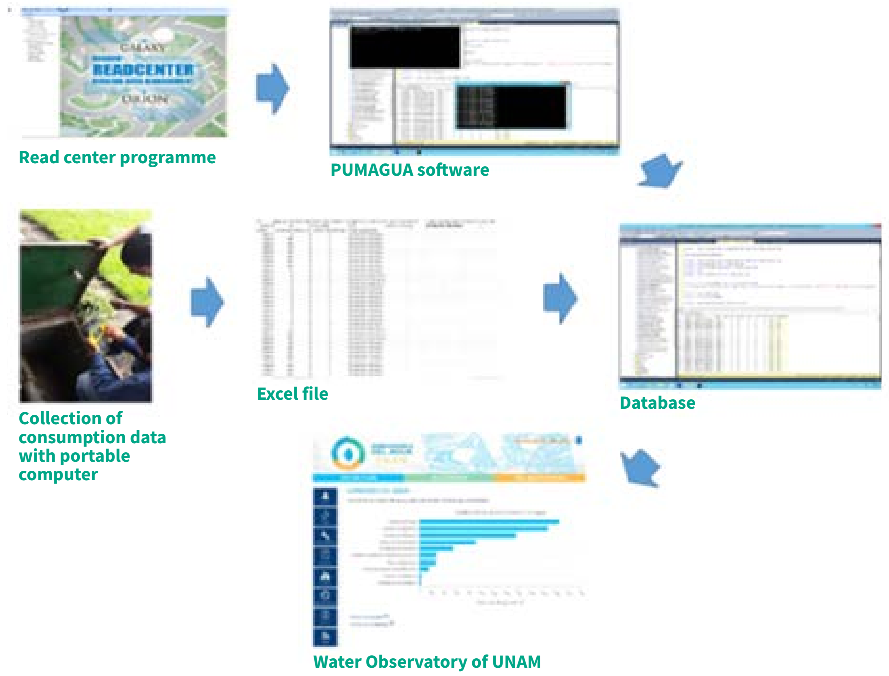

Figure 26. Integration of information to PUMAGUA database and to Water Observatory of UNAM from water meters linked to the remote system and from water meters that have not been linked yet.

The ReadCenter program stores water quantity data, which the Water Observatory then processes and displays. In Figure 27 you can see the main screen, which shows a graph of the monthly water consumption of ten randomly selected institutions (schools, institutes or administrative offices).

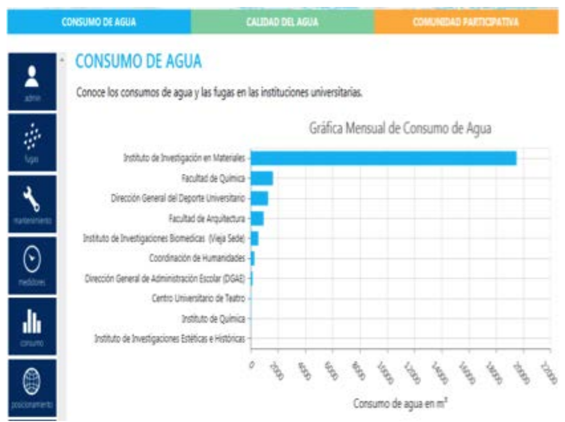

Figure 27. Main screen of the water quantity section, showing monthly water consumption of ten schools/institutes/offices randomly chosen every month.
Source: http://www.observatoriodelagua.unam.mx/Cantidad/ConsumoIndex

In the administrator mode of the Water Observatory for water quantity monitoring, the left-hand menu has eight functions:

1. Allows you to include or to eliminate any displayed element, such as water meters, antennas, or repeaters.
2. Shows the magnitude of leaks related to each water meter, through micrometers, which send continuous information in real-time. When the consumption appears to be constant, particularly during the low-use periods, such as at nighttime, the system determines that there may be a leak. This is then verified in-situ to determine the extent of the leak and to resolve the issue as quickly as possible. (Figure 28).

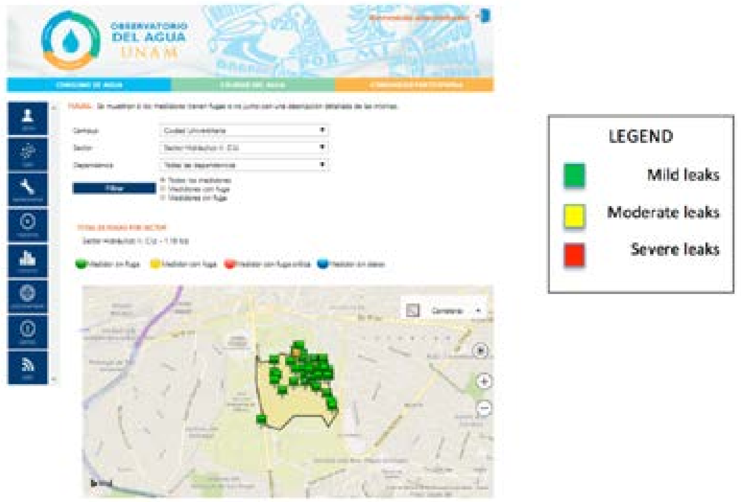

Figure 28. Screenshot of the Water Observatory of UNAM showing leak magnitude. One of the hydraulic sectors of the main campus is represented in the map.
Source: http://www.observatoriodelagua.unam.mx/Cantidad/Fugas

3. Shows the maintenance due date of water meters. It is presented as a “traffic light” system, in which if the maintenance due date is far off, a green colour is shown; if the due date is approaching, a yellow colour will be shown, and if the due date has already passed, a red colour will appear.
4. Displays every water meter installed in UNAM’s campuses. A short data sheet is linked to each device, which shows the number of the water meter, its location and its average water consumption (see Figure 29).

Figure 29. Identification of water meters and their fact sheets within the water quantity section of the Water Observatory of UNAM.
Source: http://www.observatoriodelagua.unam.mx/Cantidad/Medidores

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5. Shows the measurement of water supplied to each intake that has a water meter installed. Graphs showing daily, monthly, and yearly consumptions are displayed (see Figure 30). It is possible to make comparisons between consumptions of the University units, as well as comparisons between different periods for a given unit. This is considered one of the most important functions of the Water Observatory platform.

Figure 30. Graph showing annual water consumption of one of the buildings of the Institute of Engineering, UNAM.
Source: http://www.observatoriodelagua.unam.mx/Cantidad/Consumo

6. Displays the location of the entire hydraulic infrastructure, including wells, tanks, pipelines, antennas, signal repeaters, water meters, etc.
7. Provides access to an alarm system. In this function, it is possible to include a list of the emails of people to be notified in case of an occurrence, such as leaks that require immediate attention.
8. Enables you to check the signal quality of each water meter. If a signal is too week, PUMAGUA’s staff will physically inspect the water meter or the repeater to solve the problem.

With regards to the user mode, there are only two functions available: consumption and leaks, as it was considered that this would be the information of most interest for a regular user. For the same reason, consumption and leaks refer to a whole institution (school, institute, administrative offices) and not to each water meter.

3.3 Participatory Community Solution

In order to enhance community participation in responsible use and management of water at UNAM campuses, several activities have taken place:

- Regular meetings with authorities of institutes, schools, and administrative offices to invite them to implement the following actions: installation of water meters, installation of water saving toilet appliances, landscape management, installation of water fountains, attendance at PUMAGUA’s workshops, and dissemination of PUMAGUA’s communication campaigns.
- Activities addressed to students and academics, such as contests of proposals to improve water management and use, water festivals, artistic contests, water audits at schools.

- Capacity building activities, such as workshops for maintenance staff and for gardeners.
- Undergraduate and postgraduate theses conducted under the supervision of PUMAGUA.
- Popular science and indexed articles (e.g. Modern Environmental Science and Engineering; Rivista Digital Universitaria; Revista Ciencia y Desarrollo; and Revista ¿Cómo ves?)
- Appearance in the media: newspapers, television, radio, and digital media.

The PUMAGUA "Participative Community" module is comprised of two elements. The first is the implementation of the aforementioned six actions suggested by PUMAGUA to the schools, institutes and administrative offices of UNAM. The platform assigns different weights to each action according to their impact on water saving. For example, the installation of water meters and toilet appliances had a higher weight than workshop attendance. The actions are then added up and a "medal ranking" is applied. Consequently, each entity is awarded a gold, silver, or bronze medal (see Figure 31). The purpose of this system is to give recognition to the most enthusiastic institutions and therefore encourage participation in responsible water use.

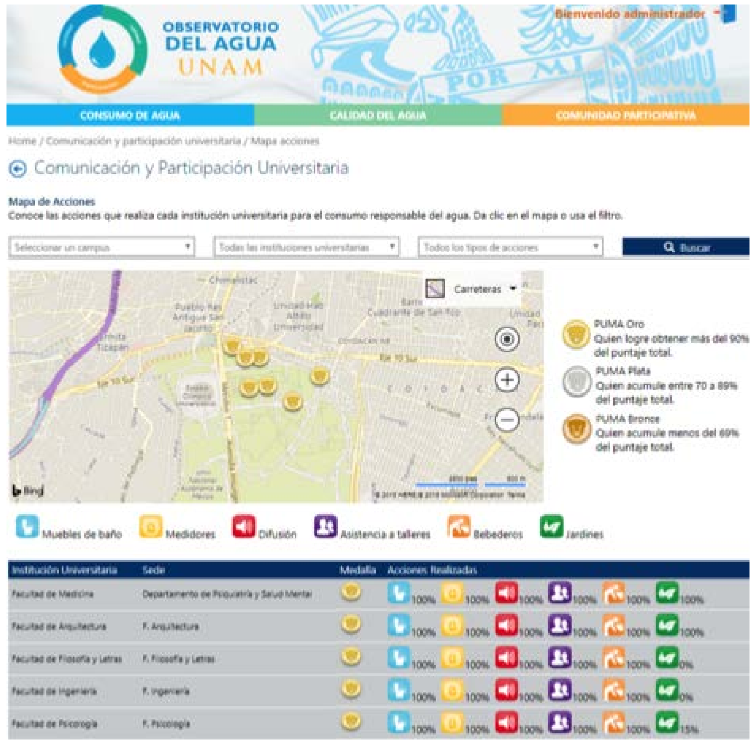

Figure 31. Screenshot of the Participatory Community module of the Water Observatory, showing water saving actions implemented by institutions of UNAM, as well as the "medal" assigned as a result.
Source: http://www.observatoriodelagua.unam.mx/Comunidad/MapaAcciones

The second element of the "Participative Community" module consists of a survey designed to enable PUMAGUA to send questionnaires to different university constituencies: students, professors, researchers, administrators, and maintenance staff (see Figure 32). The purpose of the survey is to assess the community's perception regarding water management at the campus as well as to learn their attitudes, beliefs, and behaviors regarding water use.

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Figure 32. "Participative Community" screenshot of the Water Observatory of UNAM, showing the surveys implemented, as well as a graph displaying the results of one of those surveys.
http://www.observatoriodelagua.unam.mx/Comunidad/ModuloEncuestas

3.3.1 Dissemination of the Water Observatory of UNAM

In order to announce the Water Observatory of UNAM to the Mexican public, a press conference, organized by the General Direction of Social Communication of UNAM, took place in December 2016. The general structure as well as all the functions of the Observatory were explained. Likewise, the Water Observatory was included in the most important means of internal communication.

Announcements of the UNAM Water Observatory in digital media

Gaceta UNAM
http://www.gaceta.unam.mx/20161215/monitoreo-en-tiempo-real-del-agua-en-distintos-espacios-de-la-universidad/

UNAM en línea
http://www.unamenlinea.unam.mx/recurso/83546-observatorio-del-agua

Fundación UNAM
http://www.fundacionunam.org.mx/ecopuma/unam-monitoreara-uso-de-agua-en-tiempo-real/

3.4 Benefits of SWM solutions within the PUMAGUA Program

3.4.1 Water quality

The use of smart technology has been highly beneficial for PUMAGUA and for the University community. It has helped the community to gain confidence in the drinking water quality, through enabling the immediate detection of issues in the water and providing transparency through real time water quality data. In addition, having automated monitoring and control systems for the water on campus has increased trust within the community, as there is less potential for mistakes than with manual monitoring. Implementing SWM technology at UNAM has also resulted in a rapid response time when a water quality parameter does not comply with Mexico's water quality regulations, enabling water quality to remain within drinking water requirements at all times.

Furthermore, the automation of water quality monitoring has resulted in an increase in acceptance and trust in drinking tap water on campus. In 2012, a face-to-face survey conducted on the main campus of UNAM, found that only 14% of those interviewed drank the tap water on campus (Espinosa et al. 2014). In contrast, in 2017, an online survey, via the Water Observatory of UNAM, found that 49% of interviewees were now drinking the tap water (either directly from the tap or from a water fountain). While care should be taken with the comparison between these results as the first survey was conducted using randomly selected participants, while the second was advertised in PUMAGUA's social networks, the significant increase in willingness to drink tap water on campus indicates the benefit of continuous monitoring and display of information.

3.4.2 Water quantity

The use of smart technology for water quantity measurement was fundamental to gain control over the water supply and distribution system at UNAM. It permits the accurate measurement of water consumption, allowing for comparisons between institutions and between different periods for the same institution. This information is then used to encourage water saving actions across the campus. Smart technology also permits the identification of leaks and classifies them according to their volume, which in turn, allows rapid response times for major leaks.

Water consumption measurement and leak repairs have helped to obtain a consumption pattern of UNAM institutions that corresponds to institutions characteristics, such as whether or not they have laboratories or gardens, and their population number, etc. (Figure 33). Before the SWM technology and intensive leak repair, water consumption did not correspond to the type of institutions.

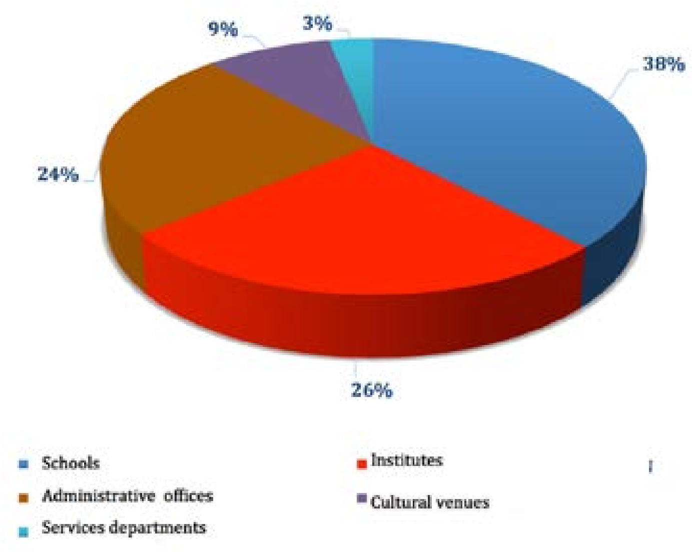

Figure 33. Water consumption pattern of different type of institutions in CU, UNAM

3.4.3 Enablers

The following is a list of project elements that contributed to PUMAGUA's success at UNAM:

- Establishment of a dedicated program and staff (i.e. PUMAGUA), with the participants deeply dedicated to PUMAGUA's goals, working even on holidays.
- Interest of specific authorities (directors, secretaries of Institutes and Schools). As PUMAGUA did not have funding to support the purchase of water saving equipment, it depended on the good will of these stakeholders, who were committed to the environment and willing to invest in water saving equipment and processes.
- Funding from the University. Without the funding from UNAM it would not have been possible to be successful in our activities.
- National targets and policies. In particular, the goal of PUMAGUA to achieve good water quality coincided with the national and local policies and laws regarding the installation of water fountains in schools.
- Visibility of the Program nationally and internationally. As a lot of work was done in order to make PUMAGUA visible outside UNAM and Mexico, this helped us to be more taken into account by UNAM's authorities.
- Multidisciplinary: Having engineers, biologists, doctors, communication professionals, architects, amongst other disciplines, working as part of the team and together in specific projects of PUMAGUA helped to have an integrated, flexible and adaptive vision.

3.5 Barriers

The main barrier across all elements of the project relate to limited resources including financial, human capital and technological resources. The following section details these limits within the project areas of water quality and quantity.

3.5.1 Water quality

One of the main challenges for the PUMAGUA project was that despite the automated water management system it introduced, supervision is still required as the sensors have occasional functionality problems, requiring constant calibration and periodic maintenance. This requires a significant investment, which must be incorporated into the budget. This has been difficult as the funds provided by UNAM have been reduced in recent years.

3.5.2 Water quantity

The Water Observatory of UNAM has become one of the main tools of the water quantity area of PUMAGUA, and it is therefore of the utmost importance that it works properly. Accordingly, the PUMAGUA team checks the information displayed through the Observatory on a daily basis, to detect and correct any possible errors. Some of the most frequent errors are found in incorrect consumption data. This can be caused by a water meter sending information to two repeaters, resulting in the duplication of information. Another detected error has been the occurrence of negative measurements (Figure 34), which are caused by signal interruptions from repeaters, water meters, or antennas. Incorrect graphs also need to be corrected immediately, as do any difficulties found when editing the information in the Water Observatory.

Figure 34. Error in water quantity section: a graph showing negative values of water consumption within one of UNAM's Institutes taken from the Water Observatory.
Source: http://www.observatoriodelagua.unam.mx/Cantidad/ConsumoIndex

As a result, there is still a need to have people constantly supervising and correcting errors in the digital platform and database, as well as in the equipment installed throughout the campus, despite the automated technology. Solving this problem requires an investment in human resources, which PUMAGUA cannot afford at this stage.

Another challenge this project faces is the constant updating of technology. It required significant investments to acquire the technology described above, and recently PUMAGUA was informed that the manufacturing company is no longer producing antennas, and that mobile cellular signal has become favoured over radio-frequency. Although investing in a technological update would result in the challenge of finding the necessary financial resources, it is also an opportunity to acquire technology that will solve the problem of occasional water consumption reading errors and high maintenance requirements.

3.6 Replication of PUMAGUA outside UNAM

To share the success of the PUMAGUA project outside of the university campuses, PUMAGUA ran trial replications of the program three times throughout Mexico with varying success. The following section provides an overview of these three replication attempts, including the barriers faced and successes achieved.

3.6.1 Cities within the states of Puebla, Oaxaca, and Tlaxcala

In order to contribute to improved drinking water supply in disadvantaged cities in Mexico, the PUMAGUA program was replicated as the Project for Hydraulic Support for the States of Puebla, Oaxaca, and Tlaxcala (PADHPOT, for its acronym in Spanish), which was launched in 2013. As an initial step in the project, ultrasonic water meters were used to make a first diagnosis of water volumes for each city (Figure 35).

Figure 35: Use of smart water technology to measure water flow in one of the cities addressed by PADHPOT, UNAM.
Source: Rocha Guzmán 2013

Table 2. Existing, effective, and needed water flow in the Mexican cities involved in PADHPOT

State	City	Population	Average needed water flow (l/s)	Average existing water flow (l/s)	Average effective water flow (l/s)	Water provision (l/person per day)
Oaxaca	San Francisco	12, 000	17	9	5	37
	Ocotlán	21,000	36	15	5	28
	Zimatlán	19,000	44	14	9	37
	Cuetzalan	47, 000	55	66	40	72
Puebla	Izúcar	73, 000	126	134	80	95
	Tehuitzingo	11, 328	20	9	6	44
Tlaxcala	El Carmen	15, 000	27	51	15	85

The analysis showed that the hydraulic systems of these cities operated with physical efficiencies of less than 50%, due to the infrastructure being used for twice its lifespan and the water capacity of the infrastructure not being properly considered during installation. A lack of updated infrastructure plans and statistical registers of their operations also created a challenge, as did the reduced access to water for most residents of the cities, who only received water on average of twice a week for five hours at a time (González and Arriaga, 2014).

Deficiencies in drinking water services had forced the inhabitants of these localities to buy water from mobile water tanks distributed by tanker trucks and bottled water, spending up to 15 times the amount they pay for the tapped drinking water service (González and Arriaga, 2014).

With regards to water quality, the water was manually disinfected with chlorine hypochlorite. In some localities it was not done regularly, putting the inhabitants' health at risk (González and Arriaga, 2014).

In order to improve the water provision for these communities, the project developed two lines of action:

1. Drinking water and sanitation: Smart technology macro-meters were installed in wells and in distribution tanks, providing the basis for an action plan. To increase the water supply efficiency, concrete actions regarding infrastructure were also proposed, and technical staff were provided.
2. Water Observatory: To enhance the perceptions of the water supply system performance in the community, participatory workshops were delivered alongside technical courses to engage with the operators of the water services (González and Arriaga, 2014).

Unfortunately, after three years of work, the project was abandoned due to the constant change of water system authorities, at all government levels (federal, state, and municipal) and prolonged delays in bureaucratic procedures (e.g. signing contracts and gaining funds), both from government institutions and UNAM. Despite this, the initial success of the project did result in some benefits for the local community: works were started in Ocotlán, Oaxaca to improve the drinking water supply system, several talks about the importance of water disinfection were given, as well as water culture workshops for children to increase the awareness sustainable water use in the community (Rocha Guzmán, pers. comm).

3.6.2 National Autonomous University of Baja California Sur (UABCS, for its acronym in Spanish)

In 2014, at the request of the authorities of the National Autonomous University of Baja California Sur (UABCS) and with the facilitation of the nongovernmental organisation Niparajá, an agreement was signed with PUMAGUA in order to implement some of its actions at UABCS.

As part of this agreement, PUMAGUA's staff carried out a diagnosis of the hydraulic infrastructure of the UABCS' campus and prepared digital plans for the staff (see Figure 36). Using a portable ultrasonic water meter, the water supply on the UABCS campus was also calculated (Figure 37).

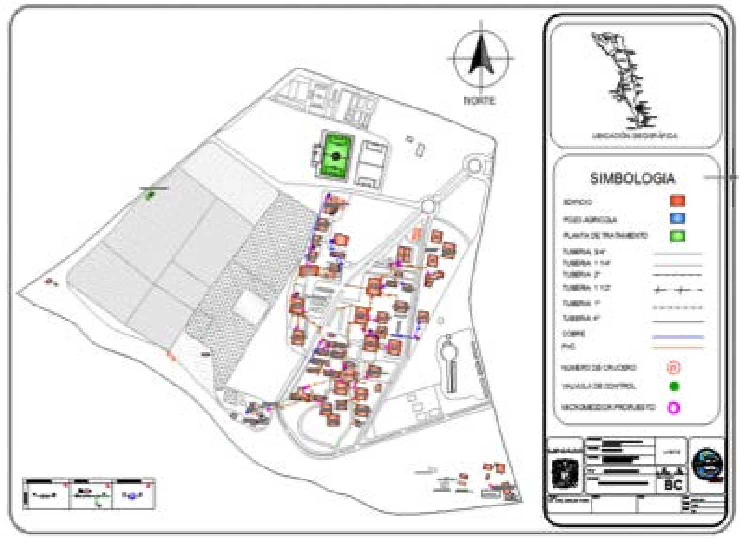

Figure 36. A digital plan of hydraulic infrastructure of the UABCS campus.
Source: PUMAGUA 2014

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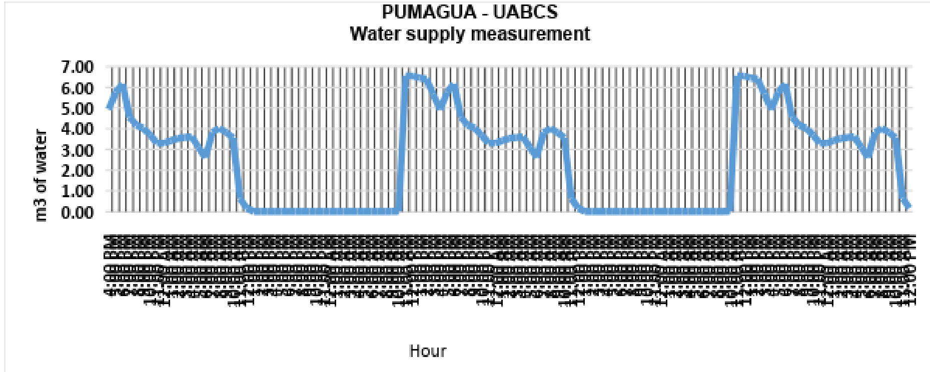

Figure 37. Hourly water supply measurement at the main campus of UABCS, using an ultrasonic water meter.
Source: PUMAGUA, 2014

As a result of these measurements, it was determined that 29 water meters using mobile signal to transmit information (instead of radio frequency) should be installed throughout the campus. As of June 2018 half of these meters have been installed. There were changes in the personnel authorities of UABCS, and these new authorities were not as interested in this project, causing delays in the projects continuation. Despite this, a new agreement with NIparaja, UABCS and PUMAGUA will be established in 2018 in order to continue actions regarding installation of remaining water meters, and also to implement actions regarding water quality and community participation.

3.6.3 Low income Housing in Mexico City

In 2017, the Ministry of Social Development of Mexico City signed an agreement with UNAM with the purpose of implementing actions of PUMAGUA in low-income housing. As part of this project, a diagnosis of the hydraulic infrastructure of the housing development called "Los Rojos", in the eastern part of the city, was carried out.

With the use of an ultrasonic water meter, it was possible to measure the water supply as well as the average water consumption in the buildings of Los Rojos. It was determined that the average water consumption corresponded with what the World Health Organization considers as sufficient to ensure that the most basic needs are met (between 50 and 100 litres per person per day), with the exception of one of the buildings, where only 43 litres per person per day was consumed. To monitor water consumption for each building, water meters were installed in each of the nine buildings (Figure 38).

Figure 38. Micro meters installed at the low income housing of "Los Rojos" in Mexico City.
Source: Josué Hidalgo, 2017

Based on the diagnosis, a list of suggestions were made to improve water supply in Los Rojos by improving infrastructure, taking management actions and promoting water savings by users with high water consumption. A second stage of this project is planned to monitor actions and to implement activities to monitor drinking water quality.

To understand the community's perceptions of the water service and their behaviour regarding water use, 30 residents were interviewed (10% of housing population) (as shown in Figure 39). The survey revealed that residents acknowledge their responsibility in water saving, and that the majority carry out important actions such as repairing leaks and closing faucets when not using water. However, less than half of the survey participants reuse water and 20% of those who have cars wash them using a hose instead of a bucket. In addition, the majority of survey participants take long showers (over 10 minutes), and very few have water saving toilet appliances. As such, these surveys showed that there is still a lot of work to do in helping this community to reduce its water consumption.

Figure 39. Survey in the low income housing Los Rojos to assess users' perceptions of the water service and behaviours in terms of water use.
Source: (Josué Hidalgo, 2017)

4. Links to the SDGs

PUMAGUA is linked to sustainable development goals (SDGs) 1 (towards zero poverty), 6 (clean water and sanitation), 9 (building resilience), 12 (sustainable consumption), 13 (climate action), and 17 (partnerships for the goals). Table 3 lists the specific targets within these SDGs that are addressed by PUMAGUA.

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Table 3. A list of the SDGs and their specific targets that relate to the PUMAGUA program.

SDG 1: Towards zero poverty **End poverty in all its forms everywhere**	
1.4	Ensure access to basic services, including natural resources and appropriate new technology
SDG 6: Clean water & sanitation **Ensure availability and sustainable management of water and sanitation for all**	
6.1	By 2030 achieve universal and equitable access to safe and affordable water for all
6.2	By 2030, achieve access to adequate and equitable sanitation and hygiene for all
6.4	By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity
6.B	Support and strengthen the participation of local communities in improving water and sanitation management
SDG 9: Building resilience **Build resilient infrastructure, promote inclusive and sustainable industrialisation and foster innovation**	
9.4	Upgrade infrastructure and retrofit industries to make them sustainable with increased resource-use efficiency
SDG 12: Sustainable consumption **Ensure sustainable consumption and production patterns**	
12.2	Achieve the sustainable management and efficient use of natural resources
12.8	Ensure that people have the relevant information and awareness for sustainable development and lifestyles in harmony with nature
12.a	Support developing countries to strengthen their scientific and technological capacity to move towards more sustainable patterns and consumption
SDG 13: Climate Action **Take urgent action to combat climate change and its impacts**	
13.3	Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning
13.B	Promote mechanisms for raising capacity for effective climate change-related planning and management in least developed countries and small island developing States, including focusing on women, youth and local and marginalized communities
SDG 17: Partnerships for the Goals **Strengthen the means of implementation and revitalize the global partnership for sustainable development**	
17.6	Enhance access to science, technology and innovation and enhance knowledge-sharing

Specifically, PUMAGUA is linked to goal 1.4 as the main consequence of its efforts is to enhance water availability for next generations of UNAM's community, as well as for the inhabitants of Mexico City. Technology is fundamental in this sense.

The main goals of the Program are tightly linked to goals 6: access to sufficient good quality water, both in terms of drinking water and treated wastewater. There is also a strong commitment to improve efficiency in water management and to increase water savings by consumers. Participation from the community and from authorities has been one of the main goals of the Program, and a lot of work has been done on that end.

Regarding SDG target 9.4 to upgrade infrastructure for sustainability and resilience, substantial investments have made within the PUMAGUA program to upgrade infrastructure at target sites: e.g., the disinfection system for drinking water and the refurbishment of wastewater treatment plants.

A significant aspect of the PUMAGUA program was in education and information dissemination, through the Water Observatory and several communication campaigns, in order to increase awareness and participation. This aligns with several targets within the SDGs, including 12.8 of ensuring people have the relevant information for sustainable consumption, 13.3 of impact reduction and increasing education for climate action and 17.6 of enhancing knowledge-sharing through partnerships. Also, regarding target 12.a, the efforts of PUMAGUA to strengthen UNAM's scientific and technological capacities towards sustainable development can serve as a model for the rest of the country and for other developing nations. All the efforts of PUMAGUA to diminish water consumption mean also adaptation to climate change, as water sources are being protected. Furthermore, the decrease in bottled water usage may help to reduce the demand and required energy for production of bottled water, and for its transportation, contributing to a reduction in greenhouse gas emissions (SDG 13).

5. Lessons learned

Smart water systems cannot fully replace traditional approaches for water management. However, complementing real time information with in-situ water sampling and analyses enriches the end results and the validity of information. Despite the newly automated water management and monitoring system, it will still require a lot of maintenance at least in the short-term. It is therefore important to consider this in the budget when planning SWM implementation to ensure sufficient funds are saved for staff and the training required to upkeep the SWM technology. A summary of lessons learned throughout the implementation of PUMAGUA are listed below:

- Technology can change and become outdated quickly. It is important to study which technology will be the most suitable, and also to conduct research on whether there are any new technologies soon to come on the market that might be more effective than the technology currently available. For example in the PUMAGUA case, sensors that use radio frequency were chosen, requiring additional infrastructure to ensure the radio waves reach the entire campus. Now mobile frequency sensors are available that do not rely on additional infrastructure, which may be more cost effective in the long-term.
- Care should be taken in order to prevent the use of SWM technology creating a dependence on one particular commercial product or manufacturer. It would be desirable for companies to have products compatible with each other in order to have different options. Compatibility would also likely accelerate their response time to project inquiries and issues.
- Despite the initial maintenance requirements of SWM technology, this project acts as a learning experience that will allow technology and the system to advance to a point where maintenance issues are fixed and it becomes more robust. As with any other technology, as smart water management becomes mainstream it will become cheaper and easier to implement.
- Through PUMAGUA, it was found that people are much more trusting of automated data than they are of people manually monitoring and updating data. This became evident throughout this project as people started to trust the drinking water quality when they knew the monitoring was automated, and when they could see the results for themselves on the Water Observatory platform. This was also observed during talks with the UNAM community, where all community members responded positively when informed that real-time automated data was available for the water quality of UNAM water taps every 5 minutes. This shows that people appreciate having access to real-time data for water quality as it assures them of the safety of the water. Automated monitoring plays a role in increasing trust in water quality in comparison to the manual monitoring of data, which is incapable of providing updated, accurate data on water quality every 5 minutes.
- This confidence from the public on automated monitoring could be of use to water utilities in some cities of Mexico, where water quality is adequate and people do not drink tap water because of distrust.
- Real time information can be very useful to build patterns about the behavior of parameters during different periods as it is possible to obtain continuous information. This could be useful to identify possible threats of pollution. For instance, if concentration of nitrates is gradually approaching regulation permissible limits, this may indicate organic pollution, which could be prevented.
- PUMAGUA originally had plans to implement SWM in some of the poorer areas of Mexico City to assist with improving water quality and leak detection. However, it was found to be increasingly difficult, especially in areas where basic infrastructure is limited or of very low quality, because it can be a challenge to implement effective monitoring systems where there is little to monitor. Instead, by focusing on what could be assisted with (monitoring the houses that did have a water connection) we were able to make a difference in these areas that we hope to extend upon in the future. It was concluded that in order for SWM to be implemented in poor areas, at least a basic water distribution and infrastructure system must exist.

6. Next steps

6.1 Water quality

Our next step in regards to water quality is to foster more tap water drinking through the installation of new water fountains throughout the UNAM campus. Due to project budget limitations, this will be accomplished with the help of other institutions of UNAM. The water fountains will be installed in schools, but also in social meeting places, such as green areas, sport facilities, and cultural venues.

PUMAGUA will keep maintaining the real time monitoring system and, if we have the necessary funding, we would like to install this kind of system in another part of the campus, in order to increase reliability of information.

The digital platform of the Water Observatory allows for the connection with other systems of UNAM campuses. Therefore, if in the near future any of the campuses of UNAM acquires a real-time monitoring system, they can also be linked to the platform and information from in-situ water quality sampling can be uploaded.

6.2 Water quantity

In order to upgrade the remote water consumption system at UNAM, we are planning to carry out a pilot project that allows us to decide which potential new system is the best one. On one hand, we will install some water meters that use mobile signals instead of radio frequency. This system has several advantages, for example, it does not require antennas or signal repeaters, reducing the infrastructure costs. However, while signal transmitting through radio frequency is free, in the case of a mobile signal, an annual fee must be paid to the mobile phone company and therefore, we will need to evaluate the pros and cons of this technology and the costs associated with these fees.

With the help of researchers from the UNAM Institute of Engineering, we will also try to develop our own technology for a remote water consumption system, in order to stop depending on private enterprises. This process will take longer, and will include water consumption measurement, data transmission, data reception, and uploading into the Water Observatory. Although this strategy is time consuming, working with a university institute represents an opportunity for research and capacity building, especially for students.

We are also looking to test a sensor to detect soil moisture in order to determine if the gardens on campus are being overwatered. If the sensor is functional, several sensors will then be installed throughout the green areas of the University City, and will be linked to the Water Observatory. This will help to involve the whole community, including gardeners, in the responsible use of water in irrigation.

6.3 Social participation

Information about the implementation of actions recommended by PUMAGUA and implemented by schools, institutes, and administrative offices, will be continuously updated in the Water Observatory.

Also, the survey module of the Water Observatory will be continuously used in the future. We are particularly interested in monitoring the ongoing progress of communication campaigns to encourage tap water drinking at UNAM and consequently the decrease of bottled water purchases.

7. Conclusion

PUMAGUA was created to improve water management, use and reuse at the campuses of UNAM. Since the implementation of PUMAGUA, there have been several achievements in terms of water savings, water quality improvement, capacity building and enhancement of community participation. The use of SWM technology has been fundamental for these achievements. It has helped to produce and disseminate a substantial amount of information, and to convince the community about the validity of this information, as it is perceived as free from human error.

This technology however does not work independently from human beings: it needs human resources for updating and for the correction of errors. Also, SWM must be supplemented by other sources of information, such as on-site sampling. In the case of PUMAGUA, real time sensors are located only in one place and provide information about six water quality parameters. In contrast, our on-site water sampling allows us to monitor 75 drinking water fountains, 25 intakes, and 52 water storage tanks. Moreover, water sampling allows us to analyze 47 parameters included in Mexican regulation, which could not be monitored by real time sensors.

Updating SWM technology is an opportunity to extend it to other aspects of monitoring and maintenance, for instance, the installation of sensors to measure soil moisture. Also, it is an opportunity to start to develop our own technology, in order to decrease dependence on commercial providers.

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Appendix

Population and economic conditions in Mexico

Mexico is the second largest economy in Latin America, after Brazil, and the fifteenth in the World (its Gross Development Product was worth 1026 billion US dollars in 2016, with an annual growth of 2.3% (World Bank, 2017). It is the country of the Organization for Economic Cooperation and Development (OECD) with the highest inequality level: the incomes of the richest are more than 25 times those of the poorest (OECD, 2017). Furthermore, the top 1% has an average annual income 47 times that of the poorest 10% (del Castillo Negrete Rovira 2012). In 2016, according to the National Social Development Commission (CONEVAL, for its acronym in Spanish), reported that 53.4% of Mexicans were poor and 9.4, extremely poor.

It has the highest inequality level of any OECD (Organisational for Economic Cooperation and Development) country with the incomes of the richest equaling more than 25 times those of the poorest (OECD, 2017). Strong disparities are also seen in the geographical and temporary distribution of water in the country. While the wealthier central, northern and north-western regions (constituting two thirds of Mexico), have a lower per capita water availability of 2044 m^3/year they contribute 84% to the GDP, increasing their ability to fund water related infrastructure. In contrast, water availability in the poorer southern regions, while significantly more abundant than the northern regions, (14,291 m^3/year per capita), presents a water management challenge in itself due to the reduced ability to develop and maintain infrastructure (Tortajada, 2006) (Figure 1).

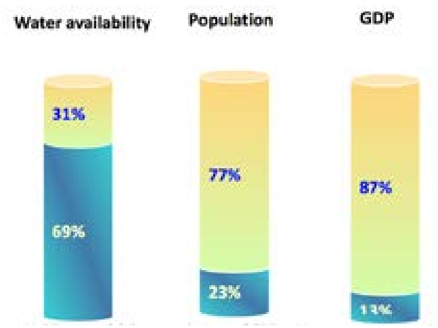


Figure 40. Map of Mexico showing water availability in regions
Figure 41. Water availability, population and GDP in Mexico

Water resources in Mexico

México receives around 1.5 millions of cubic meters of rain per year. About 72% of this water is lost through evapotranspiration, 22% flows through rivers and 6% infiltrates and recharges the aquifers. Considering the exports and imports to and from neighbor countries, Mexico has about 470 millions of renewable water (CONAGUA, 2014.).

There are strong disparities in terms of geographical and temporary distribution of water in the country. On one hand, in the central, northern and northwestern regions, which constitute two thirds of the territory, per capita water availability is of 2044 m^3 /year, while in the southern states water is an abundant resource (per capita water availability of 14 291 m^3/year) (Figure 1). However regions with low water availability contribute with 84% of the GDP, and the southern part of Mexico only produces 16% of GDP, has high rates of poverty, and low development of infrastructure (Tortajada, 2006)
Also, there are notorious differences in water availability throughout the year. Most of the rains occur in summer (from May to October), while the rest of the year is relatively dry (CONAGUA, 2014).

Climates in Mexico

As the country has many mountains with rapid changes in elevation, temperature and rainfall, in a relatively small area it is possible to find several Köppen climate categories. However, by aggregating these areas seven main climate regions are obtained (Geo-Mexico, 2017): Af (tropical wet), Aw (tropical wet-and-dry), BS (semi-arid), BW (Arid (desert), Cw(temperate with dry winters), Cf (humid subtropical), Cs(Mediterranean). Most of the territory has mean annual temperatures above 15C.

Gastrointestinal diseases and water

Temperature is widely recognized as an important factor in enhancing bacterial growth. Therefore, in climates where water temperatures are warm (above 15 °C), bacterial growth may be fast (LeChevallier, 2003). This is particularly notorious in storage tanks where water is in contact with ambient temperature and does not flow. However, water that is distributed through underground usually does not present bacterial growth (A.C. Espinosa García, November 20, 2017). Therefore in Mexico occurrence of gastrointestinal diseases is related to poverty and lack of good drinking water services, and not to temperature (see Table). The Mexican states with highest percentage of inhabitants in extreme poverty are Chiapas, Oaxaca, Guerrero, and Veracruz (CONEVAL, 2017). These four states have also the lowest drinking water coverages in the country (80% or less) (CONAGUA, 2011). It is worth pointing out that 95 of households in Mexico have water storage containers (tanks, cisterns, bottles) and more than 60% of them has more than one container (González Villarreal and Lartigue in press).

Figure 42. Valley of Mexico in pre-columbian times.
Source: Iracheta-Conecorta, 2000.

According to the last census, the ZMCM has a population of approximately 22 million, 9 of which live in Mexico City (OCDE, 2015). One in five Mexicans live in the ZMCM, considered as one of the biggest agglomerate urban areas in the world. Several studies calculate that the population will increase by 13% between 2010 and 2030 (OCDE, 2015).

The ZMCM is supplied with 72.5 m^3/s of drinking water, of which 72% come from the aquifer of the Valley of Mexico, 18% from the Cutzamala system in the State of Mexico, and Michoacán, 8% from the Lerma system in the State of Mexico, and 2% from springs and runoffs within the Valley of Mexico (Jiménez Cisneros et al. 2006).

About 10 m^3/s are used for irrigation of agricultural lands, and from the remaining 62.5 m^3/s, about 30 m^3/s are consumed by domestic users, 9 by industrial, commercial and service users, and the rest are lost through network leaks (23 m^3/s) (Jiménez Cisneros et al. 20006)

Per capita consumption volume was measured by Capella-Vizcaino et al. (2008). Although its average is 184 l/person per day, there are severe inequalities between water consumption volumes in different areas of the city (Figure 3): from less than 125 to over 475 l/person per day.

Temperature and water quality

Temperature is widely recognized as an important factor for decreased water quality, as it can play a role in enhancing bacterial growth. Therefore, in climates where water temperatures are warm (above 15 °C) such as in Mexico, bacterial growth may result quickly (LeChevallier, 2003). While this is the case, water distributed through underground infrastructure is less likely to present bacterial growth issues (A.C. Espinosa García, November 20, 2017), and therefore the issue of water quality through high bacterial growth is related to poverty and lack of good drinking water services, and not to temperature.

Climates in Mexico

As the country has many mountains with rapid changes in elevation, temperature and rainfall, in a relatively small area it is possible to find several climates including tropical, semi-arid, desert, temperate, humid subtropical and Mediterranean. Despite this range in climatic conditions, Mexico's mean average temperature is above 15°C (Geo-Mexico, 2017).

The Metropolitan Area of Mexico City

Mexico City, formerly Federal District, is part of the Metropolitan Area of Mexico City (ZMCM), which includes 59 municipalities of the State of Mexico, and one of the state of Hidalgo (OECD. 2015).

The ZMCM is located in the Valley of Mexico, one of the four valleys inside the Cuenca de México (Watershed of Mexico), which was originally an endorheic watershed (a watershed that is contained and does not flow into the ocean).

The ZMCM has six different climates (Table X), with an average annual temperature of 15oC (8oC higher in summer and lower in winter). Most of the average annual precipitation (between 600 mm in the northern areas and 1,200 mm in the southern areas) occurs between May and September, with little or no precipitation during the rest of the year (Romero-Lankao), and therefore severe floods are frequent during the rainy season.

Table 3. Climates of the ZMCM and percentage of area occupied by each one

Climate description	Symbol	Percentage of area
Temperate sub-humid, with summer rains, low humidity	C(w0)	30
Temperate sub-humid, with summer rains, medium humidity	C(wi)	17
Temperate sub-humid, with summer rains, high humidity	C(w2)	16
Semi-cold sub-humid, with abundant summer rains	C(E)(m)	2
Semi-cold sub-humid, with summer rains, high humidity	C(E)(w2)	17
Semi-dry temperate, with summer rains	BS1kw	18

Source: FUENTE: INEGI. Cuaderno Estadístico de la Zona Metropolitana de la Ciudad de México edición 2002. Aguascalientes, Ags., 2002

CASE STUDIES
SWM TECHNOLOGY FOR EFFICIENT WATER MANAGEMENT IN UNIVERSITIES:
THE CASE OF PUMAGUA, UNAM, MEXICO CITY

According to the last census, the ZMCM has a population of approximately 22 million, 9 of which live in Mexico City (OCDE, 2015). One in five Mexicans live in the ZMCM, considered one of the biggest agglomerate urban areas in the world. Several studies calculate that the population will increase by 13% between 2010 and 2030 (OCDE, 2015).

The ZMCM is supplied with 72.5 m^3/s of drinking water, of which 10 m^3/s are used for irrigation of agricultural lands, and from the remaining 62.5 m^3/s, about 30 m^3/s are consumed by domestic users, 9 by industrial, commercial and service users, and the rest are lost through network leaks (23 m^3/s) (Jiménez Cisneros et al. 2006) Per capita consumption volume was measured by Capella-Vizcaino et al. (2008).

Concerns about the environmental impacts of PET disposal have also been raised in different forums, such as the Congress, the Senate, and in several Civil Organizations, and Academic Institutions (see, for instance, Freshwater Action Network, 2017, Quadratin, 2017). In March 2017, the Federal deputy German Ralis Cumplido presented a legislative initiative to make people aware of the environmental impact of PET through labeling of bottled water (Jiménez, 2017).

TEXT BOX

Potential for well recharging through roof rainwater, to support desalination of coastal wells and recharging of unconfined aquifers

Country: India
City/region where project is based: Trichur district, Kerala State
Population (of area where the project is based): 3,110,327 (2011 Census data)
Key organisations /stakeholders involved in the project: Mazhapolima (Rain Bounty), District Rainwater Harvesting Mission (DRHM), Registered Society under Charitable Societies Act. District Collector (Executive Head of District), Government of Kerala.
Authors: Dr. Jos C Raphael - joscraphael@gmail.com
Links: www.mazhapolima.org

Water challenge

The coastal state of Kerala receives an average annual rainfall of 3000 mm, with 62% of households dependent upon homestead dug wells (a hole dug by shovel or basic machinery, distinct from drilled wells which are typically deeper) for their drinking and domestic water needs. Despite high rainfall during the rainy season, these wells go dry during summer. As a result of excessive pumping,water quality issues such as saline ingress and iron content are common in the coastal wells. Therefore, a solution is required to ensure water access in the summer months and to protect the water quality of these wells.

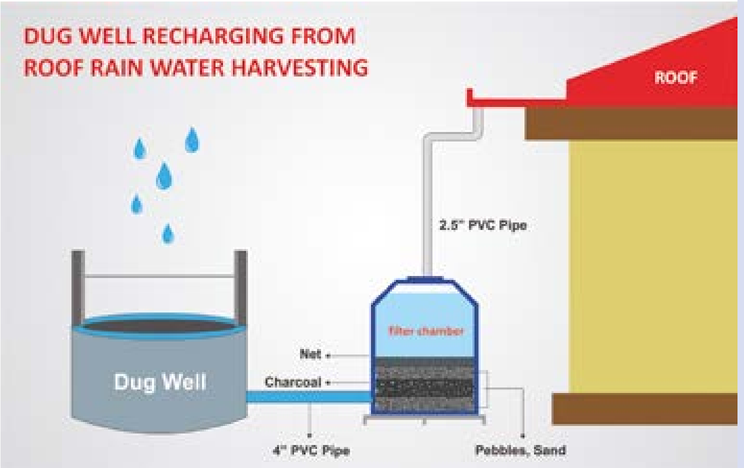
Project approach

To address this, the project works by diverting roof rainwater from homestead premises to a nearby dug well. In the coastal belt, the rainwater has to be directed to the mouth of the well whereas in the mid land and upper hilly terrains, it can be diverted towards a dug well. This results in the artificial recharging of the unconfined shallow aquifer where the well is located and with it the reversal of saline intrusion due to withdrawals of freshwater by human activities.

As of July 2018, the Well Recharging units consist of a 15 metre long PVC gutter and approximately 30 metres of down pipes-from rooftops directed towards the well. A filter unit is installed to reduce the impurities from rainwater flowing off the roof. Monitoring and communication about the quality of the water is currently completed manually. The cost of the Well Recharging unit per 1000 square foot roof is approximately US $ 100.

Results

A study conducted by the Centre for Water Resources Development and Management in Kerala to assess the impact of the project revealed that it significantly reduces saline intrusion into coastal aquifers while raising the water table across seasons. Since the beginning of the project in May 2008 more than 30,000 Well Recharging units have been installed by *Mazhapolima* in water poor households and institutions across Kerala. This has been made possible by the subsidized cost of all units by the Governments of Kerala and India. Countless households have also adopted this technology at their own cost. Sharing this water solution to poor countries of Africa, Asia and island nations could result in higher water access and security, provided it secures the financial and logistical support from international agencies.



SWM: Potential and support required

As of August 2018, the project has not yet involved smart technology. Instead, the assessment and communication of the project are conducted manually and the data is transmitted via SMS messages. This approach has its limitations. Firstly, communication through SMS is restricted to a minimum to save costs resulting in reduced communication. Secondly, water quality analysis is conducted manually in government laboratories that lack advanced smart technology and modern water quality testing methods, resulting in reduced accuracy and delayed results. While the private sector can provide faster and more accurate results, the cost for these services is very high.

Therefore, to improve the accuracy and reliability of the project, automated monitoring systems for the wells are required to detect real-time water level and water quality, with the data automatically transmitted to a central station. This data can then be relayed quickly to the community to improve awareness of the water quality and access for each well. This improvement will require financial support along with technical advice from smart water technologists.

In general, ample scope exists for installing smart technologies for rainwater filter management in India and other developing regions in the world. With the right research, development, market management and technical support smart technologies could provide a major step forward in supporting successful rainwater harvesting in these regions.

Transforming smallholder irrigation into profitable and self-sustaining systems in southern Africa

Henning Bjornlund[1], Karen Parry[1], Jamie Pittock[2], Richard Stirzaker[3], Andre van Rooyen[4], Martin Moyo[4], Makarius Mdemu[5] Wilson de Sousa[6], Etevaldo Cheveia[6], Paiva Munguambe[6], Emmanuel Kimaro[5], Luitfred Kissoly[5], Mario Chilundo[8], Alec Zuo[7], and Peter Ramshaw[2]

Tanzania, Mozambique and Zimbabwe

1. University of South Australia, Adelaide; 2. Australian National University, Canberra; 3. CSIRO; 4 International Crop Research Institute for the Semi-arid Tropics, Bulawayo; 5. Ardhi University, Dar es Salaam; 6. National Irrigation Institute, Maputo; 7. University of Adelaide; 8. Universidade Eduardo Mondlane, Maputo

Summary

Small-scale communal irrigation schemes in Africa have not realised returns on investment. Critical to this failure is that funders, designers and managers of these schemes have not recognized them as complex socio-ecological systems with a diversity of constraints. These schemes are often under-performing and characterized by a subsistence orientation, which is compounded by poor market integration, low capacity to invest in crop production, low yields, difficulties paying for water, or lack of willingness to participate in system maintenance. The end result is unsustainable utilization of resources, failed infrastructure, inefficient use of water and land and increased conflict over access to these resources.

Conventional irrigation scheme development has focused on 'hard' technologies to improve the functionality and efficiency of infrastructure and/or irrigation application technologies. However, hard technology improvements on their own have failed to deliver sustainable schemes and improve the livelihoods of irrigation farmers (Inocencio et al., 2007): broken and decaying infrastructure is just one element of an underperforming system. While technologies that are more efficient may help improve yield, they will not necessarily improve profitability. A great many irrigation schemes are trapped in a negative cycle of infrastructure provision, unprofitable farming, lack of investment in maintenance, infrastructure degradation leading to donors subsidizing infrastructure rehabilitation (Pittock & Stirzaker, 2014; Bjornlund et al., 2017).

Transitioning these complex systems into profitable, equitable and economically sustainable schemes requires investment not only in smart technologies but also in farmers, institutions and building the value-chain network (Figure 1).

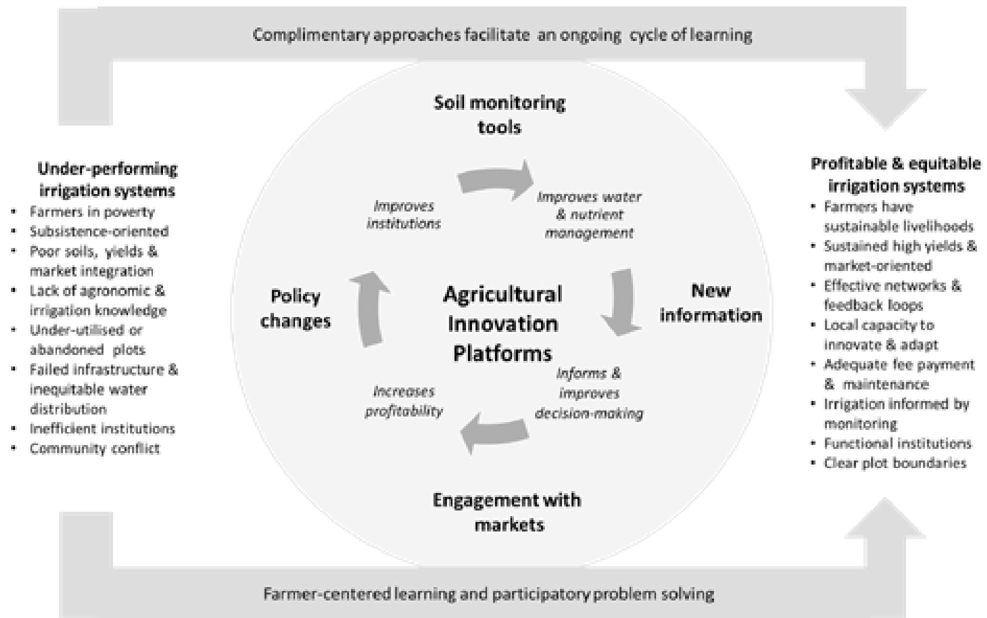


Figure 1. Transitioning under-performing small-scale irrigation schemes in Africa towards profitable and equitable irrigation systems (adapted from Pittock et al., 2018)

The project features a two-pronged approach consisting of two complementary entry points to transition small-scale irrigation schemes towards long-term sustainability (Figure 2):

- Smart water management (SWM) technologies were introduced to monitor soil moisture and nutrients and facilitate farmer learning about irrigation water management to increase yield.
- At the same time, smart water governance and learning processes, in the form of Agricultural Innovation Platforms (AIPs), were introduced to bring key stakeholders together to develop solutions to a range of challenges presenting barriers to turn increased yield into increased profitability.

In the context of SWM, it is important to understand the influence of and linkages between the two key approaches applied in this project. The soil monitoring tools represent sophisticated but simple-to-use technologies designed to support a farmer-centred learning system. These are SWM tools in the traditional sense, but the focus is on resolving the 'soft' component of the irrigation challenge by providing a means for farmers to learn about water and nutrient management, which they can use in their decision-making. The AIP is a research and development approach that draws from systems thinking and is particularly well suited to problem solving in complex systems, such as irrigation schemes. An AIP brings together stakeholders with a shared interest, builds capacity and networks, and facilitates a dialogue to identify critical barriers and appropriate hard and soft technologies to improve profitability.

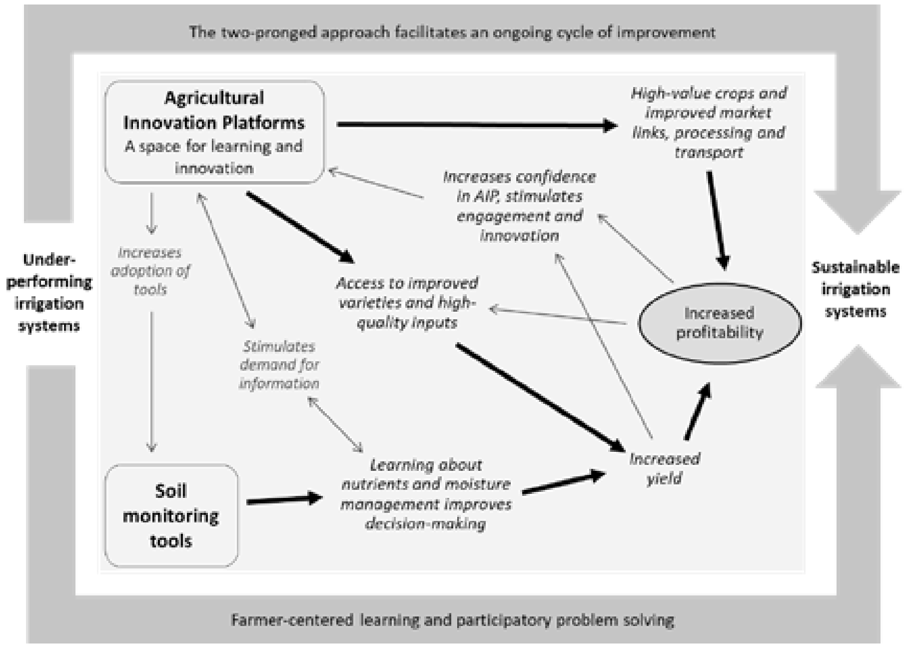


Figure 2. The two-pronged approach and how it influences profitability (Bjornlund, 2018)

Critically, there is no single solution to transitioning small-scale irrigation schemes to long-term sustainability. The AIP provides the context for the SWM technologies and identifies 'stepping stone' solutions to support ongoing learning and problem solving. Importantly, the AIP process enhances and facilitates the adoption of the learning from the SWM technologies whilst simultaneously addressing critical barriers to increasing yields and the profitability of water use[1]. In essence, the key point argued and illustrated in the chapter is that SWM technologies need to be implemented in conjunction with smart governance and learning processes (a two-pronged approach). The AIP facilitation ensures that the information generated by the tools is used to develop a deeper understanding of the water-nutrient dynamics, which allows farmers to make more informed decisions about water and nutrient management and engage in farm level experimentation., This results in critical behaviour and practice change leading to improved yields and profitability.

1. This chapter uses a simple definition of water use profitability: reduced irrigation frequency and duration of irrigation events are evidence of reduced water used. Combined with increased yield and income this is evidence of increased water use profitability.

The project outcomes described in this chapter draw mainly from a survey of project participants—a baseline survey conducted in 2014 and an end of phase one survey in 2017—as well as ongoing focus groups and field observations by the project officers working with the farmers on both elements of the two-pronged approach. Overall, the irrigators participating in this project engaged actively with the SWM technologies and the AIPs. Many farmers have experienced significant yield and income increases resulting in increased food security and prosperity. The time saved through reduced irrigation frequency has been invested in further improving yields and/or diversifying income streams: by establishing and engaging in small businesses and other non-farm income earning activities. The irrigation schemes have experienced significant water savings resulting in an increase in supply that has been especially beneficial for down-stream users and has improved reliability during periods of scarcity. The improved profitability and reliability of supply has reduced conflicts, both among irrigators and within households, and resulted in an increased willingness to engage in collective action such as system maintenance, fee payment and fence building. The outcomes presented are the preliminary analysis of the changes reported in the surveys and further evaluation of both the outcomes and the research approach are ongoing.

The research for development project described here was funded by the Australian Government through the Australian Centre for International Agricultural Research (ACIAR) and implemented in Mozambique, Tanzania and Zimbabwe. The project primarily focuses on the strategic priorities of the funding bodies and its relevance to country partners; however, it also has direct linkages to seven of the global Sustainable Development Goals (SDG) and contributes to a broad range of SDG targets

1. Context of the project

1.1 Project purpose, funding and partners

The project aims to improve the profitability of small-scale irrigation schemes. It has been developed and implemented in two phases and primarily funded by the Australian Centre for International Agricultural Research (ACIAR) (Table 1). This chapter focusses on Phase 1 of the project, which commenced in 2013 and was extended into Phase 2 in 2017.

Table 1. Project phases, timeframes, countries, expected reach and funding

Project features	Phase 1	Phase 2
ACIAR Project	FSC-2013-006	LWR-2016-137
Project title	Increasing irrigation water productivity in Mozambique, Tanzania and Zimbabwe through on-farm monitoring, adaptive management and agricultural innovation platforms	Transforming smallholder irrigation into profitable and self-sustaining systems in southern Africa
Timeframes	15 June 2013 to 14 June 2017	16 June 2017 to 15 May 2021
Countries	Mozambique, Tanzania and Zimbabwe	Mozambique, Tanzania, Zimbabwe
Schemes	6 schemes, 2,485 farmers, 1893 ha	6 original and 32 new schemes, 15,523 farmers, 6,455 ha
ACIAR funding	AU$3,416,440 (US$3,269,533[1])	AU$3,600,000 (US$2,666,400[2])
ANU[3] funding	---	AU$450,000 (US$332,550[2])
CGIAR WLE[4] funding	US$200,000	Approximately US$400,000
Total funding	US$3,469,5330	US$3,398,950

1. Based on exchange rate at 1 June 2013 (http://www.xe.com/currencytables; 2. Based on exchange rate at 1 June 2017 (http://www.xe.com/currencytables); 3. Australian National University; 4. Consultative Group for International Agricultural Research: Water, Land and Ecosystems

The research evaluates whether multi-disciplinary and learning-based adaptive approaches can solve complex socio-ecological problems and tests the following hypotheses:

1 - Widening the 'innovation space', by simultaneously addressing technological and institutional barriers, will stimulate the uptake of better farming practices;
2 - Simple monitoring of key biophysical variables can structure learning and improve decision-making towards greater crop production and water efficiency;
3 - Strengthening local institutions leads to more efficient resource use, market development, and greater gender and socio-economic equity; and
4 - Stronger local institutions create demand for more effective agricultural and water institutions at larger governance scales (Pittock & Stirzaker, 2014).

Institutions are a critical focus of the project and are defined as "the formal rules (e.g. government regulations) and informal or customary rules (e.g. types or work performed by men versus women) within a society" (Pittock et al., 2016, p. 10). The project is interested in improving institutional arrangements at several scales such as irrigator associations and government agencies to influence national and regional African policies: for example, the Comprehensive African Agricultural Development Plan (CAADP).

Whilst the Phase 1 hypotheses have yet to be fully evaluated (Pittock, forthcoming), the project was extended for four years on the strength of the positive outcomes emerging from the first phase (de Lange & Ogutu, 2016). Phase 2 investigates how the soil monitoring and AIPs can be out- and up-scaled and is briefly outlined at the end of the chapter (section 7.2).

Figure 3. Location of schemes involved in Phase 1 of the project. (© Clive Hillker, ANU)

1.1.1 Countries and collaborating partners

Key partnerships were established to work with small-scale irrigation schemes in Mozambique, Tanzania and Zimbabwe (Figure 3). Participating countries were selected based on a scoping study of nine African countries and a combination of factors: supportive national institutions; strong and relevant research capacity with good links to Australian institutions; contrasting stages of irrigation development; capacity to engage key regional African institutions; and the potential to increase food production (Pittock et al., 2013). This process established partnerships to support project development, implementation and research, and communicate outcomes to policy makers (Table 2).

The collaborating partners constitute a highly motivated team whose collective incentive is to make a difference in the lives of the small-scale farmers.

Table 2. Collaborating partners in the project

Country	Collaborating partner	Expertise/support to the project
Australia	Commissioned organization: ANU	Water governance and natural resource policy
	Key research and project partners: Commonwealth Scientific and Industrial Research Organisation, Land and Water (CSIRO)	Biophysical agricultural research, water productivity (including soil and water monitoring) and adaptive learning
	University of South Australia, Adelaide	Water policy, irrigated agriculture, socio-economic analysis, economics
Tanzania	Key research and project partners: Ardhi University, Dar es Salaam	Agricultural water management, natural resource planning, and spatial mapping
	Additional local, district or national partners: Sokoine University of Agriculture[1]	Agriculture and water catchment research
	Iringa District Council	Agricultural extension, implementation
	National Irrigation Commission, Mbeya Zonal Office	Irrigation scheme development and management, and access to and collaboration with schemes
Mozambique	Key research and project partners: Instituto Nacional de Irrigação (INIR), Direção Provincial da Agricultura, Maputo	Irrigation management (expansion and rehabilitation) & policy
	Additional local, district or national partners: Universidade Eduardo Mondlane	Agricultural research, access to and collaboration with irrigation schemes
Zimbabwe	Key research and project partners: International Crop Research Institute for the Semi-arid Tropics (ICRISAT), Bulawayo	Agricultural intensification, AIPs and value chains
	Additional local, district or national partners: Department of Irrigation, Ministry of Agriculture, Mechanization and Irrigation Development	Irrigation engineer, access to and collaboration with irrigation schemes; agricultural extension and implementation
South Africa	Key research and project partners: Food, Agriculture and Natural Resources Policy Analysis Network (FANRPAN), Pretoria	Food, agricultural and natural resources policy, governance and network analysis
	University of Pretoria, Pretoria[1]	Irrigation agronomy

1. Collaborating partners in Phase 1 only.

1.1.2 Schemes participating in the project

The selection of irrigation schemes participating in Phase 1 of the project was based on their institutional capacity, ability to improve agricultural practices, accessibility, and the level of interest in collaborating with the project. Six schemes are officially part of the project. Unfortunately, the Khanimambo scheme in Mozambique experienced significant flooding very early in the project destroying the pump and other infrastructure, which resulted in many farmers abandoning their irrigated plots. This has limited the outcomes achieved within that scheme and, hence, only five schemes are discussed in this chapter. The Magozi scheme is mostly focused on rice production and soil monitoring tools are not used in this system. However, Magozi is included in this case study as the AIP was active on this scheme and provides valuable examples of changes in yield and profitability without the use of the tools.

The location of these schemes is shown in Figure 3 and their main characteristics at project inception are shown in Table 3.

Table 3. Characteristics of irrigation schemes at project inception

	Tanzania		Mozambique	Zimbabwe	
	Kiwere	**Magozi**	**25 de Setembro**	**Mkoba**	**Silalatshani**
Year constructed[1]	2004-07	2005-07	1975	1968-69	1968-69
Location	Iringa District	Iringa District	Boane District	Gweru District	Insiza District
Farmers[2]	168	512	40	75	845
Irrigated (ha)[2]	195	939	38	10	442
Main crops[4]	Tomatoes, onions, green maize	Rice	Cabbages, tomatoes, green beans	Maize, sugar beans, leaf vegetables	Maize, wheat, sugar beans
Legal structure[1]	By-laws	By-laws	By-laws	By-laws	By-laws
Land access[1]	Inheritance, buying, renting	Inheritance buying, renting	Cooperative holds land use title	Association holds land use title	State-owned, chief allocates
Soils[4]	Sand clay varying fertility	Clay to sandy soils	Mostly fertile clay soils	Mostly infertile sandy soils	Mostly clay soils
Rainfall (mm)[4]	700	600	650-900	650-900	450-650
Main bodies governing water[1]	Basin Water Boards		Regional water authorities	Catchment Councils	
Irrigation water source and conveyance method	River, gravity canal	River, gravity canal	River, motor pump	Dam, gravity canal	Dam, gravity canal
Irrigation method	Surface flooding				

Sources: 1. Rhodes et al., 2013; 2. Zuo et al., forthcoming; 3. Bjornlund et al., forthcoming; 4. Moyo et al., 2017, de Sousa et al., 2017, van Rooyen et al., 2017; 5. Stirzaker et al., 2017; 6. In Tanzania, farmers have the legal right to private ownership but very few do so due to transaction costs.

All six schemes were constructed well before the project commenced (Table 3) and predominantly funded by government or, in some instances, donors. Irrigation associations[2] are an important component of schemes and their management and their tasks typically include ensuring water is available, water scheduling, fee collection (though fees are variable and lack clarity), organizing maintenance, information distribution, and resolving conflicts and breaches of rules and by-laws (Rhodes et al., 2014). Additional scheme information is available in Rhodes et al. (2014) and infrastructure challenges are described briefly in section 2.1.

1.2 Economic, environmental, social, technological, governance and policy context

The collective contribution of Mozambique, Tanzania and Zimbabwe to the Gross Domestic Product (GDP) of sub-Saharan Africa (SSA) is less than 5%, which is less than 2% of global GDP (Table 4). For Tanzania and Mozambique, GDP growth compares favourably to overall SSA growth; however, all three countries are categorized as low income countries (World Bank, 2017b). Poverty is a significant and ongoing problem. While extreme poverty rates have fallen for all regions of the world, SSA has experienced the highest population increase. Here, 41%

2. This is a generic term and schemes use different terminology.

of the population live in extreme poverty (half the world total), and 12% of them (47 million) reside in the three project countries (World Bank 2017a, 2017b). More than two-thirds of the population in these countries live in rural areas, where poverty rates are typically double the urban rate and agriculture is the main source of income (World Bank, 2017a, 2017b).

Table 4. GDP, agricultural land and productivity data

	Tanzania	**Mozambique**	**Zimbabwe**	**SSA**	**World**
GDP (millions US$) and global ranking in 2016[1]	47 340 (81)	11 015 (128)	16 620 (112)	1 512 596	75 845 109
GDP (% growth, 2014-15)[2]	7.0	6.6	0.5	3.0	2.7
Population (millions, 2015) and % in extreme poverty)[1]	53.5 47	28 69	15.6 21	1001.0 41	7346.7 11
Rural population (%, 2015)[2]	68	68	68	62	46
% of total country area cultivated in 1962 (top) and 2014[3] (middle) and increase (bottom)	6.3 16.5 10.2	3.3 7.4 4.1	5.2 10.5 5.3	40 42.1 2.1[4]	36 37.5 1.5[4]
Agriculture, value added (% GDP, 2016)[5]	32	25	11	17[6] 30[7]	4
Total % of irrigation- equipped area/cultivated area[3]	3.6	2.7	5.2	4[8]	18[8]
Value of irrigated output as share of total agricultural output (%)[9]	10.0	4.8	25.9	25	---

Sources: 1. World Bank, 2017a; 2. World Bank, 2017b; 3. FAOSTAT database; 4. reference years for % cultivated area is 1961 and 2014; 5. World Bank, 2017c; 6. excludes high-income countries; 7. low income countries only; 8. You et al. 2010; 9. Svendsen et al. 2009; 10. reference year varies: Mozambique, 2008, Tanzania and Zimbabwe, 2011, and SSA, 2013

While agriculture contributes only 11% to 32% of the project countries total GDP, at least 65% of rural people are directly dependent on agriculture for their livelihood. Over the last 50 years, the percentage increase in cultivated land is more than twice the increase in SSA. Africa has low levels of agricultural productivity, which can be partly attributed to the underuse of irrigation in SSA (You et al., 2010). The area equipped for irrigation in the three project countries is on a par with SSA, whilst the value of irrigated output as share of total agricultural output varies from being the same to five times less than the SSA average (Table 4).

Development of irrigation for poverty alleviation, food security and economic productivity is a priority in Africa through plans such as the Comprehensive African Agricultural Development Plan (CAADP), which commits countries to an investment of 10% of national budgets to enhance agricultural production and a six-fold increase in the rate of irrigation expansion (Pittock & Stirzaker, 2014). These priorities underpin country-specific plans e.g. Mozambique's National Agriculture Investment Plan 2014–2018; Tanzania's Agricultural Sector Development Programme; and Zimbabwe's Agricultural Policy Framework 2012-2032 (Pittock et al., 2016). Each country has its own governance and policy arrangements for water resources management: for example, the main responsibility for development, operation and maintenance of irrigation in Tanzania is the National Irrigation Commission under the National Irrigation Act 2013. There are additional national policies and legislation for water resources management more broadly (Mdemu et al., 2017). Irrigation development varies across countries:

- In Tanzania, irrigation development has included large-scale schemes for commercial and food security purposes—with a period of state-management with paid employees—most of which performed poorly and collapsed and eventually privatised or transferred to small-scale farmers (Mdemu et al., 2017).
- Both large and small schemes are part of Mozambique's irrigation history and some large schemes are experiencing abandonment. Development halted during the civil war but resumed in the early 2000s.

- Irrigation development in Zimbabwe also encompasses large and small irrigation schemes, spanning the pre- and post-independence periods but is described as ad hoc, inconsistent and lacking a specific irrigation policy (Moyo et al., 2018).

Sub-Saharan Africa has only achieved approximately 20% of its irrigation potential (Stirzaker & Pittock, 2014) but the irrigated area is predicted to increase by 30% between 1998 and 2030 (Turral, Svendsen and Faures, 2010). Water extraction varies; in Tanzania and Mozambique the proportion of total renewable water resources withdrawn is 5.7% and 0.3%, with 78% used by agriculture (World Bank 2017b; IPFRI, 2011), and in Zimbabwe it is 21% leaving the country vulnerable to water scarcity (Stirzaker & Pittock, 2014).

Irrigation development in Africa has a history of unprofitability and underutilization. The reasons for this are outlined in section 2.1 but a critical aspect is the mismatch between objectives and expectations: that is, many systems were designed for the production of staple crops for food security, which results in higher unit costs, lower performance and unprofitable systems (Inocencio et al., 2007). The underperformance of schemes resulted in a decline in funding through the 1970s and 80s, but investment has surged again since 2000.

Large new schemes are often favoured but, while they might be cheaper to construct, smaller systems offer significant performance advantages and may have less environmental impact (Inocencio et al., 2007; Pittock & Grafton, 2014). Expansion focussed solely on large-scale schemes is misplaced and more investment is required at the community-scale (Pittock and Grafton, 2014). Hence, this project focuses on small-scale communal irrigation schemes.

These schemes are highly variable with respect to size, irrigated area, number of farmers and natural resources (as demonstrated in Table 3) but are typically characterised by:

- Households providing most of the labour and low technology use.
- Communal management through a community-elected irrigation association with shared roles and responsibilities with district/local government;
- A shared water source and supply infrastructure that is partly owned/controlled by the government and the irrigation association;
- Mixed farming activities, often focused on subsistence farming; and
- Small irrigated plots of < 1 ha with a mix of land tenure arrangements.

The World Bank (2017b) cites unemployment rates of 3%, 5% and 24% in Tanzania, Zimbabwe and Mozambique, respectively. The rate on most of the project schemes is lower or comparable with national averages except for Kiwere where the rate is much higher (15% compared the national average of 3%) (Table 5). However, low unemployment rates are misleading. First, most work is irregular or informal: for example, 84% of the SSA's labour force has irregular wages (Filmer et al, 2014), and in Zimbabwe 94% are engaged in the informal economy and the majority are classified as "working poor" (Chimhowu, 2017). Second, unemployment is higher in rural areas and there is a high dependency on agriculture with 65% of the SSA population working on family farms (Filmer et al., 2014). Households on small-scale irrigation schemes are vulnerable in relation to income due to small plot sizes and the subsistence-orientation.

There are significant poverty issues to address on the schemes; for example, income inequality in the schemes is 20-60% higher than national figures (Manero, 2017). Income options are diverse and individuals look for whatever work they can find to support themselves and their families. The proportion working on-farm varies (56% to 100%) with 25% to 52% having some off-farm work (Table 5). There is a stark contrast between households in relation to income diversification with diversified-income households having 2-4 times more income than agriculture-only households. In four of the schemes, the mean for agriculture-only income households is below the US$1.90/day that defines extreme poverty (Table 5; World Bank, 2017a). Those with lower incomes typically have: housing that is more basic, fewer assets and equipment, higher debts, smaller areas for farming, and less ability to invest in education (Rhodes et al., 2014).

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Additional intra-scheme inequities have been confirmed for women, youth and tail-end users. With respect to women and decision-making, their participation is greater when they own more resources though this does not always mean that they have the final say with respect to the use of income. All-male decision-making households are associated with higher farm income while all-female decision-making households have the lowest income (Bjornlund et al., forthcoming). Research on youth work opportunities also finds issues of inequity: for example, the youngest age group (15-24) has significantly higher levels of unemployment than other youth groups and older people; and access to land is more difficult for youth from families without land and also for young women; and on some schemes there are issues relating to water access and participation in committees (Zuo et al., forthcoming). Tail-end users (those with plots at the tail-end of the water supply) not receiving adequate, timely and reliable water supply can cause conflict, which may arise due to the failure of irrigation associations to implement and manage water schedules (Mdemu et al., 2017).

Ultimately, fewer work options and lower income has broader implications than food security and impacts health, well-being and educational outcomes. Table 5 provides additional socio-economic information for each scheme.

Table 5.: Socio-economic information for each scheme

	Tanzania		Mozambique	Zimbabwe	
Socioeconomic information	**Kiwere**	**Magozi**	**25 de Setembro**	**Mkoba**	**Silalatshani**
Mean of household members[1]	6	5.5	5.3	6.8	6.4
Mean age of household head[1]	46	42	62	57	59
Mean irrigated area per household (ha)[1]	0.97	1.17	0.11	0.11	0.67
Mean annual household income (US$)[2]:					
Households with income exclusively from agriculture	607	906	1292	179	411
Households with diversified-income	1223	1754	5968	1098	940
Education (% of scheme individuals)[1]:					
Not started	2.5	11.4	9.8	7.3	6.9
Still at school	19.2	20.7	2.6	0.3	0.5
Finished schooling:					
Primary or below	60.8	58.9	54.3	52.1	52.5
Secondary of above	17.5	9.0	33.3	38.3	28.8
Unknown	0.0	0.0	0.0	2.0	11.3
Employment (% of individuals)[1, 3]:					
Working on-farm (%)	69	100	56	87	83
Working off-farm (%)[4]	31	25	47	52	46
Working away (%)[5]	7	1	14	9	3
Unemployed (%)	15	0	17	3	8

1. Zuo et al., forthcoming; 2. income exclusively from agriculture is farm income and agricultural labour; diversified income includes non-agricultural labour; regular, seasonal or self-employment; business, remittances etc; mean incomes from Manero (2017) using currency calculation for Tanzania and Mozambique based on rates on 30/6/2014 (http://www.xe.com/currencytables); 3. individuals can work both on- and off-farm; or work neither on- nor off-farm; 4. off-farm is categorized as any farm or non-farm work not on the household land; 5. work away is, living and working away from the scheme for the season).

2. The water challenge: the failure of small-scale irrigation systems

Firstly, this section outlines the environmental water challenges (e.g. salinity and over-extraction) and then outlines the contributing policy challenges (e.g. weak institutions), and the resulting challenges for the schemes, which are a mix of infrastructure and technology, institutional, and social (e.g. lack of agronomic and irrigation knowledge). The final challenge discussed relates to the complex nature of small-scale irrigation schemes and the interconnectedness of challenges and solutions.

2.1 Environmental water challenges

While irrigation faces considerable challenges to operate sustainably, expansion will take place, regardless of past failures (Stirzaker & Pittock, 2014). Globally, waterlogging and salinity affect 20-30% of irrigated land. This proportion is mirrored in Chokwe, one of Mozambique's largest schemes, where 32% of the irrigated land has been abandoned (Stirzaker & Pittock, 2014). Whilst salinity is not an issue for most of the schemes involved with this project, over-watering is common in irrigation and salinization is an ever present threat.

As population and economic growth continues, increased demand will require re-allocation of water among competing uses: such as domestic water supply, sanitation, industry, hydropower and environmental flows (Turral, Svendsen & Faures, 2010). This is particularly problematic where over-extraction is already an issue: for example, the upper Great Ruaha Basin in Tanzania is targeted for irrigation expansion but over extraction is already affecting the environment, tourism and hydropower (Pittock, 2014). Both Kiwere and Magozi are part of this basin, so there are immediate issues of competition for water resources.

Climate change will increase the uncertainty of water supply and demand (FAO, 2012). Water productivity has to improve to maintain food production. This will be challenging as farmers: i) believe more water is better than less; ii) often do not pay for water and, therefore, apply it excessively; iii) have a lack of understanding of the consequences of excessive water application; and iv) have no easy way of knowing when a crop has received enough water (Stirzaker et al., 2017). Reducing over-application of water will have positive environmental impacts by lowering transmission losses, which will minimize salinity and waterlogging and increase river flow.

2.2 Policy challenges

In general, policy challenges include: a lack of integration between agricultural, water and environmental policies (Kahinda & Masiyandima, 2014); weak water governance institutions (Shah et al.2002); perverse policy incentives (e.g. low water fees); lack of measurement and enforcement of water diversions (Pittock & Grafton, 2014); and inadequate returns on investment that discourage further funding (Inocencio et al. 2007). Another less appreciated challenge is that irrigation development—new or rehabilitation—has focussed primarily on the infrastructure and hard technology issues associated with water management, which has meant that soft issues have not been addressed. Traditionally, it has been easier to obtain funding for engineering works, while little funding has been available for soft issues such as integrating farmers into the agricultural value chain. Reasons for this include: an engineering paradigm promoted by the "hydraulic bureaucracy" (Molle et al., 2010); lack of transparency and corruption (Transparency International, 2008); expenditure rules that favour the purchase of physical items; and a lack of appreciation of the opportunities to enhance irrigation performance through investment in human capital.

Many small-scale schemes were founded on the unrealistic expectation that irrigators could manage and maintain them and that the costs of doing so would be affordable through improved yields (Shah et al., 2002; van Koppen, 2003). However, farmers frequently 'inherited' poorly constructed infrastructure that was already in decline. The subsistence-orientation of schemes—enforced in some countries by government food-security policies—traps farmers in poverty and undermines sustainability (Pittock & Stirzaker, 2014). As repeatedly reinforced in this chapter, improved crop yields do not translate to improved profitability without some focus on market integration.

2.3 Scheme challenges: infrastructure and much more

Prior to intervention, there were many challenges within the project's schemes that are specific to small-scale irrigation such as: flood damage, canal leakage (unlined canals) and siltation (lack of silt traps); inadequate water provision to plots (small intake, lack of monitoring) and scheduling difficulties; poorly defined infrastructure management and maintenance arrangements (low willingness to participate in collective actions); inadequate or non-payment of water fees; and conflict within schemes (upstream/downstream users, lack of enforcement of irrigation times) and between irrigation and other water users. More detail can be found in de Sousa et al. (2017) for Mozambique; Mdemu et al. (2017) for Tanzania; and Moyo et al. (2017) for Zimbabwe.

The adoption of new agricultural technologies is critical for improving efficiency and profitability (Wheeler et al., 2017) and, as noted, technologies associated with irrigated farming encompass both 'hard' and 'soft' options: such as irrigation infrastructure, new crops, irrigation technology, and knowledge and skills. Small-scale irrigators typically have low use of technology, rely on household labour rather than equipment, and have little or no use of artificial fertilizers and improved seeds (Rhodes et al., 2014). The traditional approach to disseminate knowledge and introduce new tools through a 'technology supply push' model of agricultural development is not appropriate in SSA. Countries that have used this approach successfully have various supportive institutional frameworks in place—such as publicly funded access to research, agri-business development, information and training, and farmers unions—but these are largely absent in SSA (Pittock and Stirzaker, 2014; Wheeler et al., 2017). Alternative farmer-centred learning systems are required that allow for experimental and adaptive learning about agronomic and irrigation practices as well as market and value chain integration (Pittock and Stirzaker, 2014).

Compounding these challenges, land tenure and land access arrangements on schemes are often unclear and access is particularly problematic for women and youth. Uncertain tenure has many implications for farmers and affects income generation, wealth accumulation, credit access, and confidence to invest and support maintenance (Deininger, 2003; Meinzen-Dick, 2014). Other barriers are similar to small-scale farming in general: for example, inequity issues such as unequal plot sizes and poor representation of disadvantaged groups; poor access to finance, inputs and equipment; low yields and profit; poor market understanding and access; lack of knowledge and little or no extension services.

The baseline surveys for this project (see section 4.1) found that the barriers for farmers included: access to knowledge, markets, equipment, transport, inputs, and finance (Bjornlund et al., 2017). This reinforced the importance of focusing attention on the soft barriers. Farmers also raised issues relating to non-functioning infrastructure and equipment during more in-depth discussions. That hard issues were raised later may reflect that the day to day challenges directly influencing each household's well-being were foremost on farmers' minds.

In summary, the underperformance of schemes affects the potential of irrigation to address poverty, food security, and improve local and national economies.

2.4 Small-scale irrigation schemes as complex systems

Small-scale irrigation schemes are complex systems with challenges and solutions that are highly interconnected. The extra level of complexity associated with managing irrigated agriculture, as opposed to dryland farming, is not fully understood and appreciated: there are new actors and interactions; there is additional infrastructure; and a new skill set is required (van Rooyen, forthcoming). In addition, the risks are higher as irrigation is labour intensive and requires expensive farm inputs. Irrigated farming reduces the time available for other income earning activities and can contribute to ongoing poverty by increasing household expenses. Farmers and households are also diverse with many households having more than one income stream—with irrigation accounting for 65% of farm income but only 42% of total household income (Bjornlund et al., forthcoming)—meaning that household decision-making is also more complex.

Schemes are not isolated systems and they have economic ties to the broader community through several sub-systems: such as farm services and other commercial suppliers, markets, and education. The diversity of sub-systems and associated agents/stakeholders is shown for the project's Zimbabwe schemes in Figure 4. Part of the complexity is that stakeholders will have different value systems and interests (Pittock & Stirzaker, 2014). Additionally, there is typically no central control within a complex system, which makes management more difficult (van Rooyen et al., 2014).

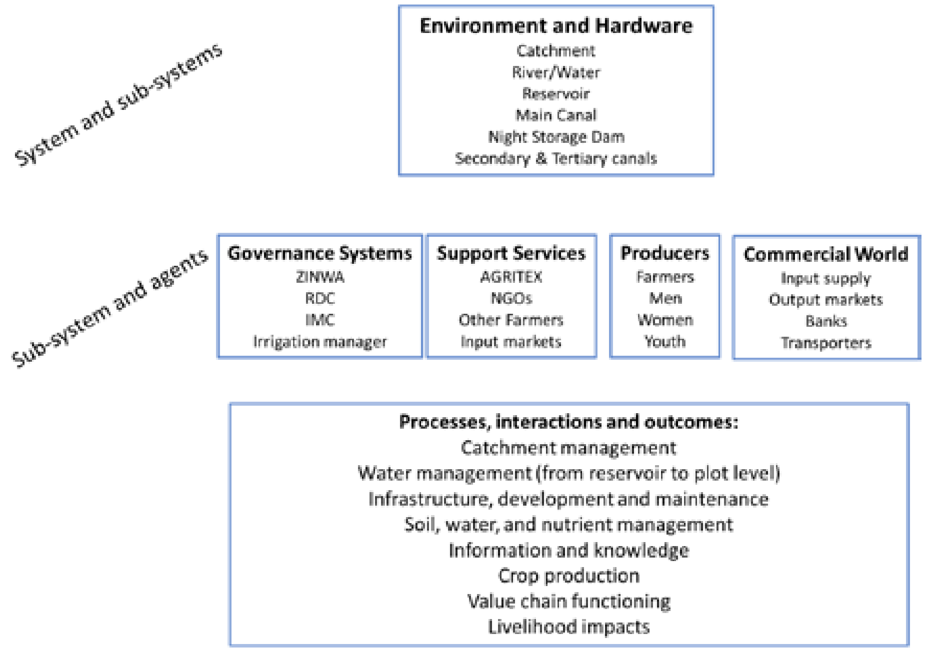

Figure 4. Example of a Zimbabwe irrigation system and its components (van Rooyen & Moyo, 2017).

Reductionist approaches are inappropriate for understanding irrigation schemes, as it is not possible to break down the system into predictable cause and effect relationships (van Rooyen et al., 2017). Rather, these systems require adaptive management where learning and improvement is part of a real-life experiment, featuring a long-term vision, consensus making, and developing shared values (Stirzaker & Pittock, 2014)

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3. The theory behind the two-pronged approach

Support for adaptive management has coalesced as: i) the complexity of socio-ecological systems is now well recognized; ii) there is an acknowledgement of the need for linked technical and institutional solutions; and iii) cheaper monitoring is available (Pittock and Stirzaker, 2014). The two-pronged approach used in this project is particularly suited to adaptive management in complex systems and creates two feedback loops. The soil monitoring tools provide immediate feedback on several critical parameters related to irrigation management. Whereas, the advantage of an AIP is to provide a surrogate coordinating mechanism that helps the schemes establish feedback loops to critical parts of the system: for example, markets and input services.

In the past, irrigation development has focused on the provision and repair of hard technologies, such as infrastructure, with little attention to technical capacity, institutional arrangements and market linkages. Whilst infrastructure challenges are of interest to the project, they are not addressed directly through funding, rather the AIP facilitates bringing relevant partners together to find solutions to the most critical issues.

Irrigation schemes therefore will continue to fail unless successfully managed to:

- i) develop water resources within sustainable limits;
- ii) schedule water and nutrient applications to enable high crop yields;
- iii) integrate farmers into the agricultural value chain; and
- iv) introduce participatory water governance with efficient and equitable water distribution (Pittock & Stirzaker, 2014).

The project's Phase 1 theory of change is shown in Figure 5. The scale of intervention is small-scale irrigation communities (two boxes on left) and their shared resources and infrastructure. The entry point is increasing crop yields through soil monitoring and using AIPs to identify market incentives to translate increased yields into increased profitability. The challenges raised within an AIP are discussed in the context of long-term outcomes, the policy and institutional environment (top down) and the current technology, barriers and hopes of the farmers (bottom up). Information and learning from the soil monitoring intend to build capacity in the local institutions and the farmers (immediate outcomes).

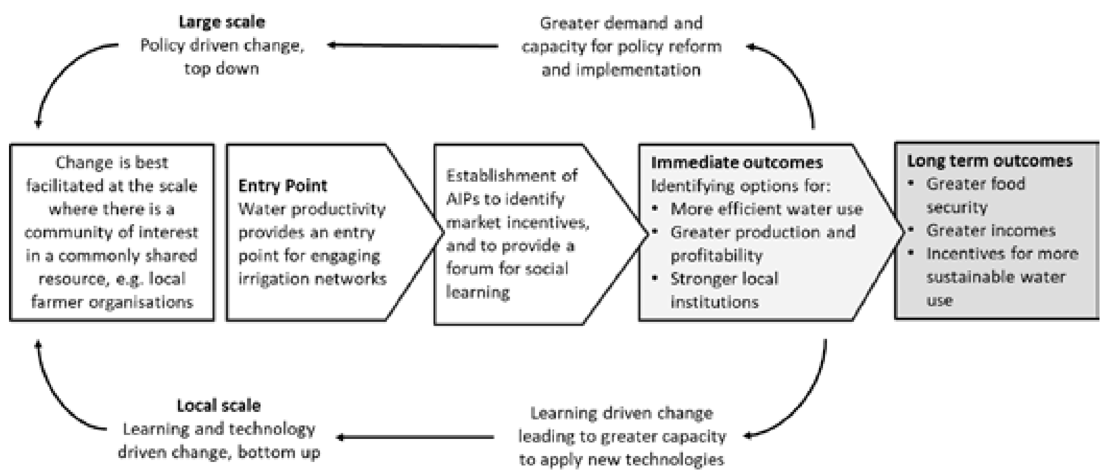

Figure 5. Project theory of change (adapted from Pittock & Stirzaker, 2014)

The approach features two critical feedback loops. An 'upward' loop of learning that fosters advocacy for improved investment of funds and reform of water licensing or pricing policy, which is stimulated as the AIP stakeholders better understand their requirements and obligations. In particular, more profitable and confident farmers put pressure on government agencies and larger businesses in the agricultural value chain to better service their needs. A second 'downward' loop represents how farmers learn about their practices and how they impact individually on profitability, and collectively on sustainability. Consequently, a virtuous cycle for improved profitability of agriculture is envisaged. The AIPs consider many constraints and, again, experience in Africa suggests that continual feeding in of information is important to stimulate and structure learning.

Phase 1 had many critical assumptions: (1) farmers are interested in adopting a business mind-set and reinvesting in their farms; (2) reliable markets can be found; (3) the value of collective effort is recognized; (4) commitment to irrigated land is maintained when rains come; and (5) efficiency improvements do not undermine equity of access to land and water.

4. The two-pronged approach to address the challenges: soil monitoring and AIPs

There is no single solution to overcoming the diversity of challenges faced by small-scale irrigation schemes to improve their profitability. Thus, problem solving and overcoming barriers is the core business of this project through the simultaneous introduction of the soil monitoring tools and the AIPs as entry points to stimulate learning and change. The tools provide a deep understanding of the water-nutrient dynamics. This allows farmers to make more informed decisions about water and nutrient management, which leads to critical changes in behaviour and practices, and results in improved yield. The AIP is a platform that facilitates the identification of challenges, their root causes and opportunities to address the challenges through context-specific measures identified by interested stakeholders. As such the AIP acts to remove the constraints that prevent farmers acting on the monitoring results and facilitates the use of and learning from the tools and translates this into increased yield and profitability. This combination is critical: earlier trialling of the FullStop device in South Africa found that interest ceased when funding ceased despite the tool being rated as easy to use and helping farmers make irrigation decisions (Stirzaker et al., 2017). Importantly, in providing these tools, it is not the intent to provide a set of solutions: farmer's livelihood choices are complex and learning from the tools will help them to apply the knowledge in their own context.

For ease of discussion, the two components of the two-pronged approach are described separately.

4.1 Soil monitoring tools

The soil monitoring tools have been developed by the Commonwealth Scientific and Industrial Research Organisation[3] (CSIRO) to stimulate farmers' learning by linking the information from the monitoring to processes that happen when water is delivered to the soil (conceptualizing the processes). The tools provide the results in the form of coloured lights, with the colours representing triggers for action. This way, the results can be easily understood by semi-literate farmers. In receiving and integrating new knowledge about soil moisture and nutrients, farmers can understand the relationships and impacts and, hence, improve crop yields and water use efficiency.

3. The development the soil monitoring tools has been supported by the South African Water Research Commission and more recently by ACIAR-funded projects.

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Traditionally, irrigation management has been taught using an engineering paradigm that uses climate, crop and soil data to provide a predicted irrigation volume to farmers. This method suffers from several issues: each variable is prone to error; application of precise volumes may not be practical (e.g. in flood irrigation systems); climate is variable; cropping patterns change; and there is a mismatch in the mental models between scientists and farmers that disrupts the transfer of knowledge (Stirzaker et al, 2017). The theoretical underpinning of the tools is that an irrigation management system for small-scale irrigators in developing countries should:

- provide people-centred and experiential learning;
- facilitate adaptive management by supporting observation, monitoring and feedback; and
- be inexpensive, robust and suitable for farmers with low literacy and numeracy: simple to use and provide the least amount of information needed for irrigation decision-making (Stirzaker et al., 2017).

4.1.1 Tool development

The design of the tools drew on a thorough understanding of the science of soil water and solute measurement techniques to determine the parameters that should be measured and how the tools should be designed to be easy to use. It is important that water, nutrients, and salt are measured together, because these factors are all inter-related and provide different insights into what is happening in the soil. Soil tension was selected for soil moisture measurement as this has the same meaning regardless of soil type and it is a measure of how hard plants must work to extract water from the soil. Nitrate was chosen for nutrient measurement as this is the major form in which soluble nitrogen is available to plants and is particularly susceptible to leaching if excess water is applied. As such, it is a lead indicator of fertility management. The third parameter is salt levels, as salinity is a common issue on irrigated land resulting in reduced yields and land degradation.

4.1.2 Description of the soil monitoring tools

Farmers received two principle devices:

- **Chameleon**™ Soil Water Sensors (Figure 6 and 7)
- **FullStop**TM Wetting Front Detector (Figure 8) supported by an electrical conductivity meter and nitrate test strips

The Chameleon is an inexpensive resistance-type sensor that measures soil tension. The technique is similar to the well-known 'Gypsum Block', except that the material inside the sensor is a highly absorbent porous media that amplifies the tension signal in the desired range. This material is encased in gypsum to buffer the sensor against variable salt levels in the soil. Three or four Chameleon sensors are included in an array, to measure the top, middle and bottom of the expected root zone. The sensors are buried permanently in the soil and connected to an 8-pin plug. The wires are colour-coded, so the farmer always knows which sensors are at which depth. Each array has a temperature sensor to allow correction of the resistance reading. This sensor includes a unique identification chip.

The Chameleon reader has an LED for each of the sensors, which can show blue, green or red, depending on the soil suction at the particular depth. The Chameleon colours are:

- **blue**, meaning that the soil layer is wet (tension is less than 20 kPa)
- **green**, meaning that soil is moist (tension is between 20-50 kPa)
- **red**, meaning that the soil layer is dry (tension is greater than 50 kPa)

A group of farmers share one Chameleon reader. The farmer inserts the sensor array plug into the reader, which displays the soil tension at each depth as blue, green or red. The reader is Wi-Fi enabled and paired with a smartphone. When the reader takes the soil water measurement it picks up the unique ID and stores the results against it. If the hotspot of the phone is on, it uploads the data to a database. If not, the data from many arrays can be stored and uploaded when the reader comes into Wi-Fi contact. In this way, the farmer sees the data in the field when recorded, but at the same time, the process records the entire season's colour pattern online. Farmers can access this pattern through their phone, but they also record the data in their field books.

Colour provides a common language about a plant's ability to extract moisture from the soil. Importantly, because the sensors measure soil tension, calibration is not required and the 'language' is independent of soil type: however, soil type will influence how quickly the colour changes from blue to green to red. Information on water availability enables farmers to avoid water stress, waterlogging and fertilizer leaching and learn about the value of rainfall. Farmers receive information to make better irrigation decisions and understand the seasonal progression of crop root depth and moisture needs in the soil profile.

Figure 6. Chameleon™ soil moisture sensors and reader (Photo: VIA Farm website)
Figure 7. Farmer demonstrating the use of the Chameleon reader at Kiwere scheme

The second device is the FullStop, which enables the measurement of soil nitrate and salt levels. The funnel-shaped devices are buried at approximately one third and two-thirds of the expected depth of the crop's root system (Figure 8). As water moves down the soil profile and reaches the wetting front detector, it is funnelled into one or both of the devices depending on three factors: amount of water applied, soil type and initial soil moisture. When sufficient moisture enters the device the indicator above the surface rises. The indicator is magnetically latched in the up position to tell the farmer that a soil water sample has been captured. This water sample is then extracted (using a rubber tube and syringe) and tested for nitrates (using colour test strips) and salinity (using a modified electrical conductivity meter that also uses colour through lights). The team is in the process of developing an automated version of the FullStop that works in a similar manner to the Chameleon sensor.

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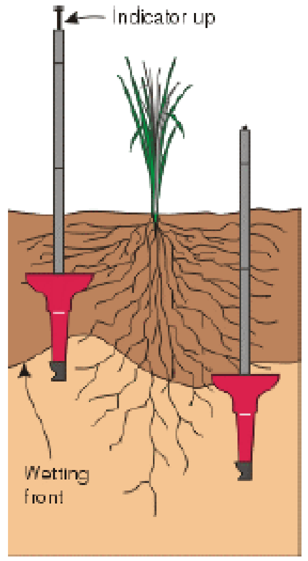

Figure 8. Placement of two FullStop devices (Photo: VIA Farm website)

4.1.3 Deployment of the technology

The FullStop was developed in the early 2000s and commercialized in 2004 (Stirzaker, 2003; Stirzaker et al., 2010); it was introduced into Tanzania, Mozambique and Zimbabwe by this project. The Chameleon was first installed on the Kiwere irrigation scheme as part of this project in mid-2014. By 2015, both tools had been provided to five irrigation schemes (not at Magozi as flooded rice production does not require these tools). Tools were deployed on 100 plots across the five schemes (20 on each) with each scheme also receiving two readers.
Field officers were trained in how to install the tools and work with the farmers to take measurements. Each farmer provided with the tools had two FullStop devices and an array of three of four sensors buried at different depths, depending on the crop (Table 6). The number of sensors and depth of deployment varies with the crop. Initially, three or four sensors were used but the final Chameleon model uses three sensors.

Table 6. Irrigation method, crops monitoring and placement depths of FullStop and Chameleon sensors on schemes (Stirzaker, et al, 2017, p. 792)

Scheme	Irrigation method	Crops monitored	Wetting front depths (cm)	Chameleon depths (cm)
Kiwere	Gravity flood	Tomatoes	20, 50	20, 30, 40, 50
Silalatshani	Gravity flood	Maize	20, 40	15, 30, 45, 60
Mkoba	Gravity flood	Maize	20, 40	15, 30, 45, 60
25 de Setembro (Boane)	Pump flood	Maize, cabbage	20, 40	15, 30, 45, 60

The field staff explained to the farmers what the colours meant, when and how to extract water from the FullStop, and how to analyse the water sample for nitrate and salt. It was then the farmer's decision how to act on the monitoring information. The reason for this approach was to remain faithful to the project philosophy—that although there may be an optimum colour pattern from a scientific standpoint, the optimum for a particular farmer may be quite different. Each farmer's management options are context-dependent, they have different appetites for risk and they face a unique set of constraints within which to optimize their business. The colour patterns simply tell the farmers the outcome of their current management and it is up to them to learn their way to a better outcome as their experience and expertise evolves. The output from the tools structures this experiential learning process.

The farmers using the tools maintain a detailed record in their field books of the readings from the tools as well as farm inputs, yield and the prices received for their crops. The installation on the schemes was designed to ensure representation of plots with a different location on the water delivery system: upstream, middle and downstream plots.

Initially, field staff took the readings once or twice a week, and nitrate and salt status were recorded when the FullStop indicator had risen. The farmers recorded the readings directly, if they were present when readings were taken, or the results were communicated to them via mobile phone. Farmers recorded the readings in their field books for their own ongoing record-keeping and learning. The field staff communicated the data to the research team.

Three early issues necessitated a change to this process: i) the cost of employing people to take the readings, record data and enter it into databases; ii) data validity, transcription and quality issues through consolidation of the data across farmers, schemes and countries; and iii) farmers sometimes moved sensors to different crops or plots mixing sensor locations. For these reasons the team abandoned the manual reading system and developed the digital Wi-Fi based version described in the section above. Some additional training was required but it removes human error and facilitates fixing data problems sooner. It also removes the at times lengthy delay from field recording to sharing data with the team. This change did not affect the farmers' access to the data.

In addition to weekly or bi-weekly discussions between the project staff and farmers about the monitoring data, 20 Kiwere farmers were interviewed at the end of the first cropping season in February 2015, about their experience of using the tools. Several months later, ten farmers participated in a focus group to discuss their experiences in more detail and some of these results are summarised in section 4.2.1. The farmers who were provided with the tools continued to use them throughout Phase 1 and into Phase 2.

4.1.4 Uses and users of the data

The key component of the improved monitoring system is the storing, uploading and reporting of data to a platform hosted by the Virtual Water Academy (VIA platform), which was introduced in 2016 (www.via.farm). Field staff upload the FullStop data manually at the time of collection and additional data—such as farm inputs, yield, crop prices and gross margins—are uploaded at the end of each season based on farmers' field books. The VIA platform has been designed for analysis and reporting at various scales, which is being explored further as part of the up- and out-scaling in Phase 2 (section 7.2). Of most relevance to the farmers, is the seasonal, daily or weekly patterns of soil moisture that show the wetting and drying of the soils, rooting depth, and how well irrigation or rainfall refills the soil (Figure 9). Farmers can access this data from their field books, but it is also available graphically on the VIA platform. However, farmers are currently still relying on their field books for learning and sharing with other farmers as reported in section 5.1.

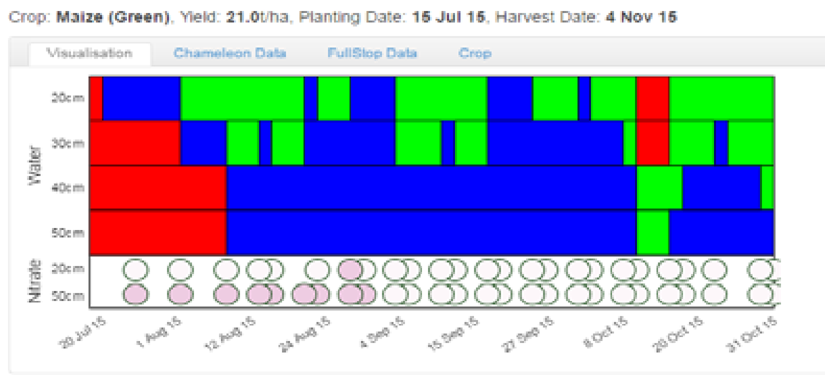

Figure 9. Seasonal pattern of soil moisture and nitrate for a maize crop on Kiwere

Figure 9 provides an example of a seasonal pattern—showing soil moisture at four depths and nitrate at two depths—available through the VIA platform, and the knowledge that can be gained from its interpretation. The soil is dry at the start of the season and the profile fills with water as irrigation water is applied or rainfall is received. The soil is too wet when all depths show blue and nutrient leaching is likely to occur. The soil is too dry when red is shown. In this example, most root activity is in the 0-30 cm zone, but nitrate is mostly available below 20cm and is leached below 50cm about half way through the season.

The design of the data system should allow different users to access data for different purposes. Farmers need their own copy of all data: so they can increase their knowledge and make their own decisions about their farming practices and conduct end-of-season evaluations. The seasonal patterns across farmers and schemes will be of interest to other stakeholders such as extension officers, local government and irrigation departments. With appropriate placement of tools on the schemes, the results can also be used to evaluate systemic management issues such as over irrigation at the top end of the canal/scheme and water scarcity at the bottom end of the canal/scheme (Pittock & Stirzaker, 2014). The platform can also support benchmarking of performance, identification of better practice and prioritization of interventions (Stirzaker et al., 2017).

4.2 Agricultural Innovation Platforms (AIPs)

AIPs are defined as forums "established to foster interaction among a group of relevant stakeholders around a shared interest" (Makini et al., 2013, p. 2) and dialogue is facilitated amongst a diversity of stakeholders to identify synergies between different components of the system (Homann-Kee Tui et al., 2013). These platforms have been widely used in Africa in a diversity of farming contexts—for example, seed, maize, honey and livestock production (Makini et al., 2013)—and the Forum for Agricultural Research in Africa has advocated their use as the preferred approach to research for development (Schut et al., 2017).

This project uses AIPs for the first time with irrigation schemes as they are particularly well-suited to simultaneously address multiple barriers, which in the scheme context are the technological, capacity and institutional challenges that are constraining adoption and profitability. The forums provide a space for learning and experimentation and generating adaptive capacity (Boogard et al., 2013) through:

- Empowering stakeholders and creating a platform where they can be active decision-makers for their own future.
- Fostering paradigm shifts amongst service providers, farmers and other stakeholders to transition from subsistence agriculture to farming practices that are more market-oriented and profitable.

- Building local capacity to innovate and analyse challenges and opportunities, reduce risk and increase income.
- Improving communication and networks between stakeholders along the value chain, and between farmers and water supply/management institutions/organisations.
- Enhancing participant's capacity for self-organization, representation and communication.
- Fostering greater respect and elevated status for farmers from government and private sector employees.

4.2.1 Setting up the AIPs: initial stakeholder selection and facilitator engagement

In this project, information was collected on each scheme to better understand the specific agricultural systems, demographics, context and challenges faced by each scheme. From this information, an initial identification was made of stakeholders that should be involved in the AIP process, either from the value chain or other relevant systems.

This was a critical exercise as the strength and success of AIPs are underpinned by the networks and connections established. Many and strong connections lead to better opportunities and solutions. The structure of an innovation platform allows for three tiers of participation from a diversity of stakeholders. With this in mind, the AIP organizers make an initial broad and careful consideration of the stakeholders and whether they are core (with continuous participation), secondary (with regular participation) or peripheral (with occasional participation) and, hence, the likely extent of their participation.

In this project, the stakeholders identified were all individuals who understood their own challenges well and could identify options to improve the efficiency of the production-to-market system. Country teams specifically considered farmers who were innovative, active and disseminators of knowledge and information (van Rooyen et al., 2014). Additional participants typically included district government, other government representatives (agriculture, water, irrigation, social welfare, youth and rural development), extension officers, private sector businesses (e.g. finance, agriculture and inputs, and produce markets), NGO representatives and scientists. In some instances, relationships needed to be built with some stakeholders to engage them in the AIP process and to ensure they attended.

Another critical aspect of the pre-implementation phase was the engagement of suitable facilitators who were then trained and mentored throughout the AIP process. The role of the facilitator is crucial, and requires a fundamental understanding of local systems, norms and cultures. Their role is to guide the diverse stakeholders through the process, uphold transparency and be aware of gender and power relations within and outside the AIP (van Rooyen et al., 2013). The facilitator must work innovatively to support inclusivity, ensure the inclusion of each stakeholder's voice, facilitate discussion of all contributions, and entertain all suggestions. A keen ear for detail and quick analytical skills are required to assess statements and provide space for the participants to discuss and reach agreements. Facilitating the group to respect and appreciate all contributions was paramount to success. Throughout the AIP, especially in the beginning, it is critical to accentuate that there is value in failure and that these experiences are important elements of success. The major role of the facilitator is to manage the process in a way that provides space for evaluation and learning, and engenders a real sense of ownership by the stakeholders: ultimately, the overall goal is to establish local capacity to innovate and self-organize.

4.2.2 The four-stage AIP process

The AIP process consists of four core stages. Each stage is not necessarily one specific meeting and several meetings may take place within each stage.

Stage 1: AIP inception and stakeholder identification
The AIP inception meeting brings the stakeholders together and they are introduced to the AIP process. This step is important to gain commitment from the diverse range of stakeholders and enables additional stakeholders to be identified. It is beneficial to have a high-profile agricultural/irrigation person to champion the AIP and welcome people to the process. In this stage, participants articulate their interest, and clarify their role and responsibilities for developing new and improved ways of doing business.

Stage 2: Identification of system constraints
Reflecting that it is human nature for individuals to want to express their problems, this stage allows many opportunities for the articulation of challenges. While this serves to set the scene for the following stages, the interconnectedness of the problems, their relationships and the feedback mechanisms between them also become apparent. For example, limited access to inputs leads to poor yields, which results in poor returns. Similarly, poor markets lead to low income and reduced incentives to invest in inputs. Participants are divided into groups (farmers, technical support staff, private sector and government) to: list and prioritize challenges and opportunities; determine the root cause of each challenge; and identify solutions and critical partners. Table 7 demonstrates that there can be multiple causes and solutions requiring the involvement of many partners.

Table 7. The challenge of low prices for rice in the Magozi scheme (van Rooyen et al., 2017)

Challenge	Root causes	Solution	Partners who can assist
Low price of rice	Lack of a joint market for farmers to sell rice	Farmers have to organize themselves and sell their rice collectively	Farmers
	Flooding the market with small quantities of different varieties	Store rice in a warehouse while waiting for better prices	Iringa District Council
	High transportation costs	Grow varieties that are in high demand	Financial institutions e.g. as non-governmental organizations, Member of Parliament
	Selling paddy instead of rice	Acquire and install rice hulling machines	Ministry of Agriculture, Food Security and Cooperatives
	Imported rice from abroad sold at low prices compared to domestic rice prices	Adopt expert advice on growing, processing and marketing	Savings and Credit Cooperative Society
		Advocate that the government give priority to locally produced rice before permitting imports	Private investors (rice hullers).

Adequate time to discuss challenges is important, as participants may not be able to move to the next stage if they have not done so. During this stage, the facilitator prompts the groups to think comprehensively to ensure that: i) known significant challenges are discussed; and ii) the stakeholders move beyond a generic articulation of a challenge and its cause. Participants were asked to repeatedly consider the 'why' question to analyse and identify the root causes and viable potential solutions. Finally, the groups reunite to discuss, clarify and confirm their findings and identify who will implement the solutions.

Stage 3: Visioning
Central to the success of the AIP process is developing a common vision of where the participants see the system in five years. Participants work in their groups to develop pictures of the current and future state of the irrigation scheme and their community. The facilitator has an important role in stimulating the forward thinking, as this can be difficult for people that have not been able to 'dream' about a different future. The desired future picture (Figure 10) expresses what stakeholders perceive to be achievable within a five-year period, but is not

limited by whether a clear pathway towards the vision is available. The pictures show the scheme layout and important local infrastructure: for example, houses and other buildings, plot and crop arrangements, irrigation infrastructure, shops and local markets. The visioning process places farmers aspirations in context and the support services and private sector can adjust their strategies to accommodate them.

In stage two, it is not uncommon that hard technological interventions are identified as a quick-fix to an issue and many projects stop the diagnostic process there. However, the visioning exercise should help bring the 'people' issues to the surface and this stage often illustrates the systemic challenges. For example, while improved agronomic practices may increase yields they do not increase income if markets are not functioning, storage is not available, or if there is no transportation to take produce to markets.

Finally, the facilitator asks participants to develop a narrative of how they envisage their scheme can move from the present to the future situation. This is helpful as it allows the AIP's stakeholders to think in terms of process and not only the technological interventions. This facilitates the development of a contextual environment so that the scheme can best utilize technological and policy interventions.

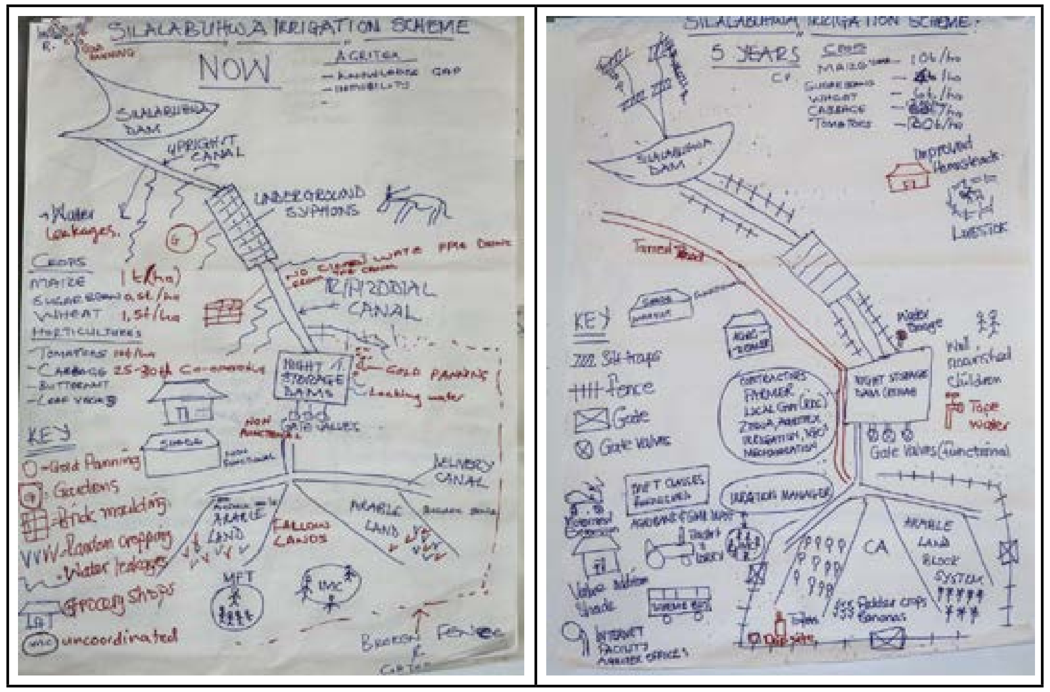

Figure 10. Examples of the current situation (*left*) and desired situation (*right*) produced from the visioning exercise in Silalatshani, Zimbabwe (van Rooyen et al., 2017)

Stage 4: Innovation process
Stages 1 to 3 identify critical issues that need immediate attention and potential strategies (with accompanying actions and resourcing requirements) that help the scheme transition to the future state. One element of innovation is that stakeholders are brought together who, whilst they might have engaged with one another previously, have never discussed common problems or identified improved business strategies. The resulting solutions and innovations draw from the diversity of knowledge and perspectives of the participants. They are tested by the stakeholders themselves, and adapted and placed into the local context to improve system efficiency to benefit all stakeholders.

The diversity of stakeholders allows for the emergence of different solutions, opportunities and activities that support the transition process. Some activities may be within the control of the AIP stakeholders to implement, while others are larger system challenges associated with policy, infrastructure, markets and knowledge needs. The stakeholders discuss the challenges to determine what can be addressed by the AIP and associated organizations and the appropriate sequence of activities. In some cases, issues may need resolving before priority activities can be implemented. Care is taken to structure activities in such a way that incentives for behavioural changes are clear and direct. Importantly, this stage results in shared ownership of a holistic set of solutions achievable in a realistic period. The project management team may deal with higher-level interventions—those beyond the control of the AIP stakeholders—or they may be set aside if participation and commitment is required beyond the reach of the project.

Now the innovations are implemented, which is an iterative process of testing, evaluating, learning and adjusting. Depending on the activity, sub-groups of stakeholders will focus on individual tasks, resolve challenges and test innovations. Stakeholders may not need or be able to participate in all meetings either because they are unavailable or their expertise is not required. Most of the actual innovation process takes place outside the AIP meetings. Groups report back on their activities and the AIP meetings enable progress to be tracked to sustain momentum, maintain transparency to foster trust in the process, and allow stakeholders to learn and adapt from the experience. Examples of AIP outcomes are described later in section 5.2.

The AIP meetings continue as coordinating and monitoring forums for as long as is required. Initially, the AIP serves as a catalyst, bringing people and organizations together into an informal network (Figure 11). Over time, the relationships and network between stakeholders strengthens and becomes formalized. There are no fixed rules about how long an AIP should last. Once the networks are formed, the role of the AIP should become redundant or evolve to address the next set of challenges, which may include working with new stakeholders and some stakeholders discontinuing. Ideally, the network becomes independent of the AIP and a self-sustaining institution is formed.

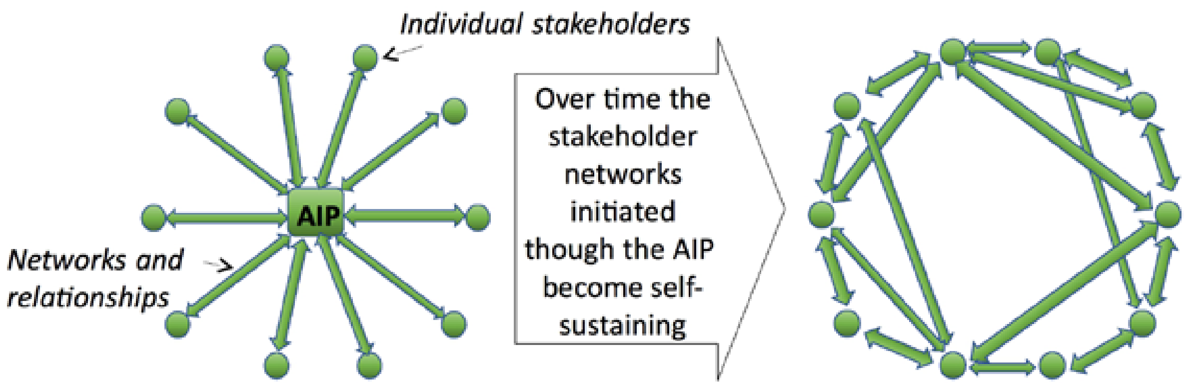

Figure 11. Developing functional networks (van Rooyen & Moyo, 2017)

The rules and process of an AIP can vary from one system to the next. For example, the facilitator's affiliations varied across the three countries and enabled the project to deploy a different facilitation model for each of the three project countries:

- independent facilitator, Tanzania
- government-led facilitation, Mozambique
- researcher-led facilitation, Zimbabwe (Pittock & Stirzaker, 2014)

In Tanzania, a researcher-led model replaced the independent facilitator in the second year of the project. The replacement was necessary after realizing that the independent facilitator perceived the AIP as a one-off event rather than an ongoing process that required a broader understanding of the project, farmers and other participating stakeholders. The facilitator is critical in the AIP process: consistency and longevity are, therefore, essential.

4.3 Key enabling components

The ACIAR, ANU and CGIAR WLE financial contributions (Table 1) have been a central enabling component with both the Australian and national research partners and the collaborating local organizations providing significant in-kind support in the form of salaries for researchers and field officers (Table 2). The management structure of the project comprises project leadership by ANU and a coordinating team of seven researchers from ANU, Australian and African collaborating partners. The coordinating team collectively bring together multi-disciplinary expertise and a robust collegiate spirit, which has been one of the key strengths of the project. The mid-term review of the project highlighted that the integration of technical and social disciplines into a cohesive research team has made a major contribution to the successful and synergistic implementation of the soil monitoring tools and the integrating role of the AIPs (de Lange & Ogutu, 2016). Capacity building within the country teams has been an important component of the project with research and facilitation skills improving through training in: multiple aspects of data collection and analysis; report and academic writing; gross-margin analysis, focus group and AIP workshop facilitation; and conference presentations.

Significant effort has been invested in establishing and maintaining partnerships, which has been essential for all stages of the project: inception, implementation, reporting and evaluation. During the application process the country representatives and their networks were vital in identifying organizations, districts and schemes that could be involved. Hence, the project links with many regional and national partners who facilitate local collaboration, support implementation, provide solutions to challenges and undertake research. The collaborating stakeholders welcomed the project from the outset, provided all the necessary support and access, and have embraced the learnings.

A three-day annual workshop is hosted on a rotational basis by the countries participating in the project, in which the entire research team and the country partners from the host country participate. This allows for extensive cross-country sharing of activities and discussion of lessons learned and future directions.

This participatory approach has been a significant enabling component and a deliberate position has been taken to have an approach that contrasts with previous top-down irrigation refurbishment projects that have focussed solely on hard solutions such as equipment and infrastructure. From the outset, it was clear that the focus would be on soft skills to empower farmers and stakeholders; to help them learn about irrigation and nutrient management and overcome their most important problems. There was some initial scepticism from farmers and other stakeholders, but this changed very quickly as early successes emerged: for example, the immediate benefit of the tools helped build trust with the researchers and the longer-term processes of the AIPs. Farmers, irrigation associations, extension officers and other stakeholders soon embraced the project's approach and their enthusiasm to be part of Phase 2 illustrates this.

CASE STUDIES
TRANSFORMING SMALLHOLDER IRRIGATION INTO PROFITABLE AND SELF-SUSTAINING SYSTEMS IN SOUTHERN AFRICA

5. Achievements and results

Considerable quantitative and qualitative data has been collected throughout Phase 1, including:

- Household surveys of the six schemes: a baseline survey of 402 households (de Sousa, et al., 2015; Moyo et al., 2015; Mziray, et al., 2015); and a Phase 1 end-of-project (Phase 1 EOP) survey of 266 households in 2017 (Moyo, et al., 2018; Cheveia et. al, 2018, Mdemu et. al, 2018). As part of the 2017 survey households were asked to consider how various things (e.g. income and yields) had changed because of the tools and AIP.
- Interviews and field visits as part of a mid-term project review by independent reviewers, which formed the basis for the project receiving extended funding (de Lange & Ogutu, 2016).
- Qualitative data from focus groups discussing: emerging issues and outcomes, and specific focus groups on soil monitoring tools, gender or youth issues.
- Observations by project staff.
- 10-20 farmers in each scheme having the tools have maintained detailed records of tool monitoring, crop choices, input, irrigation rounds, yields and prices paid.

The achievements and outcomes outlined in this section (Tables 8 to 17 and Figures 12 to 15) draw predominantly from the 2017 Phase 1 EOP surveys unless otherwise stated. It should also be noted that at the time of writing this chapter the Phase 1 EOP data was not yet fully validated, integrated across schemes and countries and analysed. Similarly, farmers' field books were not fully analysed. Analysis is ongoing, and many academic publications are at different stages of production or review.

First, outcomes related to the soil monitoring tools and the AIPs are outlined in sections 5.1 and 5.2. There are many 'flow-on' outcomes from the tools and AIP approach and these are outlined in subsequent sections, which for ease of discussion are presented as on-farm, household, gender and decision-making, and scheme outcomes (sections 5.3 to 5.6). As the outcomes are highly connected, it is hoped that readers will accept the need for some cross-referencing between the sub-sections. It is acknowledged that macro-economic factors and other local developments might also influence results. However, based on our observation in the regions and countries this has not been the case in any important way, and no attempt has been made to control for these aspects in this chapter.

Where possible, it is highlighted if outcomes are a result of the soil monitoring tools or the AIP. However, the synergistic nature of the two approaches means that, it is neither realistic nor desirable to attribute outcomes to one approach or the other and additional evaluation will be undertaken as part of Phase 2 (see section 7.3). In general, the soil monitoring tools increased crop yield and the AIPs turned this into increased profitability by facilitating better market access and introducing better varieties and new more valuable crops (Figure 2). Also, the AIP facilitated the adoption and learning from the tools which resulted in changes to farmers practices. Finally, the AIP facilitated access to better quality seed and other farm inputs as well as agronomic advice. All contribute to increasing profitability. The relationships are more complex, but it is unlikely that farmers would have been able to fully capitalise on the learning generated by the monitoring tools without the AIPs facilitating solutions to other barriers.

The section on outcomes concludes by making observations on the longer-term impacts of the project and the unexpected outcomes that have occurred (sections 5.7 and 5.8). Critically, this case study illustrates the importance of considering the context within which any new SWM technology is introduced, and the institutions and processes that are needed to ensure that the technology is adopted and properly used. Without it, SMW technology might remain on the shelf with little real impact.

5.1 Engagement with and learning from soil monitoring tools

Observations by project staff found that farmers were starting to learn from the tools and were reducing their irrigation within a few months of the tools being deployed. Additionally, farmers requested that the Chameleon reader be kept on the scheme as they wanted to take readings more frequently than the project had initially allowed (Stirzaker et al., 2017). Together with farmers asking for their own reader and other farmers asking for more sensors, this shows that the soil monitoring is valued.

Of the households surveyed, between 24% and 68% had the Chameleon and FullStop devices installed on their plots (Table 8). Despite the tools not being deployed on all household plots, the level of awareness of the tools is very high, with between 89% and 100% of households surveyed aware that some farmers have the tools. Further, of the households that know about the tools, more than two-thirds know what the tools measure and what this information is used for, and a similar proportion are aware of the changes being made because of the tools. More households report making a change from their use of the Chameleon sensors compared to the FullStop with the changes made varying across the schemes. Where households report that they have made a change based on the tools, the majority report an increase in yield and 43% to 94% report an increase in income. Whilst these figures vary significantly between the tools and across the schemes, they are very positive results.

Table 8. Engagement, awareness and changes made associated with the monitoring tools

	Tanzania[1]	Mozambique	Zimbabwe	
	Kiwere	**25 de Setembro**	**Mkoba**	**Silalatshani**
Households interviewed (n)	100	28	54	84
Households with soil monitoring tools (%)	42	68	35	24
Households aware of the tools (%)	92	100	96	89
Households that know about the tools (%):				
Are aware of changes farmers have made because of the tools	73	96	87	73
Know what tools measure and what they are used for	72	93	86	70
Households that are aware of the tools have made changes because of their learning from (%)				
The Chameleon	50	93	54	55
The FullStop:	48	68	37	26
Households that changed practice and also increased yields (%)	93	83	86	77
Households that changed practice and also increased income (%)	94	80	43	55

1. Magozi is not reported in this table as soil monitoring tools are not used on this scheme.

Farmers have learnt about the complexities of the movement of water and nutrients through the soil profile and examples of this new knowledge are shown in Figure 12. Farmers have been able to correctly interpret the Chameleon colours: for example, by reducing irrigation when blue is recorded at all depths. In some cases, the observations of one farmer—that nitrate strips show white (indicating no nitrate in the Fullstop water sample) when the Chameleon shows blue (moisture is present in the soil)—have led to the learning that overwatering leaches the fertilizer to below the root zone. In response, this farmer reduced their irrigation frequency and found that the crop's new growth was more lush and green. Knowledge about over-irrigation and the relationship to a quick drop in nitrate levels spread quickly throughout one scheme, which then led to a widespread reduction in irrigation frequency. This resulted in downstream farmers reporting that more water was available within a short period of time of tool deployment (Stirzaker et al., 2017).

Figure 12. Examples of increased understanding of complex scientific phenomena from Kiwere focus group discussion (Stirzaker, et al., 2017). Photo courtesy of Ikenna Mbakwe

Importantly, it is the combining of data from the two separate monitoring tools that has stimulated understanding and change (Stirzaker et al., 2017). The spread of knowledge and change is also a critical outcome for the project with implications for future tool deployment: for example on the Zimbabwe schemes, 35% and 24% of farmers had the Chameleon (Table 8) with half or more of households aware of the tools changing their frequency of irrigation (Table 9). As noted earlier, the learning from the tools is ongoing. Farmers using the tools in Phase 1 are continuing to use the tools in Phase 2: they are refining irrigation management, and are continuing to learn about the difference between organic and chemical fertilizer management.

5.2 AIPs outcomes

Across the schemes the AIPs have facilitated a shared vision amongst those with an interest in making the schemes more successful and valuable relationships have been built (de Lange & Ogutu, 2016). Alongside facilitating the learning generated from the tools, the AIP processes have systematically addressed many critical barriers that were negatively impacting yield and profitability, which has augmented the learning gained from the soil monitoring tools and enabled this to be translated into other outcomes.

The following briefly lists the range of AIP outcomes (van Rooyen et al., 2017):

- Capacity building – consolidating the learning from the soil monitoring tools, empowerment and relationship building through the actual AIP process, farm record keeping, gross margin calculations, demonstration plots, and visits to other schemes.
- Plot management - changed agronomic practices including crop diversification, plot levelling, manure management (see also section 5.3).
- Input supplies - collective negotiation with input suppliers, and ensuring supply of good quality seed and fertilizer.
- Financial - linking farmers to finance institutions to access credit, and addressing water payment arrears.
- Markets and marketing - identification of high-value crops and buyers for these crops, market research committees to liaise with local agri-dealers, and new storage facilities.

- Scheme maintenance – dam wall, canal and fence maintenance; canal lining, replacing broken equipment; and installing new infrastructure.
- Governance – participatory scheme mapping, revision of irrigation association constitution, scheme-scale business planning, audits of plot ownership, re-allocation of unused plots to youth.

In many cases, the solutions require a significant amount of work, which was evidenced earlier in Table 7 where multiple root causes, solutions and partners are associated with improving rice prices. AIP activities sometimes addressed several challenges simultaneously (reflected in the dot point list above). For this reason, the following examples from each country are provided in some depth so that readers can gain an appreciation of the diversity and context-specific nature of solutions and the extent of work required.

In Tanzania, the project has facilitated a participatory mapping process within the two schemes (Figure 13). During the AIP process for Magozi and Kiwere schemes, it was identified that the size of the irrigation schemes was estimated and farmers did not know the exact sizes of their plots, which is important as this is linked to the water fee owed by each farmer. It was, therefore, agreed that the schemes should be mapped as individual plots due to the importance of this information for planning and decision-making. An important component of this process was to walk all plot boundaries within the scheme with the neighbouring farmers and use a Global Positioning System (GPS) to document the coordinates along the boundaries. The resulting community mapping and database of the schemes records: plot boundaries, ownership status, mobile phone number, sizes of plots, irrigation canal networks, farm access roads and drainage networks. Several benefits have resulted from the mapping: i) the information supports the issuing of customary certificates of land occupancy by government agencies, which farmers can use to access finance; ii) farmer's trust in the fairness of area-based water use fees has increased; and iii) communication within the schemes has improved. Further, these benefits have contributed to increased participation in scheme maintenance and willingness to pay fees (Table 15). The maps are proudly displayed and used as a communication tool when the scheme hosts visitors.

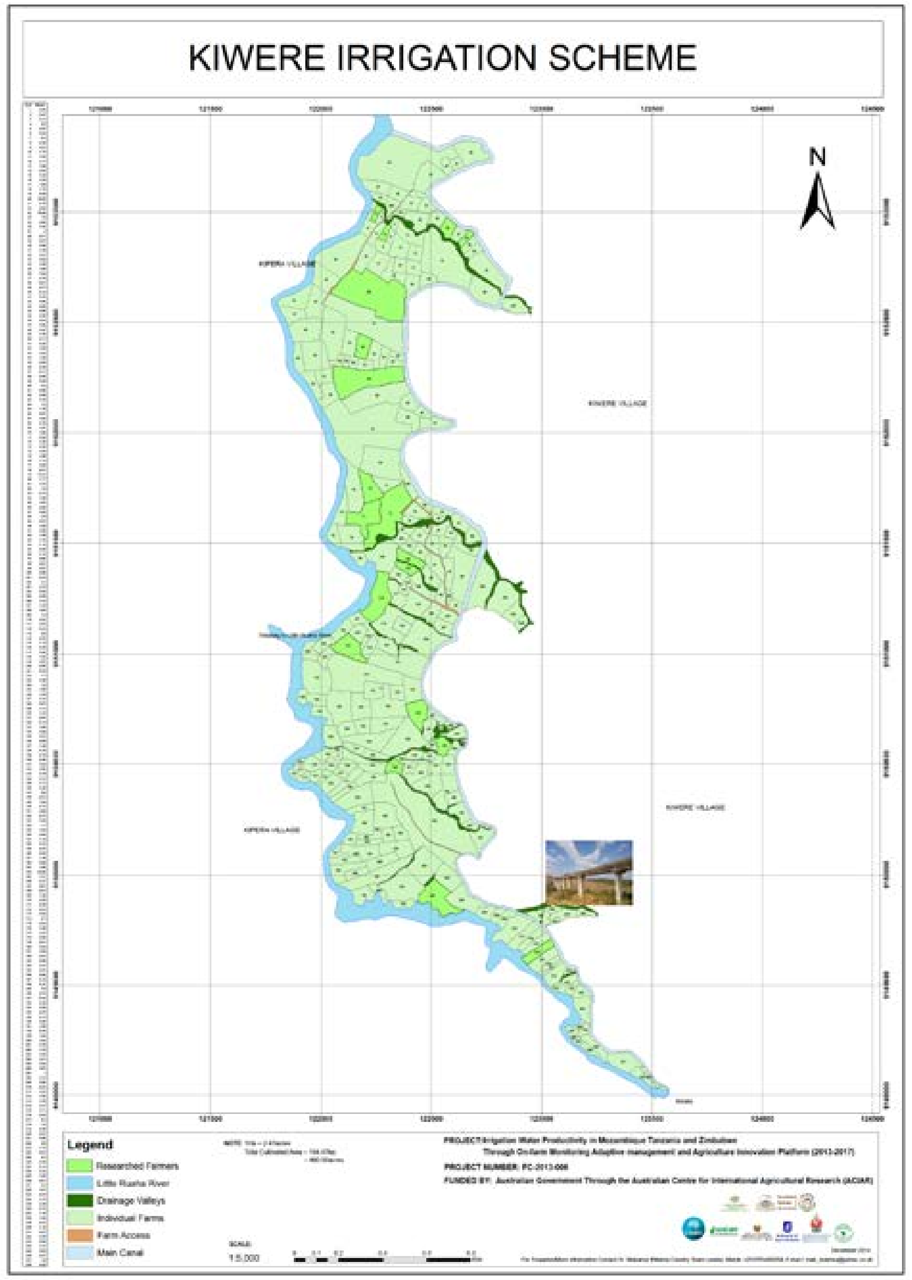

Figure 13. Scheme mapping in Tanzania

In Tanzania, the AIP process has also been instrumental in facilitating that the scheme's irrigation associations developed business plans. The associations are also proactively revising their constitutions to reflect better practice: as a result of agreement gained through the AIP and the learning gained from a visit to the Igomelo scheme in Mbeya, which was facilitated by the AIP. During this visit, farmers and leaders from Kiwere and Magozi learnt that the Igomelo scheme had: higher annual and seasonal water fees; greater enforcement of payment of water fees; higher levels of institutional organization; and a physical irrigation association office. As these outcomes were a direct result of Igomelo's constitution, the Kiwere and Magozi leaders were encouraged to urgently revise their constitutions.

In Zimbabwe, the AIPs have been very active in facilitating farmer integration into the value-chain. At the Silalatshani Scheme, the AIP facilitated the resolution to two far-reaching policy issues. The AIP helped negotiate a solution to a longstanding conflict with the local water authority, Zimbabwe National Water Authority (ZINWA). The conflict related to the size of an outstanding water bill, which had arisen during a period when Zimbabwe was experiencing hyperinflation and multiple exchange rates were in use during the transition from the Zimbabwe to the US dollar. The uncertainty over this water debt was a critical issue standing in the way of potential project success and was one of the major reasons for irrigated plots being idle at the commencement of the project. Additionally, the water fee had been based on a business model that depended on full use of the scheme and profitable farming businesses, neither of which were the case (van Rooyen et al., 2017). The negotiation resulted in a more realistic debt level and a repayment schedule that the farmers were able to agree on and have subsequently started to repay. This has resulted in an increased willingness of farmers to farm and invest in the irrigated plots.

The AIP at Silalatshani also brought stakeholders to a common understanding that land ownership was a major issue. At the second AIP meeting it became evident that a considerable number of absentee landowners were not utilizing their land. The Department of Agricultural, Technical and Extension Services (AGRITEX) indicated that the scheme was supposed to have 849 plot holders, but their registers indicated less than 300 landowners or users. At the meeting it was agreed that this needed to be resolved by the district leadership (District Administrator (DA), Chief of the Rural District Council and AGRITEX) who subsequently suggested that a plot ownership audit be conducted. The project team initially thought that these issues would be difficult to solve; however, there are strong indications that the AIP process has resulted in this policy issue being addressed. The DA and the local Chief have since held two meetings with the irrigators, discussing absentee landowners and trying to map a way forward. The project acknowledges that dealing with land tenure issues is complex in Zimbabwe, but starting the process to address some of the linked tenure issues should yield considerable economic and social impacts.

In Mozambique, the 25 de Setembro scheme has an ageing farmer population and many are therefore no longer able to manage their plots, which poses a threat to the scheme's economic and social sustainability. The farmers identified this problem during the AIP meeting. After some discussion with the district's extension services, farmers decided that, when allocating unused plots the relatives of the owners should be offered the plot first, before inviting people from outside the scheme. Unused plots have since been reallocated and approximately 17 young women and men have become involved in irrigated farming. The cooperative has elected a young farmer as vice-president, which shows that members have recognized the value of giving responsibility to young farmers.

The AIP process at the 25 de Setembro identified that the lack of a business plan made it difficult for farmers to obtain and manage a bank loan. Farmers lacked the necessary skills to develop such a plan and neither banks nor local authorities were providing this training. In order to overcome this problem, as part of the AIP process the French Agricultural Research Centre for International Development (CIRAD) was asked if it could provide business plan training, which was subsequently delivered to both farmers and extension officers. This training also included workshops with farmers to learn how to compute gross-margins for their crops.

5.3 On-farm outcomes

In this section the focus is on household's perception of changes over a four-year period for irrigation practices, yield, crop choices and prices received. Importantly, a key underpinning of this project is that households and schemes need to realise yield and profitability improvements in order for irrigation—a more expensive farming system compared to dryland farming—to be sustainable in the longer-term. Encouragingly, there are signs of improvement. However, the results also demonstrate the different starting points and journeys towards improvement: such that, irrigation on schemes may increase as infrastructure issues are overcome. There is additional discussion in the section on longer-term impacts (5.7) that acknowledges the importance of water savings with respect to environmental challenges at higher scales of interest.

Farmers have used the soil monitoring tools to make changes to the frequency or duration of irrigation events and for surveyed households: i) 50%-88% have changed their irrigation frequency; ii) the interval between irrigation events has increased by 1.4 days on Kiwere and between 4 to 9 days on the other schemes; iii) between 3 and 19 hours has been saved per irrigation event; and iv) the duration of irrigation events has been reduced by 1 to 2.4 hours (Table 9).

Table 9. Irrigation outcomes from using the monitoring tools

	Tanzania[1]	Mozambique	Zimbabwe	
Changes by households	**Kiwere**	**25 de Setembro**	**Mkoba**	**Silalatshani**
Have changed frequency %)	63	88	50	54
Interval between irrigation events has increased (days)	1.4	4	8	9
Time saved per irrigation cycle (mean hours)	19	8	4	3
Have changed number hours irrigating (%)	53	81	43	32
Mean reduction in irrigation (hrs/cycle)	2.4	2	1	2

1. Magozi is not reported in this table as soil monitoring tools are not used on this scheme
Sources: Moyo, et al, 2018; Mdemu et al., 2018; Cheveia, et al., 2018.

The reduction in irrigation is important for two reasons. Firstly, it reduces nutrient leaching, which increases the available nutrient pool and contributes to improvements in yield without additional cost to the household. Whilst salinity is only an issue in isolated pockets on some schemes, reduced irrigation is a preventative measure. There are also signs that the monitoring and AIP activities have collectively increased yields, though this is highly variable depending on the scheme and crop. Between 43% and 81% of households report an increase in yield of more than 25% for their main irrigated crop (Crop 1) and between 33% and 73% for their second and third main crops (Table 10). Interestingly, the proportion of surveyed households reporting an increased yield for their three main crops is consistently lower for Magozi, which is the scheme that does not use the soil monitoring tools and, potentially, reinforces the importance of the combination of tools plus AIP.

Table 10. Yield increase during the four years of project implementation

	Tanzania		Mozambique	Zimbabwe	
(% households unless otherwise stated)	**Kiwere**	**Magozi**	**25 de Setembro**	**Mkoba**	**Silalatshani**
Yield of three main[1] irrigated crops					
Crop 1	Tomato	Rice	Green maize	Grain maize	Grain maize
Households growing (%)	62	100	79	78	96
Households with the crop having an increase in production of 25% or more (%)	62	43	77	81	71
Crop 2	Green maize	Grain maize	Cow pea	Wheat	Wheat
Households growing (%)	59	15	36	28	64
Households with the crop having an increase in production of 25% or more (%)	57	33	66	73	58
Crop 3	Grain maize	Soybean	Tomato	Sugar beans	Sugar beans
Households growing (%)	34	3	32	57	62
Households with the crop having an increase in production of 25% or more (%)	55	33	75	59	70

1. The three main single crops listed are those with the highest proportion of households growing the crop.
Sources: Moyo, et al, 2018; Mdemu et al., 2018; Cheveia, et al., 2018.

The existence of barriers to purchase inputs is well-known, but 50% to 68% of the households surveyed believe it is now easier to purchase inputs (Table 11). Additionally, 18% to 60% report they are growing new crops. However, there has been variable success across the schemes in realizing higher prices for crops: overall, 9% to 58% of surveyed households report that prices for their crops have increased with 8% to 90% reporting improved prices for their main crop. Whilst in many cases a high proportion of the households on the Zimbabwean schemes report improvements in yield this has only translated into higher prices received for a smaller proportion of households. Part of the explanation for some farmers not receiving increased prices for their crops is the type of crop being grown. For example, in Zimbabwe, many households are still growing staple crops that receive lower prices, despite Zimbabwean extension officers calculating negative gross margins for irrigated maize. Post-harvest losses are also significant with 60%, 98% and 63% of households growing grain maize losing between one fifth to a third of their crop in Zimbabwe, Tanzanian and Mozambique, respectively (Moyo, et al, 2018; Mdemu et al., 2018; Cheveia, et al., 2018.). The inter-connections between influencing factors are complex.

Table 11. Changes to crops, range of inputs and prices received

	Tanzania		Mozambique	Zimbabwe	
On-farm outcomes over four years (% households)	**Kiwere**	**Magozi**	**25 de Setembro**	**Mkoba**	**Silalatshani**
Growing new crops	23	47	18	41	60
Household rating that the price for their crops has increased	58	41	46	9	19
Change in range of inputs has made purchase easier	64	50	50	55	68
Price received for three main irrigated crops[1]:					
Crop 1	Green maize	Rice	Green maize	Grain maize	Grain maize
Households growing (%)	59	100	79	78	96
Households with this crop receiving increased prices (%)	74	33	90	28	18
Crop 2	Tomato	Grain maize	Tomato	Sugar beans	Wheat
Households growing (%)	61	15	32	57	64
Households with this crop receiving increased prices (%)	38	56	25	17	6
Crop 3	Grain maize	Tomato	Cow pea	Wheat	Sugar beans
Households growing (%)	34	2	36	28	62
Households with this crop receiving increased prices (%)	61	0	84	17	22

1. The three main single crops listed are those with the highest proportion of households growing the crop.
Sources: Moyo, et al, 2018; Mdemu et al., 2018; Cheveia, et al., 2018.

5.4 Household outcomes

It was anticipated that the combination of the tools and AIP would stimulate farmers' demand for information and the survey data supports this expectation with more than 70% of households reporting an increase in their information needs and that their range of sources has increased (Table 12).

Table 12. Changes in information needs, sources and advice (% households)

	Tanzania		Mozambique	Zimbabwe	
	Kiwere	**Magozi**	**25 de Setembro**	**Mkoba**	**Silalatshani**
Information needs have increased	77	89	74	74	81
Range of information sources has increased	77	89	76	83	89
Getting better agricultural advice	97	96	96	91	95

Sources: Moyo, et al, 2018; Mdemu et al., 2018; Cheveia, et al., 2018.

Additionally, more than 90% of households report an improvement in obtaining agricultural advice (Table 12), which has important implications for government extension services. Whilst farmers have greater self-reliance due to the information from the monitoring tools, their demand for additional technical support from extension services has also been stimulated. The extension staff involved in the project report that their work has become more rewarding as they are providing information demanded and used by farmers, which they believe has led to better socio-economic outcomes.

Encouragingly, households surveyed are reporting changes in their income sources and improvements in income. As has occurred in the past, it is possible to improve yields but this can often result in farming households being worse off if demand and/or other market arrangements are not addressed. As the tools and AIPs are endeavouring to stimulate change on many aspects, it is a positive outcome that some household are reporting income improvements after a relatively short period of time. On the majority of schemes, between almost half and two-thirds of households report that their source of income has changed. For households where income sources have changed, small businesses or off-farm work are the main new sources in Tanzania; the provision of farm labour in Mozambique; and, for Zimbabwe, the sources appear evenly spread across the options, including remittances. With respect to increases in income there is scope for further improvement and, as noted earlier, the majority of farmers are not receiving increased prices for their crops due to a continuing focus on staple crops.

Table 13. Changes to household's income and income sources

	Tanzania		Mozambique	Zimbabwe	
Outcomes (% households)	**Kiwere**	**Magozi**	**25 de Setembro**	**Mkoba**	**Silalatshani**
Income sources have changed	66	63	11	48	44
New sources					
Providing farm labour	14	21	67	46	35
Small business or off-farm work	67	61	33	31	30
Remittances[1]	12	19	--	39	46
Farm income is now better	67	53	83	41	21
Off-farm income is now better	55	39	60	47	49

1. Remittances are transfers of money to the household usually from migrant household members
Sources: Moyo, et al, 2018; Mdemu et al., 2018; Cheveia, et al., 2018.

Between 39% and 60% of households, report that their off-farm income has improved, and on all schemes bar one more than 40% of households surveyed report improved farm income. The findings illustrate the complex livelihood strategies of farming households who are combining income earning from irrigation, dryland farming and livestock with off-farm activities. This balancing act influences how land, labour and monetary capital are used. Hence, it is not possible to explore decisions related to irrigation isolated from other livelihood strategies (Bjornlund et al. forthcoming). Off-farm income and having more time is clearly critical and focus group discussions with young farmers show that they are starting new businesses: for example, hair salons, and bread and brick making. There is a symbiotic relationship between farm and off-farm income, with income from one or the other source used to support the household's basic needs, establish or maintain a small business, or pay for farm inputs (Zuo et al., forthcoming). The increased time commitment to off-farm work could reflect two important outcomes. First, the increased yield and income enables the hiring of non-family labour allowing family members to increase their engagement in potentially better paid off-farm work to further diversify their income stream and reduce their reliance on farm income. Second, the reduced time commitment to irrigation has allowed some family members to engage in off-farm work with similar effects.

In general, households report that they are spending more time (including time saved irrigating) on a range of activities (Table 14). Whilst this varies across the schemes, spending more time on farming activities (irrigation plots, dryland plots and livestock) and home improvements appears to be particularly important. More time spent on farming—for example, weeding to reduce competition for nutrients and water—can bring immediate improvements to yield.

In some schemes, a third to a half of households use their time saved on household chores (Table 13). This is particularly beneficial to women as they shoulder the majority of household duties, which are likely to include small livestock and vegetable production on the home garden. Also, many at Kiwere and Mkoba use more time diversifying their income stream. These are important results as they indicate that the combination of the tools and the AIP has increased profitability and hence increased farmers' willingness to invest both time and money in scheme maintenance and irrigation. That fewer households at de Setembro report spending more time on scheme maintenance, probably reflects that the canals were lined and gates improved, which was facilitated by the AIP process. In general, this has reduced the need for farmers to undertake maintenance during this period; the lining reduces the time it takes for water to reach the farmers gate and allows the system to supply sufficient water for irrigation.

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Table 14. Household's use of time and extra income

	Tanzania		Mozambique	Zimbabwe	
Outcomes (% households)	**Kiwere**	**Magozi**	**25 de Setembro**	**Mkoba**	**Silalatshani**
Are now spending more time on:					
Irrigation plot	46	37	15	41	49
Irrigation/scheme maintenance	34	28	7	19	34
Dryland farming	32	15	5	37	29
Livestock	29	21	21	26	31
Home improvements	38	42	39	28	28
Off-farm income earning activities	21	17	0	34	18
Time saved on irrigation through monitoring tools is used for[1]:					
Resting, family time or family works	25	--[2]	4	30	27
Farm management (crops, ridge/land preparation, improvements, dryland)	37	--	44	30	46
Fishing	--	--	4	--	--
Household chores	--	--	22	52	38
Infrastructure maintenance	--	--	13	15	9
Small business[3]	27	--	13	22	2
Livestock management	2	--	30	11	13
School	--	--	--	0	2
Farming plot that was not cultivated	8	--	--	--	--
Carpentry	--	--	4	--	--
Nutrition garden project	--	--	13	--	--
Are now spending more money on:					
Irrigation and farm inputs	73	65	61	64	65
Irrigation/scheme maintenance	31	49	18	28	48
Education	49	42	61	68	55
Food	62	54	72	50	36
Farm implements	66	65	46	35	31
Home	64	64	64	56	36
Are now spending more money on inputs:					
Chemical fertilizer	77	57	93	68	55
Insecticide	68	56	100	27	14
Herbicide	67	57	67	27	14
Manure	42	0	50	19	5
Water fees for irrigation	34	40	83	2	41
Non-family labour	73	81	81	22	32
Equipment	54	74	68	21	20
Seeds	68	64	92	66	44
Post-harvest management	53	74	88	11	3
Households indicating they have extra income spend this on:					
Food	45	71	50	73	60
Education	57	54	36	67	71
Health	39	53	25	10	4
Farm input	54	28	25	53	67
Investment in home	45	38	18	27	15
Investment in farm	39	44	14	30	27

1. Open question; 2. there is no data for Magozi as soil monitoring tools are not used on this scheme; 3. reported as 'other business' on Kiwere.
Sources: Moyo, et al, 2018; Mdemu et al., 2018; Cheveia, et al., 2018.

In general, the majority of households spend more money on a mix of expenses, with irrigation and farm inputs (61%-73%), education (42%-68%) and food (36%-72%) of particular importance (Table 14). With respect to spending on critical inputs, the majority of farmers are reporting increases in spending on farm inputs, with chemical fertilizer, herbicides and seeds of most importance. This at first may not seem to be a desirable outcome: but, again, the starting point is important and the nutrient status of soils is low with animal manure often in short supply and farmers previously unable to afford chemical fertilizer. Farmers know that fertilizer, herbicides and better seeds will make a difference but they can only purchase these inputs when incomes are improved. Reflecting this, farm input is one of the areas in which farmers spend most of their increased income. Additionally, they need to be confident before they make the investment that their increased spending will result in improved profitability: the AIP helps remove the barriers that impact profitability.

The households that specifically reported they had more income are spending this extra income on food, education and farm inputs. It is clear that household know what their priorities are and they are investing in: the farm to increase crop production and future income; food to improve household nutrition; and education of their household to underpin future income and livelihoods.

Ultimately, what is anticipated is that improvements in income will bring about broader improvements for the households. And there are signs that households are experiencing real and tangible improvements to household food-security and well-being (Table 15). Approximately two-thirds of surveyed households report improved food security. Households' health and capacity to pay for education have also improved, though this has varied significantly across the schemes: 42%-75% and 31%-61% of households, respectively.

Table 15. Household perceptions on well-being

	Tanzania		Mozambique	Zimbabwe	
Outcomes (% households)	**Kiwere**	**Magozi**	**25 de Setembro**	**Mkoba**	**Silalatshani**
Household food security is better	70	58	67	64	66
Family members health is better	75	75	61	42	62
Capacity to pay for education is better	59	58	61	31	37

Sources: Moyo, et al, 2018; Mdemu et al., 2018; Cheveia, et al., 2018.

Collectively, the benefits of improved income and more time have also led to a reduction in household conflict in 44% to 89% of households surveyed (Figure 14).

5.5 Gender and decision-making outcomes

While the project did not focus specifically on gender issues, there has been an influence on gender roles across schemes. Qualitative data suggest women predominantly adopted the high-value crops. Hence, women's contribution to household finances has increased significantly, which should increase their influence both within households and the broader community. Even in Tanzania (the most male-dominated of the three countries) observations, qualitative data and anecdotal evidence suggest that women have increased their presence and influence within the schemes. Households surveyed have observed changes in gender roles, and in Tanzanian and Zimbabwe, they represent more than three-quarters of households (Table 16). In Zimbabwe, the main changes reported are that women are now more involved in physical work (50% and 61% of those reporting changes in the two schemes), men are now involved in household chores (41% and 27%), and there is more gender equality in leadership (34% and 36%). The greater involvement in physical work may be due to more men working in urban areas resulting in women having little choice but to do more physical work.

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In Tanzania, the two main changes are that men and women now jointly perform the work (23% and 30%) and women have decision-making rights (20% and 27%). The main changes reported in 25 de Setembro are that women are now more involved in physical work (50%) and there is more gender equality in leadership (40%).

In Tanzania, the number of households where men alone make decisions has dropped by between 11% and 25% (depending on scheme and type of decision) with the shift mostly to joint decision-making and a smaller shift for decisions on spending income (between 7% and 18%) compared to decisions relating to resources (Mdemu et al., 2018). While decision making within the household in Tanzania has shifted from being all male-dominated, men still dominate activities away from the home, such as accessing information and participating in farming-related meetings. In Zimbabwe, the farmers are predominantly women. The decision-making structure varies between female and male-headed households. In female-headed households, women make the majority of decisions, and no households report men as the decision-maker, but about 15% report joint decision-making (Moyo et al., 2017). This reflects that there is either no husband or the husband is working away. In male-headed households, women still predominantly make decisions (except for large livestock) or they are joint, with the man being the sole decision-maker in only about 20% of households. In de Setembro, households report little or no change for resource allocation decisions with women being the more dominant decision-makers. With respect to income the decision-making is more even with women becoming more dominant with respect to off-farm work decisions and men more dominant with respect to salaries (Cheveia et al., 2018).

Table 16. Change in gender roles and decision-making

	Tanzania		Mozambique	Zimbabwe	
Outcomes (% households)	**Kiwere**	**Magozi**	**25 de Setembro**	**Mkoba**	**Silalatshani**
Households observing change in gender roles	79	91	36	82	79
Main changes reported[1]:					
Women are now involved in physical work	--	--	50	50	61
Men now involved household chores	--	--	10	41	27
Gender equality on leadership	--	--	40	34	36
Men and women jointly perform the job /involved in all cropping tasks	29	33	20	--	--
Women participate in irrigation farming	19	18	--	--	--
Participation of women in different income generating activities	19	13	--	--	--
Women currently have rights in making decisions	25	30	--	--	--

1. Options differed across the countries. 'Main' is where more than 12% of households reported the change.
Sources: Moyo, et al, 2018; Mdemu et al., 2018; Cheveia, et al., 2018.

5.6 Scheme-scale outcomes

Improvements in income and confidence have translated into scheme-scale outcomes: almost all households surveyed are participating more in scheme maintenance; there is greater willingness to pay for water (more than 64% on all schemes and all of the Tanzanian households); more than two-thirds are more able to pay for water; and 70% or more perceive water allocation to be fairer (Table 17). These are critical achievements as lack of maintenance and fee payment have, historically, contributed to the degradation of irrigation schemes. Importantly, the findings related to 'willingness' reflect qualitative findings and anecdotal data that actual participation and fee payment is increasing.

Table 17. Household perceptions on scheme maintenance and water payment and allocation

	Tanzania		Mozambique	Zimbabwe	
Outcomes (% households)	**Kiwere**	**Magozi**	**25 de Setembro**	**Mkoba**	**Silalatshani**
Participating more in scheme maintenance	100	99	89	87	91
More willing to pay for water	100	100	64	76	69
More able to pay for water	98	99	79	79	69
Perceive process of water allocation & use to be fairer	79	87	86	70	75

Sources: Moyo, et al, 2018; Mdemu et al., 2018; Cheveia, et al., 2018.

These changes also reflect households' willingness to engage in collective action, which can be directly related to the activities of the project. The reduction in irrigation frequency and length of an irrigation round has significantly reduced water use. As a result, more water is available for tail-end users, which has resulted in a significant reduction in conflict between irrigators: particularly for both Tanzanian schemes and Mkoba in Zimbabwe where more than half of the farmers surveyed report decreased conflict (Figure 14).

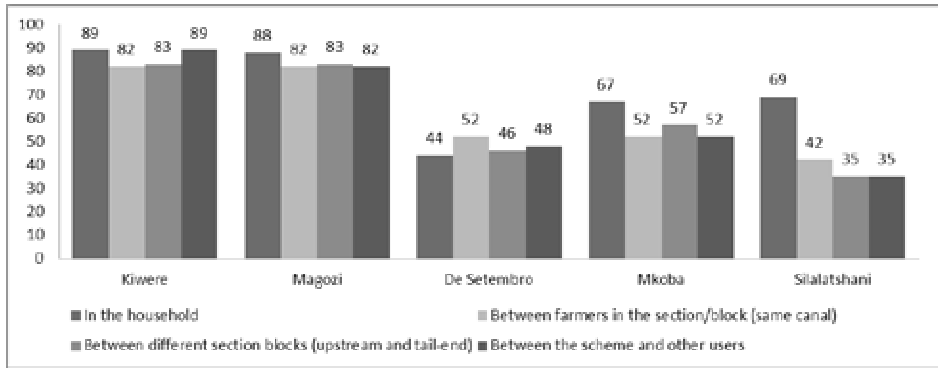


Figure 14. Percentage of farmers reporting decreased conflict over a four-year project period
Sources: Moyo, et al, 2018; Mdemu et al., 2018; Cheveia, et al., 2018.

Apart from scheme maintenance and fee payment, farmers report other important examples of collective actions: in Silalatshani for example, farmers agreed to pay an additional $3 per month to erect a fence around the irrigation blocks to protect against damage from livestock (as identified in their AIP visioning exercise) and the scheme has now purchased the fencing materials. There are several examples of collective bargaining with produce buyers. In Tanzania, farmers have initiated road maintenance, set land aside for a scheme office and agreed to pay for the office construction. In Mozambique, the farmers at 25 de Setembro have agreed on standard prices for the more important crops such as green maize and cabbage, so they no longer accept the price offered by buyers.

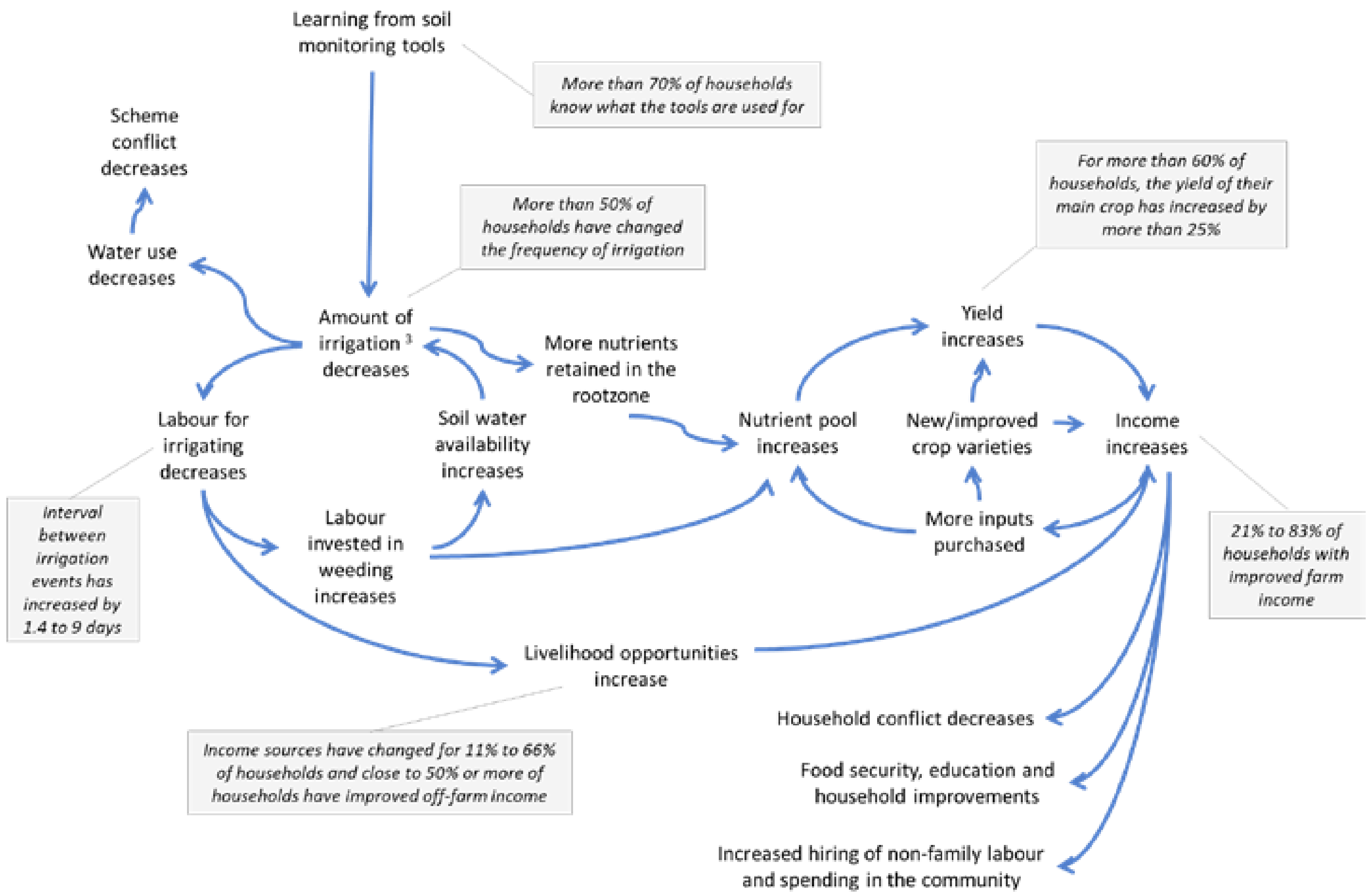
At all schemes, some previously unused land is now utilized: 11% of households on both schemes in Zimbabwe; between 20% and 43% in Tanzania; and 25% in de Setembro report bringing unused land back into production. This change is likely to be a result of the increased profitability of farming. There is also anecdotal evidence from all countries that family members are coming back because of increased profitability. This may be due to specific project outcomes such as improved water supply to tail-end users (Tanzania); re-allocation of unused plots to youth (de Setembro); reallocation of plots and increased confidence in irrigation due to the resolution of the previous water bill (Silalatshani). Land utilization has therefore increased from less than 30% to near 100%. That only 11% of households on the Zimbabwe schemes report bringing land back into production reflects an under-reporting in the end of project survey. The baseline survey found that only 20% of plots were farmed and today almost all land

is used. This under-reporting is probably due to the current policy focus of giving underutilized land to deserving farmers; hence many did not want to admit that they previously had some land that was unused.

5.7 Longer-term impacts

Importantly, the early outcomes of the project have provided the research team with a better understanding of the complex relationships between the factors that influence improvement in small-scale irrigation schemes, which will be further enhanced as additional research is undertaken in Phase 2. Figure 15 shows a model of the influence of key factors and the cycle of change as initiated by the AIPs and the soil monitoring tools: i) through their learning from monitoring tools, farmers have reduced their irrigation frequencies and duration because they can see that their crops do not use as much water as they previously thought and that excessive irrigation results in leaching of nitrates below the root zone; ii) reduced labour required for irrigating means more labour for weeding (which flows through to increases in the nutrient pool and yield) and more time for alternative livelihood opportunities; iii) improvements in yield are further enhanced by increased income and households' ability to purchase more inputs and improved crop varieties. As a result, households involved in Phase 1 of the project and those surveyed have reported significant increases in household income, an improvement in food security and health, and an increased ability to pay for children's education, water fees, and farm inputs.

Figure 15. Influence model of key changes initiated by monitoring tools and AIPs[1] with selected outcomes[2] (adapted from van Rooyen and Moyo, 2017)



Notes: 1. The AIPs influence is not shown in the diagram but includes facilitating improved access to inputs and markets and enhancing learning from the tools; 2. Outcomes from the 2017 Phase 1 EOP survey for Kiwere, 25 de Setembro, Mkoba and Silalatshani; 3. An aggregate term representing frequency, length of time, and/or volume.

Whilst, the longer-term impacts are more difficult to assess at this early stage, the model suggests that households have entered a beneficial and self-reinforcing cycle of development, which will lead to further positive impacts in the long-term. Better management of the nutrient and moisture pool will continue to increase yield; higher yields of higher value crops with improved market integration will increase income; and more income will facilitate investment in more and better farm inputs and implements. Increased spending on food, education and health, results in better educated youth who have improved chances of obtaining off-farm work or successfully transitioning to urban jobs. This development will ease the current pressure on household finances, which are supporting young people who are struggling to gain secure and decent employment (Zou et al, forthcoming). Additionally, the increased intensification of irrigation has resulted in increased use of non-family labour (Table 13) and the increased willingness to pay the water fees has resulted in increased hiring of labour for system maintenance and scheme improvements. Both of these outcomes have provided off-farm jobs for both land-holding and non-land-holding households. This cycle of development should continue as long as the external conditions remain the same or improve.

Farmers regularly monitoring their soil and nutrients is step one and a relatively easy 'win'. In the future, success would see far greater use of the information: patterns of one farmer over time, benchmarking across the scheme, comparisons among schemes and even countries, and other aggregations of the datasets. Encouragingly, there are some early signs of this occurring and the value of the monitoring information has been recognized beyond the farmers on the irrigation scheme, which is essential for the building of a wider learning system that surrounds small-scale irrigation schemes. Learning has spread to extension officers, managers of irrigation schemes and senior irrigation bureaucrats and the value of the information at different scales is becoming recognized (Table 17).

Table 17. Scales of interest in the tools and decision-making opportunity (Stirzaker et al., 2017, p. 799)

Scale	Interest	Opportunity
Farmer	Crop yield	Avoid crop water stress and nitrate leaching
Extension worker	Demonstrate good practice	Demonstrate clear links between irrigation and fertiliser management and data from monitoring tools and crop yield and quality outcomes
Water user association	Equity of water distribution, increased scheme production and hence income	Feedback as to whether different parts of a scheme obtain water when required. More fees paid to maintain the system
Regional government manager	Rehabilitation of schemes	Identification of schemes with infrastructure contributing to poor water distribution
Government agency	Stewardship of common resources	Demonstration of learning systems to achieve best practice

The results have shown that reduced water use by head-end farmers has had immediate benefits for tail-end users by increasing downstream supply. Also, that reduced nutrient leaching has immediate benefits for the farmers: with 43% to 81% of households reporting a 25% or more increase in yields for their main crop. There is also scope for water savings to spread to farmers within the existing schemes. If the current outcome of increased yields (between 43% to 81% across schemes report increases of 25% or more for households' main crop) can be out-scaled, there will be ongoing and long-term improvements in the performance of small scale irrigation schemes and the well-being of the households and communities that depend on them.

This project has documented widespread over-irrigation in all three countries suggesting that there are relatively simple interventions to increase water use efficiency, reduce nutrient leaching and increase crop yield (Stirzaker et al., 2017). While it is very difficult to calculate exact gains, increasing the footprint of this impact will have significant reductions in water use, and increases in yields and incomes at region and nationals scale.

Understanding the environmental and sustainability impacts of the project's approach is complex. Considering agriculture more broadly, the project helps reduce the amount of natural resources used in terms of land, water and fertiliser per unit of food produced. This is a goal of sustainable development policies and a sound demonstration of agricultural intensification. More efficient water use is reducing the leaching of nutrients from irrigated fields into the broader environment; a very positive outcome.

Importantly, the project does not address Jevon's paradox, namely, that by making irrigation more profitable through more efficient water use it is likely that there will be added incentive to expand irrigation beyond the existing schemes with negative environmental impacts. Each country makes its own societal choice of how to allocate any 'spare' land and water resources; including expanding irrigation or improving other environmental and socio-economic activities. Capping water extraction for agriculture can be challenging in countries where governance is weak. In the three countries involved in this project, government policies currently favour the expansion of irrigated agriculture. This project may therefore contribute to improved decision making in that regard.

5.8 Unexpected or unanticipated impacts

The two-pronged approach had at least three early and very important unanticipated impacts. First, labour saving from using the tools enabled households to invest their time in other activities. Second, the reduction in irrigation events resulted in increased reliability of supply, especially for tail-end users. This has significantly reduced the level of conflicts between irrigators, and is reflected in a willingness to participate in collective action. Third, increased profitability has resulted in the hiring of non-family members (Table 13) with significant flow-on effects in the community.

The project has been more successful than anticipated and created demand for the soil monitoring tools that has proven hard to meet. The testing of the Chameleon in farmers' fields has identified several problems, resulting in new design elements, greater reliability, and cheaper manufacture and data collation. However, the exorbitant importation fees charged by African governments for this type of agricultural equipment remain problematic.

The national partners in the project are now mainstreaming many of the project learnings. For example, the National Irrigation Institute in Mozambique incorporated many ideas from the project in new regulations for more effective irrigation associations. In the Insiza District of Zimbabwe, the AGRITEX extension staff are transferring better practices and market opportunities from the scheme involved in the project to others schemes within their jurisdiction.

6. Links to the Sustainable Development Goals

The project was developed to link primarily with the strategic priorities of the funding bodies and to be relevant to each country partner. However, the project activities contribute directly to seven of the global Sustainable Development Goals and a broad range of the associated targets: section 6.1 briefly describes how activities link to the targets, which are listed in Table 16. Indirect project linkages are outlined in section 6.2.

6.1 Direct project contribution

Target 1.4

The project helps identify and improve the institutions that reinforce inequity with particular interest in gender, youth and tail-end users and a focus on social capital, access to natural resources, economic well-being, and agency in decision-making. Additionally, farmers have direct use and control of appropriate technology.

Target 1.5

The purpose of irrigation technology is to reduce vulnerability of crop production from weather variability, but these benefits require functioning irrigation schemes. Increased understanding of sustainable resource use; enhanced individual and community capacity (knowledge, empowerment and agency); reduced conflict has fostered collaboration, strong networks and increased willingness for collective action; and income and crop diversification.

Target 1b

Communicating and advocating for policy change is facilitated through government partners in the project and regional African policy partners (e.g. FANRAPAN) and will be accelerated in Phase 2. Policy messages are also communicated through academic papers, FANRAPAN work-shops and conferences with a policy focus.

Target 2.3

New crops and markets, and increased yields have increased farmer's incomes. Women in particular are growing higher value crops and young farmers have gained access to land in some schemes. Land tenures have been clarified in a number of schemes through mapping, reallocation of abandoned plots and issuing of certificates. More efficient water use has improved reliability of access for tail-end farmers.

Target 2.4

Farmers have: increased awareness of sustainable irrigation practices; changed practices to reduce water use and improve fertilizer management; and an increased appetite for more information.

Target 5.5

Women's incomes have increased and there have been increases in joint decision-making and also in female decision-making. Household conflict has reduced.

Targets 6.3 and 6.4

Farmers have improved understanding of fertilizer run-off and leaching and have changed their irrigation and fertilizer practices. Farmers have improved water use efficiency and water productivity.

Targets 8.1 – 8.6

Household incomes have increased and income and crop diversification changes have been made. Reductions in irrigation time have been used to improve crop management, establish new small business or undertake labouring for other farmers. There has been an increase in youth farming in the schemes.

Target 10.1

Virtually all farmers in these schemes would be in the bottom 40% for income. Farmers in the schemes have reported increased incomes.

Target 10.2

See targets 1.4, 1.5 and 5.5

Target 10.3

See targets 5.5 and 8.1-8.6. Phase 2 has greater focus on disadvantaged groups: women, youth and tail-end users.

Targets 16.6 and 16.7

Irrigation associations have been strengthened through the project and new rules are being negotiated. Reduced conflict has been reported in households, within the scheme and between the scheme and other users.

6.2 Indirect project contribution

There are additional indirect links to goals 2, 4 and 5. The monitoring and AIP process are indirectly improving agricultural and extension services. Farmers have been stimulated to acquire more information from a range of sources. There is also evidence that the increased household income has increased household investment in farm input and system mainte-nance. The AIP also indirectly provides better market information, access and integration. The tools and the AIP are aimed at improving yield and profitability: however, the pathway to achieve this necessitates increased knowledge and skills about agriculture and business management. This will equip farmers for improved farm management and resilience.

The project has increased farmers' incomes and there are examples of farmers, including women farmers, using this income to send their children to school and even university. The project also directly supports a small number of research scholarships. Technology is a critical aspect of this project and whilst its specific use is to improve water use efficiency resulting in more profitable irrigation schemes, the project also seeks to empower farmers through greater knowledge, including women and youth. Women in the project have reported enhanced participation in decision-making and also a reduction in household conflict due to the increased household income.

Table 16. Direct project linkages to global Sustainable Development Goals4 and targets

Sustainable Development Goals and Targets	
SDG 1: Towards zero poverty **End poverty in all forms everywhere**	
1.4	By 2030, ensure that all men and women, in particular the poor and the vulnerable, have equal rights to economic resources, as well as access to basic services, ownership and control over land and other forms of property, inheritance, natural resources, appropriate new technology and financial services, including microfinance
1.5	By 2030, build the resilience of the poor and those in vulnerable situations and reduce their exposure and vulnerability to climate-related extreme events and other economic, social and environmental shocks and disasters.
1b	Create sound policy frameworks at the national, regional and international levels, based on pro-poor and gender-sensitive development strategies, to support accelerated investment in poverty eradication actions.

4. Based on the list in the Report of the Inter-Agency and Expert Group on Sustainable Development Goal Indicators (E/CN.3/2017/2), Annex III, March 2017.

SDG 2: Towards zero hunger **End hunger, achieve food security and improved nutrients and promote sustainable agriculture**	
2.3	By 2030, double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment.
2.4	By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality.
SDG 5: Gender equality **Achieve gender equality and empower all women and girls**	
5.5	Ensure women's full and effective participation and equal opportunities for leadership at all levels of decision-making in political, economic and public life
SDG 6: Water for all **Ensure availability and sustainable management of water and sanitation for all**	
6.3	By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally
6.4	By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity
SDG 8: Sustainable economic growth **Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all**	
8.1	Sustain per capita economic growth in accordance with national circumstances and, in particular, at least 7 per cent gross domestic product growth per annum in the least development countries
8.2	Achieve higher levels of economic productivity through diversification, technological upgrading and innovation, including through a focus on high-value added and labour-intensive sectors
8.3	Promote development-oriented policies that support productive activities, decent job creation, entrepreneurship, creativity and innovation, and encourage the formalization and growth of micro small- and medium-sized enterprises, including through access to financial services
8.4	Improve progressively, through 2030, global resource efficiency in consumption and production and endeavour to decouple economic growth from environmental degradation, in accordance with the 10-Year Framework of Programmes on Sustainable Consumption and Production, with developed countries taking the lead
8.5	By 2030, achieve full and productive employment and decent work for all women and men, including for young people and persons with disabilities, and equal pay for work of equal value
8.6	By 2020, substantially reduce the proportion of youth not in employment, education or training
SDG 10: Climate change action **Take urgent action to combat climate change and its impacts**	
10.1	By 2030, progressively achieve and sustain income growth of the bottom 40 per cent of the population at a rate higher than the national average
10.2	By 2030, empower and promote the social, economic and political inclusion of all, irrespective of age, sex, disability, race, ethnicity, origin, religion or economic or other status
10.3	Ensure equal opportunity and reduce inequalities of outcome, including by eliminating discriminatory laws, policies and practices and promoting appropriate legislation, policies and action in this regard.
SDG16: Partnerships for the Goals **Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels**	
16.6	Develop effective, accountable and transparent institutions at all levels
16.7	Ensure responsive, inclusive, participatory and representative decision-making at all levels

7. Lessons learned

During project implementation, the team learned many critical lessons about how to facilitate the process of change towards profitable and sustainable small-scale communal irrigation systems.

Lesson 1: Complex socio-ecological systems require multiple interventions.

Small scale-irrigation schemes are complex systems that require many physical and institutional elements to work well for schemes to be sustainable. Multiple interventions are, therefore, needed to transform irrigation systems to a more sustainable and profitable state; thus, contributing to poverty reduction, food security and economic growth. The soil monitoring tools and AIP constitute two broad interventions with the AIP facilitating multiple context-specific solutions to challenges.

Lesson 2: Invest in institutions and human capacities

Substantial investment in institutions and human capacity is essential for irrigation schemes to thrive. This requires a paradigm shift from irrigation development that only focusses on water infrastructure.

Lesson 3: Never forget profitability

It is delusional to think that small-scale irrigation can be sustainable in the medium to long term if schemes remain dependent on government subsidies that have political objectives of poverty reduction and food security. Schemes must be profitable, and this often means growing high-value rather than staple food crops. A paradigm shift is needed from subsistence farming to commercial farming. Farmers must focus on generating profit, which provides them with the financial means to secure their food supply as well as their families health and education.

Lesson 4: Draw on local knowledge

A purely 'top-down' technocratic approach to governing small-scale irrigation schemes results in failures. Irrigation agencies need to draw on the different kinds of knowledge held by farmers and foster the capacities of farmer organisations to enhance their self-reliance and profitability. The concept of subsidiarity is important: devolving to farming communities clearly defined responsibilities and opportunities for self-governance.

Lesson 5: Choose entry points to achieve early positive outcomes

Previous experiences with implementing AIPs in Africa, shows that they are only successful if there is a focussed entry point (Pittock and Stirzaker, 2014). One entry point for this project was soil monitoring, which has helped farmers to understand the root causes of low yields. And farmers' adoption of learning from the tools was swift. The second entry point was the AIP, which facilitated learning from the tools, identified priority barriers and solutions, and achieved early positive results. As irrigators have a mix of farming operations—including dryland and livestock managed as a joint enterprise—there should be broad consideration of entry points: for example, addressing the significant crop and livestock losses could be valuable entry points to provide 'quick gains'.

Lesson 6: Allow extension officers' roles to evolve

AIPs work well when they continuously receive information to stimulate and structure learning. Encouraging involvement of stakeholders along the value chain stimulates new connections and options for solutions: facilitation is key to their success. There is potential for the role of extension officers in Africa to evolve from a 'command and control' approach that is failing, into a facilitation role that is more rewarding and effective.

Lesson 7: Irrigation decision-making must be understood within the context of diverse livelihood strategies

Farmers' main concern is how to feed their household and educate their children. To achieve this, each household pursues diverse and complex income generating strategies. They combine income and food production from dryland farming, irrigation and livestock with off-farm income from activities such as small businesses and farm labouring. Households' irrigation decision-making, and how they allocate their land, water, labour and financial resources are subject to this complexity.

Lesson 8: Address the issue of small plot size

Complex livelihood strategies are, in part, a consequence of the small size of irrigated plots, which mean that farm households cannot support themselves from irrigation alone. When allocating their scarce land, labour and financial resources, households must consider how best to use these resources from the perspective of total household income. This inevitably results in suboptimal use of irrigation water and land.

Lesson 9: Foster collective thinking to identify opportunities based on a common vision and priorities

Farmers' main constraints are those that influence their income earning capabilities. Such as, access to: markets for quality inputs and selling produce; knowledge about what to grow and how to grow it; transport to take produce to markets; farm implements to ensure optimal timing of fieldwork; finance to ensure ability to purchase quality inputs; and storage to retain produce until prices are best. Whilst this confirms existing literature on the plethora of constraints common to all small-scale farmers, the lesson relates to providing supportive mechanisms, such as the AIP, that enables collective identification of problems and opportunities, agreement on a common vision, and prioritization of interventions: collective thinking to overcome barriers.

Lesson 10: Address soft and hard issues simultaneously

While the soft access issues in Lesson 9 are foremost on farmers mind, hard issues—such as infrastructure and reliability of water supply—are also critical and can be principal barriers to change (see Lesson 11), or will become urgent once farmers experience that it is profitable to maximize the use of land and water. Hence, it is critical to work on both at the same time.

Lesson 11: Identify and resolve the 'deal breakers'

It is critical to identify the key issues within each irrigation scheme that might be deal breakers. These are issues that, if not resolved, will prevent or negate all other efforts. For example, the unsettled ZINWA water bill in the Silalatshani scheme in Zimbabwe and the leaking infrastructure in 25 de Setembro in Mozambique

Lesson 12: Understand the flow-on effect

Learning spread widely within the schemes (evidence of social learning) and practices changed faster than expected, which contrasts with African adoption of soil water monitoring equipment, in general. The number of farmers who changed behaviour and adopted new practices based on learning from the soil monitoring tools far exceeds the number of farmers who had the tools deployed in their plots. For example, 24% of Silalatshani households surveyed had the tools, but up to 73% had changed their irrigation practices. This has important implications for future interventions; as it shows that the flow-on effect within a community can be substantial and this needs to be understood to maximize both the return on investment in the equipment and the anticipated 'reach' of the learning.

Lesson 13: Demonstrate benefits to create willingness to pay for tools (SWM technology)

In the early stages of the project, farmers were reluctant to say how much they were willing to pay for the tools. By the end of Phase 1, the value of the tools had been recognized and most households indicated a willingness to pay.[5] Farmers who currently have the Chameleon arrays want more of them to use in different locations and crops and some would like their own Chameleon reader to take readings more frequently.

Given, the current approximate hardware cost of US$40 for a Chameleon array and US$115 for the reader, the survey results show that 38% to 94% of households would be prepared to pay the amount required for four households to share an array and 78-94% of households would be prepared to pay the cost of 10 households sharing a reader. The flow-on effect suggests that such sharing might be the most cost-effective deployment option. Given that some farmers want their own tools, despite the demonstrated flow-on effect, this raises an interesting question around how many farmers actually need the tools. There is more to be learnt about how trust in a technology is developed and spread.

Lessons 14: Understand the public and private benefits of the tools and apportion the cost accordingly

The data generated by the Chameleon arrays and readers and uploaded to the Virtual Irrigation Academy has value at several levels: private, scheme, Basin and National as well as for future research. This database collates a wealth of information about water use across different locations and crops (such as crop yield and gross margins), which is currently only available as estimates. For the first time, this system will aggregate data based on plot level data. This raises important questions about how much the farmers, who will only receive the private benefits, should pay for tools that generate data that provides additional public benefits. Hence, Phase 2 aims to develop different business models for how farmers can access the tools and how other institutions such as government and donors can contribute to the cost in exchange for access to the data.

Lesson 15: Irrigation learning systems must be self-sustaining

Despite the positive outcomes, the distribution of free equipment and use of external capacity to implement AIPs do not guarantee longevity of use and continuing impact. That farmers have expressed a willingness to pay for the tools, is confirmation of the positive outcomes that they have experienced and an important first step. However, for the learning system to be successful in the longer term, farmers need to take their learning from the tools to a deeper level (e.g. exploring the seasonal patterns), the learning from the tools and AIP needs to spread beyond the project schemes, and institutional arrangements and networks (i.e. AIP or equiv-

5. During the Phase 1 EOP survey, at least 80% of households surveyed expressed willingness to make a payment of US$5 or more for a Chameleon array and between 12% and 35% of households are willing to pay US$40. Similarly, 78% to 94% of households are willing to pay US$10 for weekly access to a reader.

alent institution) need to become self-sustaining. Phase 2 will explore models of access to the tools and how farmers and organizations can implement the two-pronged approach without external support.

Lesson 16: Inflexible water supply constrains farmers' ability to benefit from the two-pronged approach

Farmer have used the monitoring data and improved their irrigation practices: however, they may still be constrained in fully utilizing the learning due to water systems that have fixed delivery schedules. It is critical that new water delivery systems are developed to provide flexible scheduling that meets individual irrigators' needs. Only then can farmers use the tools to make irrigation decisions that maximize yield and profitability.

Lesson 17: Recognize women as early adopters of high-value crops and the linkage to empowerment

As part of the complexity of households' income earning strategies, many adult men contribute by working off-farm. Collaboration of spouses around decision-making at a distance is, therefore, critical. Additionally, an important lesson from the project is that women are the predominant adopters of higher value crops, which has increased their contribution to household income and strengthened their position in the household and within their communities. There has, therefore, been a shift towards joint decision-making within households and women are more engaged in decision-making and more vocal in meetings. The end-of-project survey revealed several changes related to gender roles and the balance of decision-making. This is important for several reasons: i) traditional gender roles do not change quickly; ii) increased decision-making has linkages to empowerment and equity; and iii) women's greater involvement in decision-making, including use of income, has beneficial linkages to household well-being.

Lesson 18: Understand the role of irrigated farming in youth livelihood options

The likely pace of structural adjustment is such that farming will remain an important income source for several decades. Policies that recognize and facilitate the improved profitability of irrigation schemes are, thus, acting to improve the livelihood options for the burgeoning youth population. The role of irrigated farming in this regard is multi-faceted: profitable irrigation provides direct employment (on family farms or labour for others), supports the establishment and growth of household enterprises and also enables families to provide a better education for their children. Policies that seek to improve irrigated farming should be augmented by policies that support local business development, which allows young people to stay in their community and also contributes to rural development. With respect to education, there is an interesting dynamic: educated youth are more likely to gain wage employment and transition to city living, yet irrigated farming stands to benefit from more educated and entrepreneurial youth. However, not all youth can or will remain in rural areas and some migration to cities is inevitable.

Lesson 19: Recognize the potential role of youth

As small-scale irrigation households experience increased profitability, there are signs that household members, including young people, are returning to the village and engaging in irrigated farming. Increased profitability partly overcomes the issue of the unattractiveness of farming, but the increased involvement of young people also creates an opportunity to foster scheme resilience. There is no future for small-scale irrigation if youth are not engaged: schemes need to gain new ideas and address inter-generational transfer. For this to happen, schemes need to encourage youth engagement by overcoming youth-specific constraints—such as facilitating access to land and participation in scheme decision-making forums— to foster their involvement and harness their energy. Additionally, increasing the involvement of young women may be the most effective way of increasing women farmers' empowerment in the longer-term.

Lesson 20: Understand the value proposition of the two-pronged approach

In terms of private benefit, farmers have learned to appreciate the tools and are, therefore, willing to pay for the arrays and reader. Considering only the time saved, it becomes clear why the tools make a difference to farmers. Farmers from 25 de Setembro, Mkoba and Silalatshani have changed from irrigating once a week to once a fortnight, which potentially releases 16 days per year for a household member to engage in other income generating activities.[6] In terms of benefit at the scheme-scale, more land is under production and, if all else is equal, this must translate to increased crop production for the scheme. The increased participation in collective action, such as payment of fees and willingness to participate in scheme maintenance, also has significant scheme level benefits with respect to long-term sustainability.

At the scale of public investment in irrigation development, the lessons from this project suggest that investment in the two-pronged approach is critical to secure a return on investment in irrigation infrastructure. Currently, nearly all money invested in irrigation development goes into infrastructure and many schemes are struggling to be viable. Future research should investigate what proportion of investment in irrigation development should be allocated to building a learning system to enable the infrastructure to be used successfully for the long-term.

8. Additional information and next steps

8.1 Recommendations for those wanting to implement a similar project

The project approach of context-specific learning and innovation has been trialled successfully in Phase 1 and can benefit new or existing small-scale irrigation schemes. Those developing new schemes need to be aware of the history of irrigation development and the detrimental impacts (socially, environmentally and economically) that can result from scheme dysfunctionality. There is benefit also for smallholder private irrigation where irrigators draw from a common pool resource that needs collective awareness and management to avoid over-exploitation and degradation of the resource.

There are some fundamental underpinnings of the two-pronged approach that should be considered by those wanting to implement a similar approach:

i) There is considerable depth to the rationale and theory that underpins the project and its success. Essentially, a new paradigm of adaptive management for research for development is being tested and promoted. Those seeking to implement a similar approach should gain a full appreciation of the project's 'why'.

ii) Together, the complementary approaches of soil monitoring tools and AIPs are fostering two farmer-centred learning loops that address different barriers to overcoming challenges to improving yields and profitability. Those wanting to implement a similar project should resist the temptation to cherry-pick elements of the project as a cost-cutting measure. This is the 'what' of the project.

6. Assuming two 16 week irrigation seasons per year and an average 8.5 hours saved per irrigation event, means that households have approximately 16 days per year (at 8 hours/day) that they can use for other activities.

iii) Farmer empowerment, community knowledge and relationship building and stakeholder-led innovation—a bottom up approach and 'how' this project works—is central to this project but might take more time to implement. A top-down approach will not yield the individual, scheme and community resilience outcomes that can result from stakeholder participation, ownership and direction.
iv) What if …? Notwithstanding the above points, there is scope for experimentation as no two irrigation schemes are the same: farmers, natural resources, institutions and market systems will differ. Linked with the ethos of a research project, there is always more to learn and improve through application in new contexts.

In addition to the practical on-ground benefits, it is hoped that the research findings will influence and stimulate other research for development proponents interested in farmer-centred learning, innovation platforms, multiple and complementary interventions, and equity.

8.2 Out- and up-scaling in Phase 2

On the strength of the outcomes reported in the mid-term review of Phase 1 (de Lange & Ogutu, 2016), the project received funding for a four-year Phase 2, which commenced in 2017. Importantly, Phase 1 determined that there is an appetite for out- and up-scaling of the soil monitoring tools and AIPs. In general, the objective of Phase 2 is to develop ways of spreading the learning and impact of the project more widely and testing how the two-pronged approach can become sustainable with a minimum of external resources. Ongoing research is essential to evaluate whether the approach is widely replicable in developing countries and to develop irrigation policy options for governments and multilateral agencies. Central to Phase 2 is determining how the two-pronged approach of AIPs and soil monitoring tools can be:

- Scaled up to enable innovation at higher political scales using five district and three national-scale AIPs. It is anticipated that district AIPs will develop a critical mass of capacity that will last beyond the project's timeframes. Also, national case studies will test the transferability to new districts as well as innovative partnerships for agri-food systems.
- Scaled out to 32 or more new irrigation schemes by establishing new AIPs or by more cost effectively replicating innovations for implementation on schemes with similar circumstances (agricultural, markets and stakeholders). The project will test how best to spread the learnings and associated behavioural changes from the existing AIPs to surrounding schemes and determine how large an area an existing AIP can cover.

The project will continue to work closely with the ACIAR project that is developing the VIA platform. The production of the tools has moved from Australia to a facility in Pretoria, which will enable cheaper production and more effective shipping to ensure sufficient tools to support the out-scaling. Phase 2 will test different business models to sustain the production and spread of the tools—for example, public sector pays, private sector pays, finance, co-payment—with a consideration for how the options might hamper take-up or create inequity of access. The project will also explore how the data—such as estimates of soil fertility, water consumption, water efficiency and yield—that is aggregated by VIA can be used by irrigator associations and governments to improve scheme performance: for example, identification of under- and well-performing irrigation plots and schemes; prioritization of places for intervention; and enhancement of agronomic practices to maximize crop yields. The VIA project already operates in other countries, in addition to Mozambique, Tanzania and Zimbabwe, and will also be used as an entry point to engage new countries in the use of AIPs.

Several successful Phase 1 AIP innovations will be given greater focus in Phase 2. The Tanzanian project team will extend the participatory plot-level mapping produced in Tanzania by out-scaling it to other schemes and in other countries and work with local agencies to produce certificates of customary land occupation (or their equivalent), which can be used to qualify for access to micro-finance. The value of this mapping and its use in clarifying boundaries to reduce conflict, improve fee collection and enhance governance will be assessed. The Zimbabwe team will work through the AIP and with irrigator associations, and the departments responsible for them, to: i) revise their constitutions and strengthen their roles and ability to enforce the constitutional rules; and ii) clarify the issues of ownership of and responsibility for irrigation infrastructure such as dams and off-takes to the canals that supply individual plots. Negotiations are taking place with the Zimbabwe government to spread the use of the two-pronged approach at a large scale, including the large-scale training of irrigation extension workers in the existing irrigation-training centre. In Mozambique, as the out-scaling takes place and moves further away from Maputo, it is expected that there will be more women and young people who have agriculture as their main source of income and who have loans with micro-banks. It will be important to promote business plan training for more farmers to improve and guarantee the sustainability of their farming activities.

Across the project, farmer record keeping will receive greater emphasis. Farmers, who have the tools, will use a refined version of the farmer field-book to record seasonal data; the farm household, their land and livestock; cropping program; readings from the monitoring tools; and farm activities including the purchase of inputs, fieldwork, harvest, and prices obtained. Farmers will fill out the final section of the field book during an end of season workshop, where farmers will compute yield and gross margins and discuss learning from using the tools and market integration during the season.

Phase 2 will have a stronger focus on disadvantaged groups such as women, youth and tail-end users. The aim will be to provide guidance on how to reduce inequity by examining how institutions enable or limit access to natural resources, economic well-being, agency in decision-making and the building of social capital. For example, the project will investigate whether plot-level mapping is an opportunity to assist with the re-allocation of plots to increase equity. Similarly, the project will examine water saving opportunities and their potential to improve equitable water sharing. Some opportunities need to be more visible but discussed sensitively according to the local context.

A challenge related to out-scaling is the cost of data collection. Hence, at the end of Phase 2 the project will only comprehensively survey the households there were part of Phase 1 to allow an analysis of change over eight years. Based on the baseline and end-of-project surveys, the research team has chosen a smaller set of indicators to support adaptive management and track positive changes, perverse impacts, and identify new opportunities. The national teams will discuss these indicators with existing and new schemes so that the irrigation communities agree to help measure progress towards the desired state of the scheme.

The projected impacts for Phase 2 are ambitious and a sufficient number of stakeholders at scheme, district and national scale need to be motivated to ensure that the project succeeds. Thus, a key assumption for engagement is that the incentives for participation can be communicated successfully and are sufficiently motivating. Additional assumptions and challenges associated with out- and up-scaling include:

- There is a known appetite, and therefore some pressure, to out-scale quickly to benefit more farmers. However, this needs to be balanced by having sufficient depth of intervention to produce robust research findings.
- Irrigation schemes will fall into one of two assessment categories for AIP out-scaling in terms of their similarity with Phase 1 schemes: those that are similar can be drawn into existing AIPs, whereas others may require new, resource-intensive AIPs to be established.

- Uncertainty of whether there is sufficient commonality of barriers and opportunities at district scale to derive common solutions across several schemes.
- A bottom-up and facilitation for empowerment approach has underpinned the success of Phase 1 AIPs. As up-scaling occurs, there may be a temptation for the district-scale AIPs that are based on government agencies to direct rather than facilitate change (Pittock et al., 2016).

As with all development projects working with natural resources, there are the inevitable risks associated with seasonal variations and climate change.

8.3 Further information and research

A 'how to' (Pittock et al., 2018) guide is available, which summarizes the approach and knowledge gained through the project. The guide provides practical advice to farming leaders, community organizations and government officers on interventions for sustainable and profitable irrigation. Overall, the guide will help ensure that public or private investment in the rehabilitation or development of new small-scale irrigation schemes is used to best effect.

This chapter has been limited in the research that can be communicated. Key findings from the initial 2014 baseline survey are reported in a special issue of the International Journal of Water Resources Development (Volume 33, Number 5, 2017), which have been further communicated during two special sessions at the World Water Congress in Cancun in May 2017 and at the Stockholm Water Week in September 2017. Research is ongoing and additional in-depth analysis will be available in the future: for example:

- Separate Phase 1 End-of-project surveys reports for Tanzania, Mozambique and Zimbabwe;
- Country-specific academic papers on adoption and impact of soil monitoring tools on yield and profitability of irrigation farmers; and
- Cross-cutting papers on the soil monitoring tools (e.g. beneficiaries, willingness to pay) and the project's theory of change.

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Changa Pani Program (CPP):
A clean water and sanitation solution

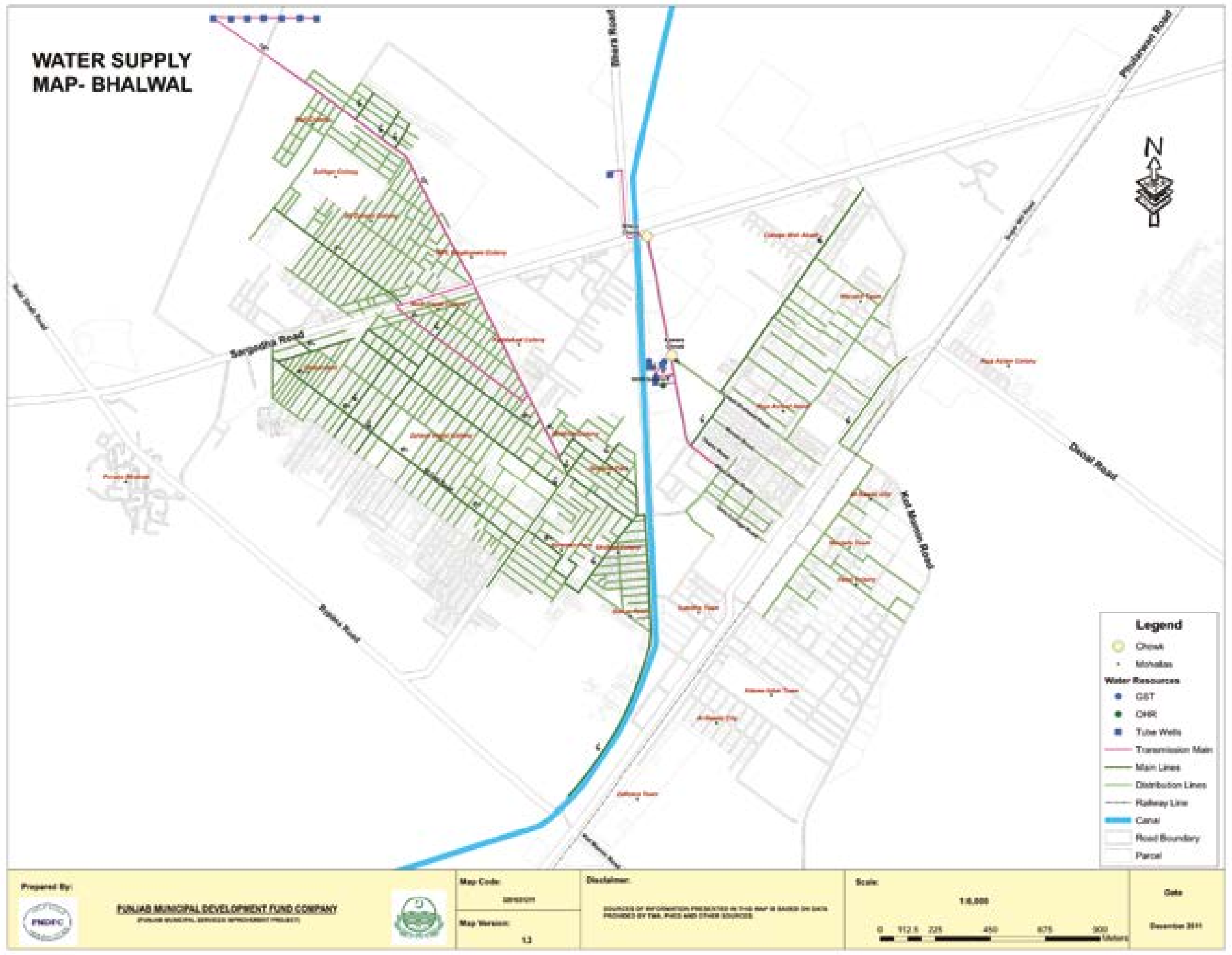
Country: Pakistan

City/region where project is based: Bhalwal, District of Sargodha

Population (of area where the project is based): 3 500 houses with approximately 21 000 beneficiaries

Key organisations /stakeholders involved in the project: A public private partnership. Local Bhalwal community members, Bhalwal Municipal Committee (MC), WASCO and NGO Anjum Samaji Babood (ASB).

Authors: Brigadier Muhammad Aslam Khan



Water challenge

Due to the absence of safe drinking water and lack of proper disposal of solid waste via sewerage, water borne diseases top the list of ailments prevailing in Bhalwal, Pakistan. Water needs to be brought in from a far, making the domestic water expensive and unsafe. Another challenge this project addresses is water conservation by keeping a track on water usage.

Project approach

The project began with mobilizing the Bhalwal community to form a steering committee, to ensure that each house would be provided with safe drinking water uninterrupted. Groundwater served as the primary source for drinking water in the project. A set of 16-inch pipelines stretching at a distance of 7 km from the Lower Jhelum canal were installed to transport safe drinking water to the community. An overhead tank with a capacity of 100 000 gallons stores water transferred through 8 tube wells. Water meters were also installed on buildings at a cost of 3000 PKR ($25 USD), which may be repaid in instalments of 50 PKR ($ 0.5) per month.

An average household pays approx. 300-350PKR ($3USD) per month for water delivery. Despite no previous culture of bills payment, 90% of covered users reliably pay their bills. An appropriate pricing strategy promotes customers' confidence, necessary for proper water conservation and management.

Results and next steps

Outcomes achieved:

- The water quality improved, and subsequently the health of people in the community also improved significantly;
- Conservation of water by communities has resulted in a 50% reduction of water loss;
- There is a 90% rate of recovery for bills from customers;
- 2500 out of a planned 4000 meters have been installed;
- The project provides technical training and employment opportunities to the inhabitants.

Outcomes to be achieved:

- Scaling up the project, through effective social mobilization, advocacy and partnership with relevant government departments;
- Fixing faults in the metering system and late detection of leakages.

SWM: Potential and barriers

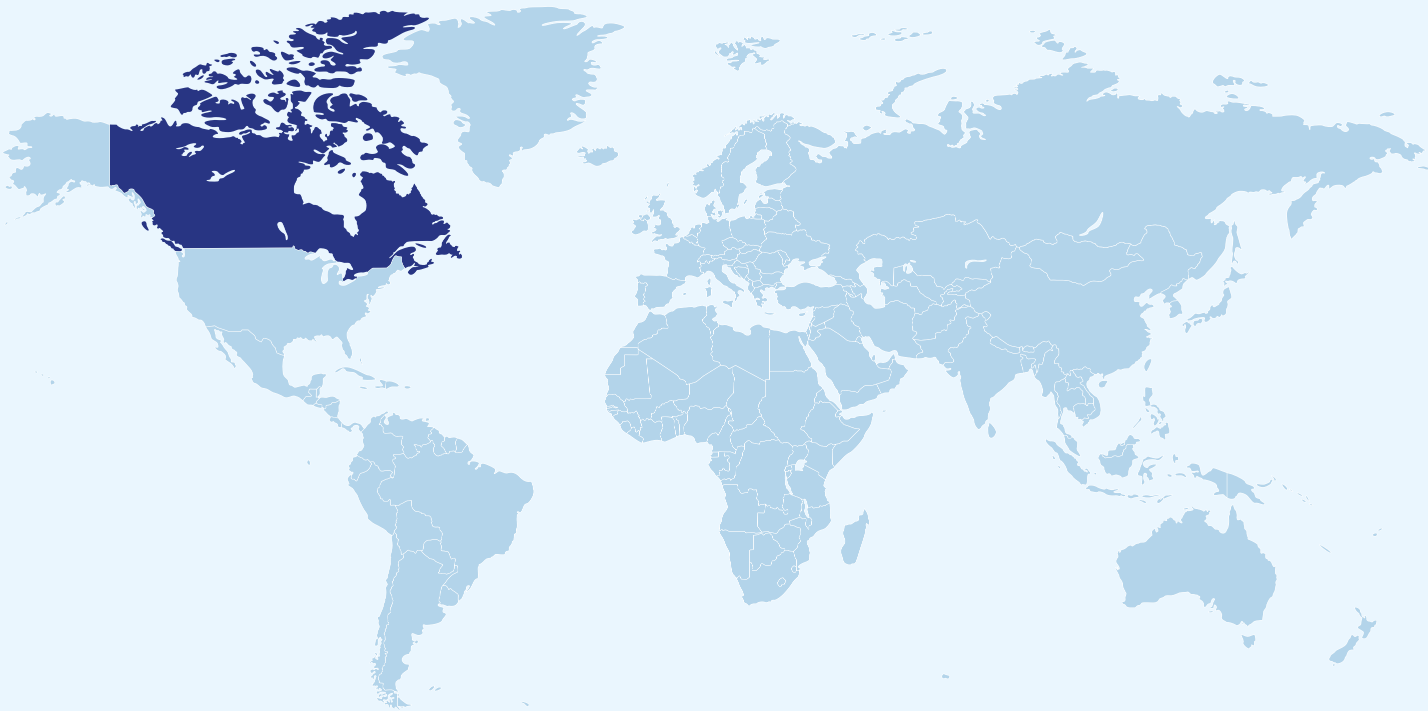
The project managers are interested in adding smart technology to the water distribution system in Bhalwal. This would help address the system's shortcomings by:

- Reducing the maintenance cost;
- Improving the efficiency of meter readers.

Currently, limited financial and technical resources hinder the transition to SWM. Once SWM is able to be implemented, it will require proper capacity building of communities and staff. Thus, there is the need for community training to overcome technological barriers.

Community-based Stormwater Smartgrids: Distributed AI/IoT Rain Harvesting Networks for Flood and Drought Resilience

Kevin Mercer,
Cristina Cholkan,
RainGrid Inc. Toronto,
Canada



Canada

Summary

Cities around the world, including in Canada, are committing to sustainable stormwater management, by increasing permeable surfaces through water sensitive urban design (such as bioswales, raingardens and permeable paving) or investing in stormwater harvesting to collect and retain large volumes of stormwater. These approaches help to reduce pollutants entering sewers and subsequently urban waterways. At the individual property or residential household level, rain tanks have similarly been promoted to collect rainwater runoff. However, property based rain harvesting faces the same problem as land based infiltration systems – how to ensure there is sufficient reserve capacity to reduce stormwater overflow, when the system is already storing a previous rain event. Households do not typically install sufficient capacity to undertake the sophisticated storage and release operations of commercial facilities' automation systems. As residential rain harvesting has relied on operation and maintenance by the property owner, municipal water utilities have been reluctant to incorporate it into urban water design.

To address this issue the RainGrid Stormwater Smartgrid was developed to apply real-time weather artificial intelligence (AI) management and internet of things (IoT) automation to passive residential-scale stormwater cisterns. The purpose of the AI is to determine how much rainfall will runoff from household roofs given the predicted rainfall and rooftop area, while the IoT automated cistern captures, filters and stores it in a suitably sized cistern. Thereafter the water is available for use in the household and garden as 1) recycled water, 2) groundwater recharge or 3) timed discharge into the sewerage system, by means of electrically actuated valves controlled by the IoT, until the next predicted rainfall.

A Stormwater Smartgrid operational data dashboard, specific to each property, visualizes the AI micro-climate rainfall data while on-board sensors calculate temperature, barometric pressure and rooftop runoff retained in the cistern. Extrapolating from these data sets we are also able to determine consumer behaviour regarding potable water demand offset, and potential flood and drought conditions in real-time, providing an exciting big data insight into community based rainfall patterns and property owner behaviours for utility operators. As the average household (or 'lot level') rooftop in Canada represents 40-60% of gross impermeable surfaces of the property, and residential rooftops represent an average of 47-56% of gross urban impermeable area, households offer an important but unmet opportunity for intelligent, climate resilience stormwater management. An average yearly rainfall of approximately 780mm in Canada over a typical roof size of 250m^2 yields 195,000 litres of water that can be captured and either reused or returned to the groundwater or sewerage system. Therefore by automating the operation of household rainwater cisterns, we can both achieve reliable, measurable and effective stormwater management as close to where the rain falls as possible (truly local source control), and increase access to carbon neutral water for environmental and domestic uses.

Beyond addressing stormwater challenges, the Stormwater Smartgrid also opens up the opportunity to generate highly granular (lot-level), optimally effective real-time microclimate data visualization and analytics. AI capacity to determine on a property by property basis when the next rainfall is likely to come, and to consequently empty cisterns to provide appropriate storage to ensure practically zero stormwater runoff from the rooftops that constitute the majority of urban impermeable area. This local climate data and distributed infrastructure should be extremely valuable for water utilities and municipalities.

This case study demonstrates the potential for the adoption of Stormwater Smartgrid technology to empower individual property owners to engage in and act on a shared community basis to ultimately make a significant difference to stormwater management in urban areas. It also shows the barriers that have been faced to date to implement this type of technology on a large scale. Among those barriers is the need to reach a 40% voluntary participation threshold to attain measurable volume reduction on the municipal system, the absence thus far of a business case utilities are comfortable with adopting, and the technical issues such as perfecting a cost-effective internet communications and power platform and effectively designed cisterns for year round operational reliability under various climate scenarios. It is hoped that by sharing this case study, others interested in smart technology for urban stormwater/water management capture and use will gain an understanding of the challenges faced, and the potential for moving forward.

1. Background

Traditional urban centres evolved their drainage practices to emphasize the rapid and efficient drainage of rainfall. As cities evolved, sanitary piped systems were typically used for street drainage and/or to convey rooftop runoff using the same pipes, a practice known as combined or semi-combined sewers. The outcome of which is that during wet weather events, in-pipe volumes exceeded the capacity of the piped conveyance, and by-passed contaminated flows to waterways.

To address this low impact development (LID) or green infrastructure (GI) has evolved over the past twenty-five years into a source control basic of urban stormwater management. As stated by the Ontario Ministry of Environment and Climate Change '*LID is an innovative state of the art approach to managing stormwater by first and foremost treating runoff (precipitation) at its source, as a resource to be managed and protected rather than a waste. In this regard, the emphasis is to maintain the existing pre-development water balance through the use of source (lot level) and conveyance measures in combination with end-of-pipe controls using what is referred to as a 'treatment train' approach to stormwater management.*' (Ontario Ministry of Environment and Climate Change, 2017)

That evolution itself reflects a recognition that the design and operation of conventional end-of-pipe civic infrastructure did not meet the need for an ecosystem, fiscally and operationally efficient urban water management approach. LID was designed to detain, retain and infiltrate stormwater in the highly impermeable urban landscape to re-establishing permeability or mimicking the timing of the natural hydrological cycle with appropriate scale engineered solutions. Stormwater LID was city building for water, and it evolved over twenty years after much debate and push-back from the highly entrenched engineering profession into standardized applications of bio-infiltration trenches, green roofs, street tree infiltration boxes, conveyance and property based rain gardens, and property based rain harvesting.

In the United States, Canada, the United Kingdom and other jurisdictions, utility owned and asset managed green infrastructure is generally only implemented on public property. Distributed residential and commercial property-based green infrastructure is not typically integrated into the asset management planning or costing of water utilities.

Water utilities and municipal stormwater programs illustrate this lack of property-based engagement most ably by the continued practice of distributing inadequately sized, passive and under-utilized rain barrels as public education and outreach engagement tools. Almost universally these programs do not achieve the water conservation or stormwater attenuation goals they espouse, but cities are wedded to them because they fulfil a low-cost, high profile community engagement role.

Within that context the age-old practice of rain harvesting re-appeared as an early staple of residential LID. It was determined that distributing large volumes of small rain barrels, citizens would be enhanced in their appreciation of stormwater runoff retention and potable water conservation. Unfortunately, most rain barrel programs achieved nothing of the sort. They exist as education and outreach trinkets, whose validity as LID has been unreliable, minimal to non-existent, and for the most part unmeasurable.

We say for the most part because in the U.S. there are a few MS4 (Municipal Separate Storm Sewer System) mandated utility LID programs delivering effective residential rain harvesting infrastructure – Washington, D.C.; San Francisco, CA; Seattle, WA. However, even these are universally passive in their technology. The promise of real-time IoT to enhance their reliability, measurability and effectiveness is dependent upon resolving the administrative barrier represented by the delineation of public versus private property. Until such time as that changes, most water utilities programmers will not undertake installing utility-scale, property-based intelligent rain harvesting infrastructure.

This condition exists notwithstanding The Nine Mile Run RainBarrel Initiative a definitive research study undertaken in 2003-05 in Pittsburgh, PA, to determine the positive impact residential LID methods, and rain harvesting in particular, could bring to reducing stormwater flows, combined sewer overflows and instream flows during wet weather events. The NMRRI analysis report shows that as little as 1m3 of residential rain harvesting retention significantly reduced stormwater infiltration of combined sewers, reduced surface runoff, in stream flows and overall pollutant loadings. (Three Rivers Wet Weather Inc., Nine Mile Run Watershed Association, RiverSides Stewardship Alliance, The Student Conservation Association, CDM Inc., 2005)

This was the definitive proof that residential harvesting of rooftop downspouts diverted significant enough volumes of rooftop runoff that it was possible to measure the subsequent reductions of thermal loadings, suspended solids and non-organic pollutants that make up stormwater as it transits from rooftop, across yards, sidewalks and roads into storm sewers (York 2017).

City and regional economies, whether in developed or developing nations, grow and prosper on their ability to provide safe and reliable water infrastructure, services and prices that advance the health, economic and ecosystem objectives, supportive of the sustainable development goals (SDGs). While the conventional centralized water and wastewater infrastructure business model is often seen as the best approach to manage water supplies sustainable, it is also partially responsible for the infrastructure deficits threatening their ability to maintain secure water services. The vast capital required for engineering design and construction is dwarfed by the operations and maintenance costs, including the extensive energy demand of pumping and treating water; one of the largest energy expenditures and GhG contributors of global cities.

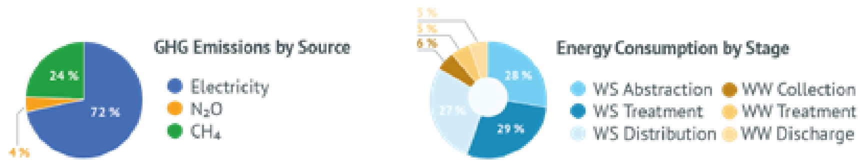


Figure 1. Energy Water Nexus Data International Climate Initiative – Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB)

Cities face an unsustainable fiscal burden associated with maintaining and expanding the highly-engineered, capital intensive conventional water systems developed over the past century. This accumulates as an infrastructure debt burden that reflects an unwillingness or inability to upgrade drinking water and sanitation infrastructure largely due to a lack of real-cost accounting. In the worst instance this results in societal disinvestment and decay of the infrastructure assets with a middle-ground occupied by privatization and the conversion of social good into profit (only leavened by good political governance), and in the best instances represents an opportunity for wholesale organizational, technological and fiscal restructuring of publically-owned utilities, including the adoption of intelligent, distributed water and wastewater infrastructure innovation.

Furthermore, cities' struggling to maintain their capital intensive, highly engineered, centralized water, wastewater and stormwater infrastructure are complicated further by climate change impacts, population shifts, and competition for limited fiscal and natural resources.
One of the major areas of concern for cities is stormwater and the impact it has on both water management and water quality. Non-point surface-runoff from urban and rural landscapes constitutes one of the largest pollutant sources for many cities, with a combination of pollutants including oils, grease, heavy metals, organic and inorganic waste. This is then coupled with the thermal loadings and sheer volume of stormwater, which after heavy rainfall is all magnified and accelerated by sewers designed to drain as rapidly as possible.

With regard to wet weather or stormwater runoff, and seasonal flooding, echoes the same 'infrastructure, fiscal, social and ecosystem deficit' language. Stormwater or 'drainage' infrastructure is the baseline upon which most societies have built their cities. The pipes and pumps that drained 'swamps', controlled flooding rivers, held back the tides, and most often corralled and drained away the rains as soon as they fell made habitation, farming, industry and other pursuits viable.

Builders for instance, perceive rain as the ultimate enemy, to be shielded from and protected against rather than taken into the building envelope. Buildings, landscapes, and even watersheds are hardened, even armoured against runoff through the introduction of impermeable surfaces (e.g. concrete, roads and footpaths). From where the rain falls to where it discharges into receiving water bodies, the traditional infrastructure of drainage is at odds with 'ecosystem' or 'watershed' based planning. The effect of this piped drainage and centralized stormwater management has been a magnification of impacts as increasing urbanization reduces permeability and natural hydrological flows, while variable climate change weather patterns challenge the ability of existing infrastructure design and sizing to cope with highly variable rainfall intensities, frequencies or temperature.

To simplify these myriad challenges, it is best to characterize the challenge cities face as determined by variability in the presence or absence of rainfall, and how much it will cost to operate and maintain water security, piped sewer systems and treatment facilities in cities coping with that variability of climate manifested stormwater or drought.

1.1 The Lot Level Approach to Stormwater Management and the Founding of RainGrid

Within the context of modern urban stormwater management, two trends have evolved that recognize and magnify the value proposition of distributed water infrastructure: 1) Low Impact or Sustainable Urban Design methods, and 2) intelligent technologies. Each of these interfaces with the existing conventional centralized infrastructure dynamic in a unique manner.

Traditional, centralised infrastructure is separated into three silos (drinking, waste and stormwater) all publically run. In modern urban stormwater management the thinking has shifted, and there is no such thing as 'wastewater'. The traditional three silos are now becoming a closed loop, or 'one water'. Rainwater harvesting takes rain where it falls reuses it on-site, usually at a small, lot level scale. The importance of small-scale and localised water is not often recognised, despite it being sensible water management to manage the water where it falls, as the lot level is where floods begin and where water demand originates. Despite the benefits and technological capacity to shift to a localized, decentralized approach to stormwater management, such a transformation poses concerns for public utilities. They cast this transformation as one of increasing the uncertainly around the safety and health of the community. Therefore, decentralisation of water management will need to have strong cooperation between utilities and the property owner for it to be successful.

IoT-enabled networks of utility-scale distributed rain harvesting infrastructure on private property have already evolved into a dynamic and promising future for city water security, and they encompass the complexities, barriers and opportunities of what would be a groundbreaking shift in water management in cities around the globe. Just as with distributed PV electrical production, the individual residential lot level is seen as ground zero in the debate over distributed water technology, and just as PV focused on rooftops, so does intelligent rain harvesting. The unrealised value proposition of utilizing individual rooftops derives from the fact they represent both the primary source for rain harvesting and the primary cost source for stormwater.

1.2 Public vs. private property for water management

What delineates whether as a public utility manager one sees the lot level as a value or cost location is determined by how one views the relationship between public and private property. The key to the rise of intelligent rain harvesting is found in the long standing debate between whether utility owned stormwater infrastructure can be constructed on private property. The typical municipal utility operates on an extremely unusual dichotomy of public and private. The whole notion of public services to individual properties – whether residential, commercial or institutional – is premised on maintaining a delineation between where the public (or private) utility places its infrastructure, and who pays for what. Water service utilities are responsible for centralized collection and treatment of wastewaters, and the provision and distribution of potable water – up to the property line. The piping of either service is the responsibility of the property owner, although it is typically regulated by strictly enforced building codes.

Municipal infrastructure has rapidly implemented distributed 'smart' systems utilizing AI (Artificial Intelligence), IoT (Internet of Things) automation, and software as a service (SaaS) data visualization and analytics for a wide variety of applications. When installed on a city-wide network or utility-scale, smart (real-time) distributed systems (i.e. decentralised infrastructure with central software analytics) have a transformative effect on the reliability, effectiveness, and monitoring of urban infrastructure and services.

For water utilities and users nowhere else does smart AI/IoT better illustrate its market disruptive transformative power than in the pivotal change brought to the previously passive, low-tech water conservation practice of property-based rain harvesting for conservation and stormwater management. AI/IoT has the potential to transform analogue rain harvesting (RwH) into a powerful, digital, distributed asset-managed infrastructure providing reliable, measureable, and effective operational capacity for flood and drought resilience, drinking water security of supply, groundwater recharge and climate adaptation/resilience, and highly value-added operational data visualization and analytics, and micro-climate data maps of rainfall and runoff on an individual property and city-wide utility basis providing a real-time analysis of how rainfall affects sewers, properties, neighbourhoods, and whole cities, and how harvested rainfall is used as security of supply for property-based potable water offsets of irrigation or toilet flushing, a stable source of groundwater recharge or environmental flows, or simply a low impact development detention for subsequent discharge to either surface or sewer systems following the storm event.

1.3 RainGrid

RainGrid is a climate adaptation and resilience company dedicated to technology and business model transformation of distributed residential rain harvesting by configuring it as smart city, utility-scale stormwater (flood and drought adaptation/resilience) distributed infrastructure. RainGrid evolved from the community based NGO RiverSides which delivered residential stormwater social marketing programs until morphing into the design and supply of rain barrel programs for cities.

In the process of discussions with a Washington, D.C. client about future-proofing the RiverSides' rain cistern, it became clear that analogue rain harvesting faced a market limiting future unless it resolved two challenges associated with the operation and maintenance of its products. Residential rain barrels needed a thorough redesign to reduce rising product and transportation costs, to increase operational efficiencies and to accommodate scalability. In designing a scalable, nestable cistern it was revealed that the original research challenge was really one that distilled into one challenge – owner operation and maintenance. One user issue, an ability to know the volume of the cistern and one programmer issue, ensuring that cisterns were emptied prior to subsequent rainfalls lead to discussions about automation, and from that an exploration of how the internet of things could be applied to residential rain harvesting. We believed that what the market needed was a smart cistern that would solve the social challenge of property owner management and maintenance of cisterns, and the administrative challenge of knowing that residential rain harvesting cisterns were emptied and available to serve as stormwater storage when needed as opposed to remaining full to serve their user's determined desires for water offsets. In short, these are two diametrically opposite goals for rain harvesting complicated by the passive, analogue cisterns. Solving for that challenge by designing a smart rain barrel that would resolved these two challenges for residential private property stormwater infrastructure is what engendered the founding of RainGrid in 2012.

At the beginning of the project our goal was to design an 'out-of-the-box' cistern retrofit, using an 'Internet of Things' (IoT) controller, and managed by weather artificial intelligence (AI).

As we developed several prototypes iterations of the technology, we also embarked upon solving the challenges related to the operational ownership of the technology, implementation, and business model.

RainGrid's 'lot level utility approach' facilitates the evolution of a community private public partnership (P3) business model, whereby residential property owners trade their property access for utility-owned and third party maintained intelligent infrastructure.

As RainGrid's Ai/IoT rain harvesting systems are capable of taking 90+% of rainfall runoff from residential rooftops, reducing the pressure on stormwater management for utilities, and providing data visualization and analytics of the captured rainfall, the Smart Cistern seemed to meet the consumer demand to know what was in their cisterns, and the utility's needs to control the water.

While utility-scale residential lot-level stormwater best management practice implementation is not yet readily adopted in municipal stormwater programs, the opportunity for tangible returns could convince municipal programs to convert their analogue residential rain barrel programs to digital read-time assets instead of passive education and out-reach tools.

2. Water Challenge

2.1 Stormwater management

Stormwater management is an area of increasing concern as urban areas increase impermeable surfaces by introducing more concrete, roads and buildings. With reduced permeability in the soil surface, rainfall is unable to follow the natural water cycle by recharging the groundwater, and is instead forced to flow across impermeable surfaces, collecting pollutants along the way to drainage points.

The residential lot level typically constitutes 45% of gross impermeable area (largely rooftops) and encompasses a majority of the landscape of the typical urban residential development footprint. The reason why this is an issue is that impermeable surfaces stop the water naturally being able to reach the groundwater, therefore requiring more infrastructure to manage.

This has been addressed in the past by installing piped drainage systems, either through combined or separate stormwater sewers. Combined sewers are usually found in older parts of cities and carry both sewage and stormwater to wastewater treatment plants in one pipe (City of Toronto, 2017). Conversely, storm sewers contain only rainwater or snowmelt, which travel from roadside catch basins to receiving water bodies. Combined sewers can work effectively, but have negative environmental consequences during heavy precipitation events. When the volume of water exceeds the pipes' capacity, combined sewer overflows (CSOs) allow for the contents of the pipes to bypass treatment and go into the receiving body of water in order to prevent flooding of private property (City of Toronto, 2017). In order to prevent the negative environmental impacts associated with discharging untreated water during storm events, storage tanks and/or tunnels have been built in North America and Europe (City of Toronto, 2017). Examples of such are Toronto's Western Beaches Storage Tunnel and Eastern Beaches Detention Tanks, both of which intercept water from combined sewer overflows and stormwater. The storage time allows for settling before the water is subsequently pumped to the nearby wastewater treatment plant before being discharged back into receiving water bodies. While this solution addresses the issue of water quality associated with stormwater runoff and combined sewer overflows, the projects are largely capital intensive. For instance, the Western Beaches Tunnel cost $52 million in 2002 and required an additional pumping station (C &M McNally Tunnel Constructors, 2017). Similar projects are built around the globe and can be on a much larger scale. The Thames Tideway tunnel in London, England is currently under construction to address the problem of sewer overflows during heavy rainfall. The tunnel is to be 15 miles long and is expected to prevent 18 million tonnes of sewage from entering the Thames river (Gayle & Taylor, 2016). This project is estimated to cost £4.2 billion (Tideway, 2017), demonstrating the capital-intensive nature of such centralized solutions. These projects also take many years to complete, as the Thames Tideway is estimated to take 9 years from planning to completion; the Coxwell Sanitary Trunk Sewer in Toronto is planned to be constructed in phases over a 25-year span; and construction for the Anacostia River Tunnel Project in D.C is expected to take 5 years. As many cities experience the acute effects of climate change, the speed at which large centralized projects are completed may not be sufficient for adaptation and flood mitigation. In addition, whilst water is retained in storage tanks, it is alienated from the surrounding ecosystem.

Another common method of stormwater detention is the use of stormwater management ponds, which are prevalent in relatively newer suburban developments throughout North America. Within Ontario, they have become increasingly popular in the past 25 years (Drake & Guo, 2008). Upon the MOE recognition of stormwater management ponds as 'effective and efficient' stormwater management facilities, developers have been required to include them in subdivision designs (Drake & Guo, 2008). While these facilities mimic the natural environment in performing passive water quantity and quality control, they require regular monitoring and sediment removal to maintain performance. However, lack of budget and/or planning has resulted in the majority of stormwater management ponds being underserviced, and therefore underperforming, in Ontario (Drake and Guo, 2008).

Furthermore, the USEPA has expressed the shortcomings in focusing primarily on large infrastructure in stating that stormwater management 'needs to be designed as a system [that integrates] structural and non-structural [elements] and incorporate[s] watershed goals, site characteristics, development land use…monitoring and maintenance' (USEPA, 2008). These historically dominant practices of detaining stormwater on a centralized or regional basis have not been fully effective at protecting water quality in receiving water bodies or meeting flood control requirements (USEPA, 2008). Another increasingly common stormwater management method being implemented at the municipal or city level are downspout disconnections. Incentive programs are being introduced to encourage home-owners to disconnect their downspout from the storm (or combined) sewer system (McKenzie-Mohr et. al.). This reduces the stormwater volume that travels from rooftops to municipal pipes, storage tanks, and/or other related infrastructure; however, it does not allow for reuse of the water as it either infiltrates into the ground or becomes runoff that is captured by catch basins.

2.2 Drought Tolerance

The other side of the coin in water harvesting is the ability to save water for times of low rainfall or drought. The threat of drought has been managed through the exploration of alternative technologies, namely desalination, as well as groundwater recharging or water storage. For example, California has been practicing groundwater recharge since the 1970's wherein treated recycled water is injected into aquifers to prevent salt water intrusion and contribute potable ground water supply (EPA). Moreover, consideration of desalination as a primary water supply has become a reality in places such as Australia and South Africa. Ontario Teachers' Pension Plan and Hastings Funds Management invested in a 50-year lease of the Sydney Desalination Plant (SDP) in 2012 (Ontario Teachers' Pension Plan, 2012) under the premise of drought risk management. However, subsequent storms in the area have challenged its usefulness and the significant energy costs associated with the technology are also subject to climate risk due to the water-energy nexus. This means that large energy demands still contribute to climate change and the reliability of energy sources is vulnerable to the effects of climate change, demonstrating the shortcomings of placing heavy reliance on this technology. Therefore, we need to start looking towards solutions for water scarcity that are less energy intensive and able to be managed at the local scale.

2.3 Climate change adaptation and decentralisation

Cities have before them a challenge to adapt to climate change that reflects their organic evolution of land use development, wastewater management, and drainage of surface waters and rainfall. As cities traditionally evolve, they strain to maintain the piped drainage, sewage wastewater management and stormwater management functions facilitating public health, economic growth and eventually ecosystem protection. Paradoxically, that very growth they pursue strains the infrastructure. Into that equation we add the complexities of climate change which stresses the designed capacity of centralized water and wastewater infrastructure because that infrastructure is a hard, capital intensive response to a variable set of pre-climatic conditions. Nowhere is this more evident than in terms of managing stormwater and drought conditions. Moving water is energy intensive and complicated with most cities dedicating on average of 40-60% of their total electrical energy use to that task. Solving water challenges by pumping water from one location to another shifts the issue at hand from one of water use to electricity use. To address this, we need to reduce the reliance on centralized infrastructure. By supporting centralized infrastructure with distributed infrastructure, we can become more efficient with water management, capturing the water where it falls. Climate change will impose significant costs on municipal water utilities in years to come.

One solution they have at their disposal to support their actions to counter this trend is the application of smart and decentralized infrastructure on private properties, where utilities have not typically operated. As distributed intelligent rain harvesting penetrates a community there are two significant outcomes: 1) a decline in stormwater flows from the retention of rooftop runoff, and 2) an increase in uses to which that captive water is applied to the water cycle in the utility service area. The captured water can be applied to one of three demand management needs: 1) potable water offsetting for either potable or non-potable uses such as toilet flushing, irrigation, cooling tower water laundry or, after treatment, drinking water; 2) groundwater recharge for desalination, aquifer recharge and environmental flows; or 3) reentering into the sewerage system at a later time for water balance requirements of sewage treatment facilities.

2.4 Smart data on a micro-scale

Localized micro-climate data (rainfall, temperature, barometric pressure, humidity) is nothing new, but the typical distribution of weather stations to capture this data is highly variable. As cities become more dependent on data to plan for resilience and adaptation capacity, microclimate data at the household (or lot) scale becomes more and more important to ensure that forecasts are relevant for the areas of concern. The integration of smart water management enables a whole-city approach to infrastructure that not only enhances the range of operational facilities, but which generates significant data for water utilities, weather bureaus, municipalities, insurance companies, builders and more. In addition, by making real-time climate data and rainfall available for the community, households can see in real-time how much water they are using and storing, and can adapt their usage patterns to suit their needs. In the future, utilities may move towards credit people with the management of stormwater on their private property, creating community utilities, where individual homeowners share the responsibility for the solution.

3. Smart Water Solution

3.1 How Stormwater Smartgrids created reliable, measurable and efficient residential rain harvesting

3.1.1 Origins of a Residential Stormwater Smartgrid

RainGrid, and its Stormwater Smartgrid Utility Technology, evolved from the brain-trust of two seasoned water professionals: one a non-profit/social enterprise advocate who designed social marketing for residential rain barrel programs and who manufactured a purpose-built cistern for North American municipal stormwater management low impact development (LID) programs; the other an engineer who designed and managed conventional pipe and pond stormwater infrastructure for the land development industry and the municipalities who inherited that legacy infrastructure. Each saw the limitations of their contribution to solving the stormwater problem plaguing cities, and the technological, ecological, fiscal and social deficiencies that stood in the way of progressing past the existing paradigm in the face of climate change.

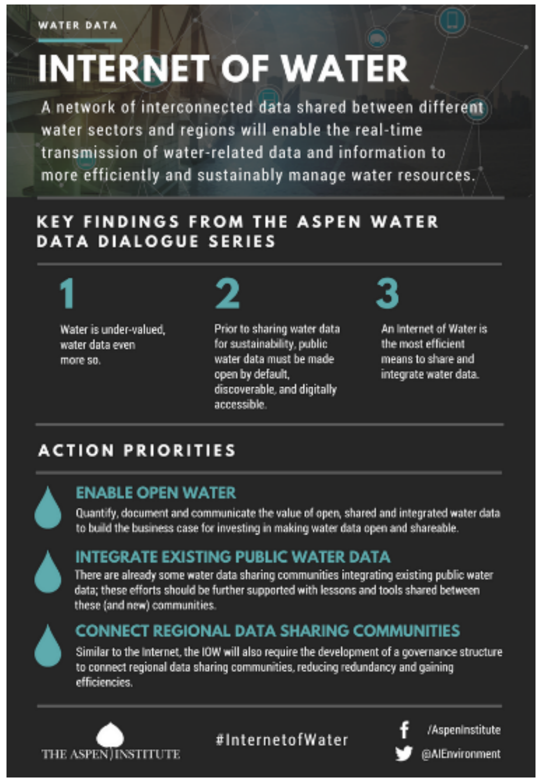


Figure 2. Internet of Water (Aspen Institute)

What attracted the stormwater engineer was the value added that smart distributed infrastructure represented as the missing piece in the land developer/municipal arsenal of coping with increasingly variable stormwater impacts, while the non-profit advocate saw AI/IoT technology as the solution to the social engagement barrier, represented by the reliance on property owner engagement and maintenance responsibilities, that minimized the legitimacy and use of passive distributed stormwater infrastructure.

The RainGrid founders not only acknowledged there exists a disconnect between the performance outcomes anticipated, and the restrictions that a traditional municipal stormwater business model delivered but that without a wholesale technological and business model restructuring, municipalities, land developers and stormwater utilities would be trapped in a negative feedback loop of building greater quantities of pipe conveyance, public land LID and end of pipe treatment facilities as their landscape became more impermeable and densely developed. While the might eliminate combined sewer overflows, non-point source contaminated stormwater impacts would magnify.

The typical municipal stormwater utility business model does not include private property as the basis of its asset management regime. That planning cycle begins and ends with the collection, conveyance and treatment plan. Although some municipalities such as Philadelphia, PA have encouraged the application of privately purchased and operated LID on commercial properties through subsidy programs, they still refuse to expand their reach into the residential sphere. (Philadephia Water Department, 2018) The Green Acres Program offers $5 million each year in stormwater grants to provide non-residential PWD customers with financial incentives to manage stormwater runoff with the added incentive of reducing their stormwater bill. In the second year of the program, PWD awarded $4.7 million to 17 projects that will capture runoff totalling 77 greened acres. Non-residential customers in Special Services Districts can

also apply collectively for additional funding through Business Improvement District Grants. This lack of residential property engagement largely reflects a limited capacity in public engagement and a reticence in adopting distributing infrastructure based on its terrible record for operation and maintenance.

Residential properties do however represent an average of 45-57% of gross impermeable area in the average city as the below table illustrates for a typical low-rise suburban development.

Table 1. Gross impermeable area analysis of a typical low rise subdivision (RainGrid 2014)

Example 1 - Low Density Green Field Subdivision					
Total Area Assumed	40ha				
Total imperviousness, averages 45% broken down as follows:					
Type of Use	**% Subdivision**	**% Impervious**	**Impervious Area (ha)**	**Pervious Area (ha)**	**Total Area (ha)**
Park	5	0	0	2	2
Road (incl sidewalks)	17	75	5.1	1.7	6.8
Commercial/Institutional	5%				
Commercial Roofs	2	100	0.8	0	0.8
Commercial Parking	2.5	100	1	0	1
Commercial Yards	0.5	0	0	0.2	0.2
Residential Lots:	73%				
Houses & Sheds	25.55	100	10.22	0	10.22
Res Driveways	5.475	100	2.19	0	2.19
Res Yards	41.975	0	0	16.79	16.79
TOTAL			19.31	20.69	40
Total imperviousness: 0.48275 (fairly close to predicted 45%)					
What can be controlled by RSSUT (residential + commercial): 11.02ha is equal to a little more than half of the impervious area (57%)					
SWM Designer's context					
Only the 2 year storm could realistically be captured					
The overall storage per impervious hectare is 218.3m3					
The overall storage per hectare of subdivision is 105.4m3					

The recent evolution of affordable and reliable AI and IoT applications have facilitated the transformation and easier adoption of one of the most intractable challenges facing urban stormwater – residential rain harvesting and reuse for flood and drought resilience on previously unmanaged private properties.

3.1.2 AI/IoT Innovation For Distributed Infrastructure: Stormwater Smartgrid Utility Technology

Residential Stormwater Smartgrid Utility Technology (RSSUT) builds an AI cloud-managed, Internet of Things (IoT) operationally connected lot-level stormwater harvesting infrastructure for reliable, measureable and effective flood and drought adaptation by residential properties. By bringing AI and IoT to individual property rooftop runoff harvesting, cities can adapt to climate variable stormwater management objectives at a significantly lower capital and operating costs (CAPEX/OPEX) than by expanding the capacity, operation and maintenance of conveyance and treatment infrastructure.

A community-based Stormwater Smartgrid utility infrastructure is built upon the years of research and innovation associated with the benefits of implementing distributed green infrastructure. Add AI/IoT networking capabilities to otherwise passive GI transforms those methods into proactive, utility-scalable, asset-managed municipal stormwater management infrastructure for climate adaptation. An RSSUT system delivers stormwater management at significantly lower capital cost per litre retained, at a fraction of the time required for conventional solutions such as sewer or retention pond retrofitting, and delivers cost-effective and space-efficient LID. Capable of effectively taking rooftops 'offline' from the minor storm system, neighbourhood Stormwater Smartgrid networks transform passively operated, unmeasurable and rarely maintained municipal voluntary rain barrel programs, into a measureable, reliable and effective community utility asset-managed infrastructure.

RainGrid offers real-time rainfall/diversion data visualisation and micro-climate analytics on an individual property and network wide aggregation. Data streams can be analyse to provide municipalities with advanced monitoring and event analytics to improve resilience planning and the infrastructure maintenance.

Whether applied as a residential groundwater recharging strategy or as a potable demand efficiency offset, residential Stormwater Smartgrid complements source water protection, and improved water quality. Meanwhile, system users gain access to potable water offset volumes for exterior irrigation or interior envelope (household) non-potable use.

Direct real-time information on stormwater flow diversion and use offers a distinctive opportunity for engagement with property owners in real-time on climate adaptation, stormwater and potable water efficiency. This direct line of communication to user's smartphones of desktops offers a personalised engagement portal for their engagement with the municipality owned infrastructure located on their property, filling a gap that stormwater education programs have long aimed to have with communities.

3.2 RainGrid Stormwater Smartgrid System Design and AI/IoT Architecture

RainGrid's Residential Stormwater Smartgrid Utility Technology (RSSUT) is a smart water management technology designed to capture rain runoff from rooftops that otherwise flows unregulated across properties and which constitutes the majority of contaminated stormwater discharge from residential and commercial properties.

The RainGrid system consists of: individual property cisterns, an artificial intelligent cloud-based weather algorithm, localized sensors, and electrically actuated drainage for harvested water reuse either within or exterior to the building envelope. A basic RainGrid System offers two stage primary filtration and storage in either above or below ground cisterns.

A Stormwater Smartgrid System has the primary goal of taking rooftops offline from the storm sewer system, with a secondary goal of providing harvested water for one of three use demand management conditions:

a. Groundwater recharge or sewer system flow balancing
b. Potable water offsets for exterior irrigation
C. Potable water offsets for interior envelope non-potable uses, or post-treatment potable replacement

The third goal of the RainGrid system is micro-climate data visualization and analytics. The system harvests environmental and operational data from its algorithmic analysis of real-time rain fall runoff, real-time capture, real-time use, and real time discharge in six minute intervals.

CASE STUDIES
COMMUNITY-BASED STORMWATER SMARTGRIDS: DISTRIBUTED AI/IOT RAIN HARVESTING NETWORKS FOR FLOOD AND DROUGHT RESILIENCE

3.2.1 The Stormwater Engineering

The basic focus of Stormwater Smartgrids is to address the majority of imperious surface runoff in urban neighbourhoods. As the table below illustrates, residential housing rooftops represent the largest individual percentage of impermeable area.

Low Density Green Field Subdivision
Total Area Assumed: 40 ha
Total imperviousness, averages 45% broken down as follows:

Table 2. Low Density Green Field Subdivision

Type of Use	% of Subdivision	% Impervious	Impervious Area (ha)	Pervious Area (ha)	Total Area (ha)
Park	5	0	0	2	2
Road (incl sidewalks)	17	75	5.1	1.7	6.8
Commercial/Institutional	5%				
Roofs	**2**	**100**	**0.8**	**0**	**0.8**
Parking	2.5	100	1	0	1
Yards	0.5	0	0	0.2	0.2
Residential Lots:	73%				
Residential Rooftops					
Houses & Sheds	**25.55**	**100**	**10.22**	**0**	**10.22**
Residential Driveways	5.475	100	2.19	0	2.19
Residential Yards	41.975	0	0	16.79	16.79
Total			19.31	20.69	40

Total residential (10.22 ha) and commercial (0.8 ha) roof area impervious -=11.02 ha
Total imperviousness: 0.48275/48.27% of gross area and rooftops represent: 57% of impervious.

For this scenario, we presume that the average household has roughly 1300ft2/120.77m^2 of roof area. For this size of property, a 1.3'/33.2mm rainfall would generate 39.6m3 of rooftop runoff. Presuming a RainGrid Stormwater Smartgrid cistern with 1800ft3/50.97m3 of storage on every property, we would be capable of sufficiently managing 99% of all annual rain events with a return frequency capable of managing cascading wet weather events.

3.2.2 Regulatory Framework

Regulatory frameworks vary widely but virtually all stormwater regulatory regimes are tending toward the 90% rule in their application of runoff reduction. In Ontario, the Lake Simcoe Region Conservation Authority, for example, requires land developers to create stormwater BMPs for new non-linear & redevelopment lands that retain the first 25 mm from impervious surfaces.
Linear Development, greater of:
The first 12.5 mm of runoff from new or fully reconstructed
The first 25 mm of runoff from the net increase in impervious area

Flexible (restricted sites):
1. Min 12.5 mm & 75% annual TP load reduction
2. Maximum extent practical of volume reduction & 60% annual total phosphorus load reduction
3. Off-site treatment requires the use of LIDs

In this scenario, Residential Stormwater Smartgrid cisterns would effectively take the property rooftop offline from the storm sewer system, and significantly reduce or potentially eliminate the need for an end-of-pipe pond systems.

3.3 RainGrid Stormwater Smartgrid Design

Stormwater Smartgrid systems provide operational interfaces for individual property owners and network administrators through one of two data visualization and analytics dashboards.

3.3.1 AI/IoT System Architecture

The RainGrid Residential Stormwater Smartgrid Utility Technology is a basic Ai/IoT infrastructure consisting of three basic parts:

1- A quantitative precipitation algorithm (AI) using Environment Canada or NOAA raw weather data correlated to address, roof area and cistern volume

2 - An IoT controller operating sensors for temperature, barometric pressure, and cistern level, and an electrically actuated valve for drainage (and where installed a pump)

3 - Individual unit operational and data visualization dashboards <my.raingrid.com> and administrative operational command and control dashboards <manage.raingrid.com>

The system architecture is illustrated in the following diagram, which represents data flows of the intelligent cistern on a network basis.

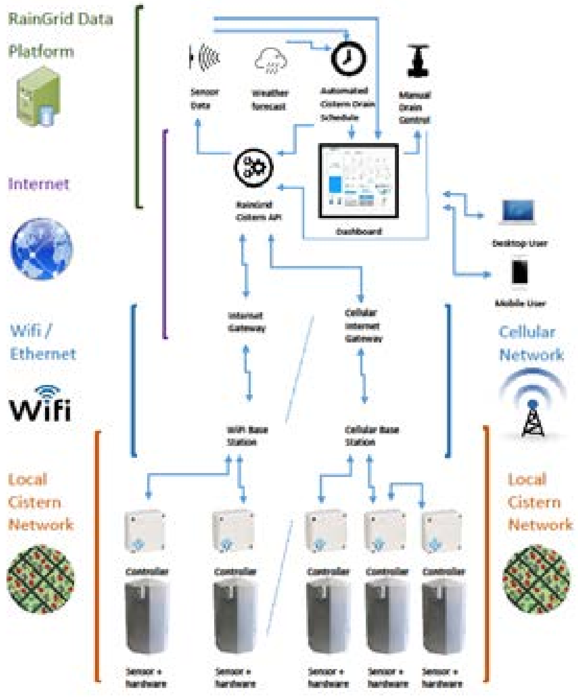


Figure 3. RainGrid Stormwater Smartgrid Architecture

3.3.2 Network Structure

Each Stormwater Smartgrid cistern has a level sensor comprising either an ultrasonic or pressure transducer sensor linked to an RSSUT controller. The controller communicates data through the household modem/router by means of either a Power over Ethernet (PoE) cabled connection, or an AC powered wireless connection.

For a greenfield subdivision, a Stormwater Smartgrid network structure can be installed in concert with the ISP service to the home from the internet gateway servicing the development via the fibre or coaxial cable.

3.3.3. Residential UI/UX Dashboards

The individual residential property dashboard <my.raingrid.com> consists of the following visualizations on two pages:

Operational Overview

a. A cistern graphic illustrates degrees of available storage (i.e., 0% is full and 100% is empty).

b. A valve graphic illustrates whether the valve is open, intermediate or closed.

c. A five day predictive weather forecast illustrates temperature, barometric pressure, predicted precipitation, and algorithmic predictions of the cistern's electrically actuated (EA) drain valve operation, and percentages of volume to be drained in correlation to predicted rainfall, and runoff top runoff relative to the cistern's existing available storage capacity.

d. A stormwater diversion graphic of weekly, monthly and annual cistern capture.

e. A numeric graphic of real-time cistern controller location, temperature and barometric pressure.

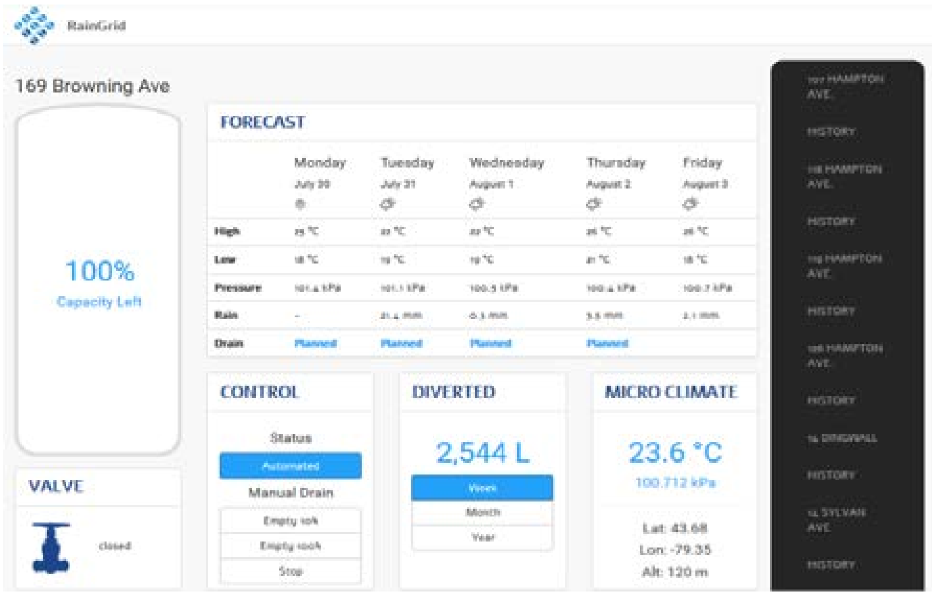


Figure 4. Residential Cistern Dashboard #1

Historic Graphical Overview: three graphs illustrates real-time operational histories

a. Total Diversion and Real-time Storage: a three axis graph showing a solid line for cumulative stormwater diversion by the cistern, and a histogram of the actual real-time storage volumes in the cistern available in one hour, three hour, one day, three day, one week, one month, and nine month periods.

b. Micro-climate: a three axis graph of temperature and barometric pressure in real-time over one hour, three hour, one day, three day, one week, one month, and nine month periods.

c. Diversion Rate: a thirty day analysis of runoff capture and bypass.

Figure 5. Residential Cistern Dashboard #2

3.3.4 Residential Network Administrator UI/UX Dashboards

The **<manage.raingrid.com>** network administrators' dashboard consists of ten individual system and network operational data visualization and analytics dashboards:

1. System – an overview of the primary operational conditions of each property by: Address, Last Sync Date, Cistern Fullness, Valve Status, Temperature, Sensor Pressure, System Voltage, and System Current
2. Map - google maps of the locations of the RainGrid systems
3. Reports – data reports of diversion, use and other variables for each individual cistern location
4. Filter Data – correction of data anomalies
5. Test – diagnostic assessment of individual cistern operations
6. Provisioning – set up for individual cistern operations
7. Users – project access users
8. Regions – groupings of cisterns by either locale or system type or both
9. Administrators – permissions for administrative control by Region, Region Administrator, Provisioning or Read Only Access
10. Options – password and access changes

CASE STUDIES
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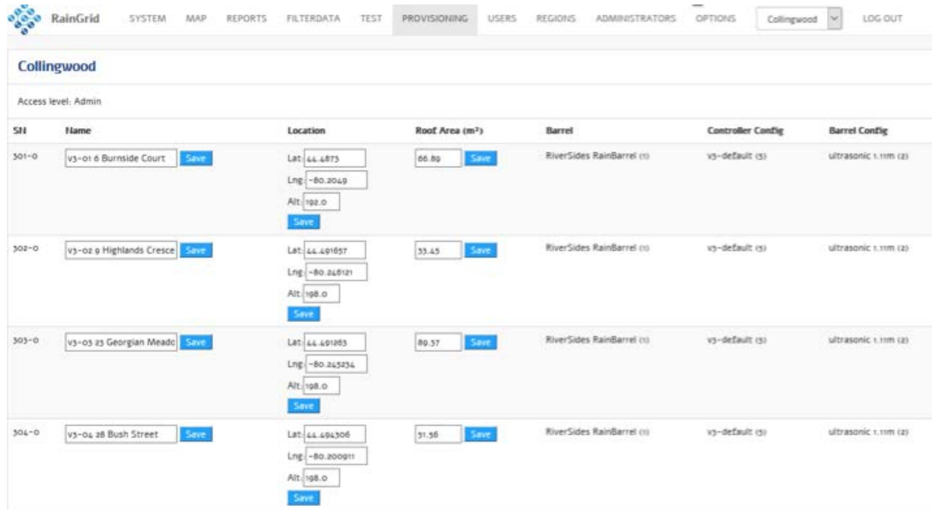

Figure 6. Collingwood 3.0 Smart Stormwater Pilot Project (Provisioning)

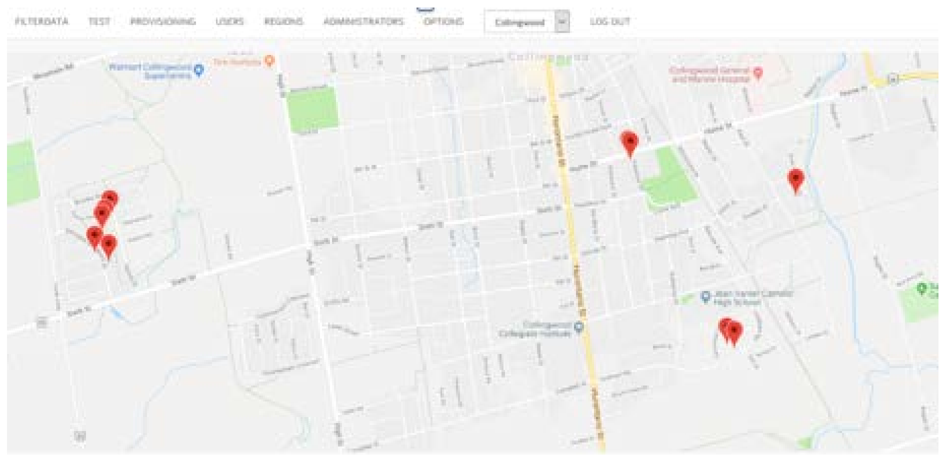

Figure 7. Collingwood 3.0 Smart Stormwater Pilot Project (Map)

3.3.5 Cistern Design

In addition to real-time controller design and development, RainGrid undertakes research into residential cistern design. Cistern design is essential to the success of implementing smart rain harvesting for both greenfield home builders and existing home retrofit implementation. The objective is to create cisterns that integrate well with real-time automation, that require minimal maintenance, and that seamlessly integrate rain harvesting into the home, not dissimilar to any other utility service.

To meet its promise of reducing or eliminating the costs of end-of-pipe pond demands for land, materials for piped conveyance and regular maintenance, residential rain harvesting must by design and practice offer reliable, effective and measurable results. This begins by designing a controller that integrates well with existing cistern design or designing OEM cisterns that address the highly variable needs of retrofit and greenfield applications.

3.3.6 RainGrid Smart Cisterns

A Stormwater Smartgrid system effectively reduces 90%+ of rooftop runoff depending on the size of the cistern serving the roof area, or the storage capacity of the rooftop for a smartBlu Roof system. Because the algorithm of a stormwater smartgird is capable of predictive and real-time weather analytics it that correlate rainfall volume intensities to rooftop area and cistern capacity. In this regard, we can store runoff in less space than before because we can fully discharge to ensure full rooftop runoff capture..

In aggregate terms, a fully functional Stormwater Smartgrid, operating on a lot by lot basis in either residential or commercial property configurations, is capable of retaining roughly 60% of all urban runoff as system penetration rises from 20-80%.

Figure 8. Stormwater Smartgrid cistern

Table 3. Estimated scalable cost of residential RaidGrid Stormwater Smartgrid Utility Technology (RSSUT) showing economies of scale (System for a 100m² roof area, 3000 litres cistern, US dollars)

Costs	1 system	500 systems	1000 systems	5000 systems
Cistern Incl. filtration, quietening inflow	$1500	$1300	$1000	$1000
Collection piping	$300	$200	$150	$100
Electrically Actuated Pump & Valve	$800	$500	$400	$400
RSSUT including US or PT sensor(s)	$1600	$1000	$600	$400
Total Cost	$4200	$3000	$2150	$1900

CASE STUDIES
COMMUNITY-BASED STORMWATER SMARTGRIDS: DISTRIBUTED AI/IOT RAIN HARVESTING NETWORKS FOR FLOOD AND DROUGHT RESILIENCE

The costs associated with Stormwater Smartgrid technology applications vary widely between whether they are applied on a utility asset managed basis or within the voluntary property owned context. New built single family residential properties can be fitted with AI/IoT managed subterranean cisterns sized to match the roof area on the basis of eliminating 90%+ flows. This figure reflects the reality that it is impossible to size a cistern to manage 100% of flows since 100+ year storm events cannot be predicted. A standardized configuration for 5,000-10,000/ gallons would be $2500.

3.3.7 UI/UX Data Visualization

Each RainGrid User has a perfect window on their home's micro-climate conditions thanks to the Stormwater Smartgrid IoT cistern's 5 day predictive weather algorithm, volume/flow sensors, and electrically actuated drain valves, wirelessly linked to their home internet connection. Individual property users have access to their RSSUT data and operations through <my.raingrid.com> an interactive desktop or mobile data interface providing visualization of specific property microclimate and cistern operations, cistern water use control, and a VPN platform for messaging. The dashboard provides real-time operational status visualization of their Stormwater Smartgrid cisterns consisting of the 5 day predicted rainfall which indicates and any automated drainage events for their cistern, detailed insights into their cistern's operation while also providing manual operational access to thousands of litres of diverted rooftop runoff.

The residential data visualization platform <my.raingrid.com> visualizes in fifteen minute increments of 30 second real-time data, six month to one hour graphs of household stormwater diversion and use, and temperature and barometric pressure.

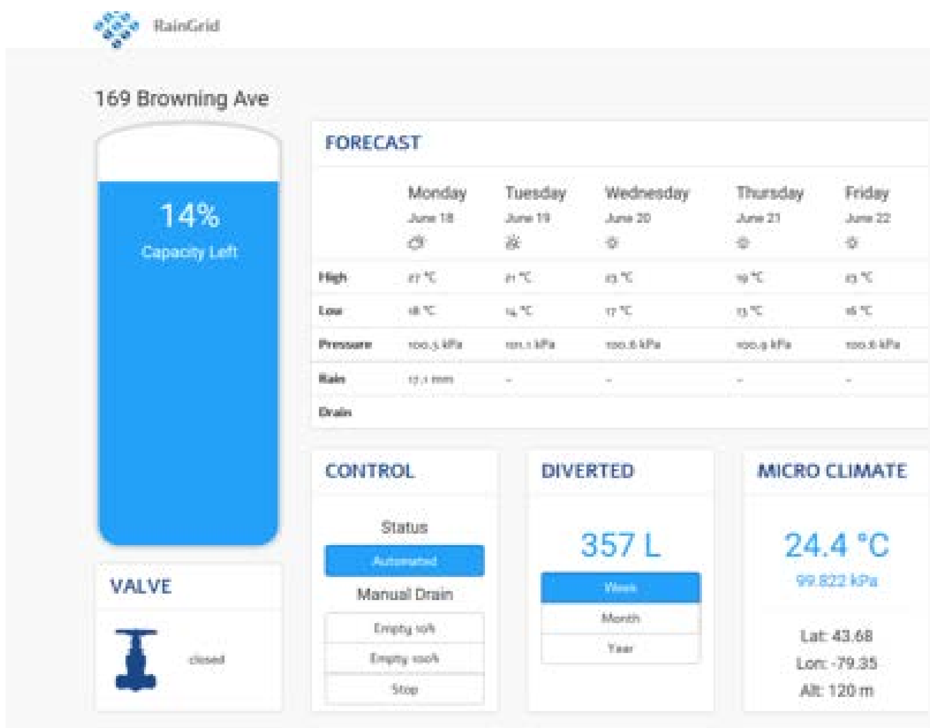

Figure 9. My.raingrid.com Residential Data Visualization›

The data visualization UI/UX ***<manage.raingrid.com>*** – is a comprehensive network administrative backend consisting of: a list of property addresses & cisterns, a Google map by address and GIS coordinates (capable of integrating municipal sewershed GIS layers), a property list of individual cistern component status and fault alerts, stormwater diversion & potable water offset data visualization by individual and/or network properties, administrative management protocols and access designations, ability to establish sub-networks by community boundaries, postal code or other characteristics.

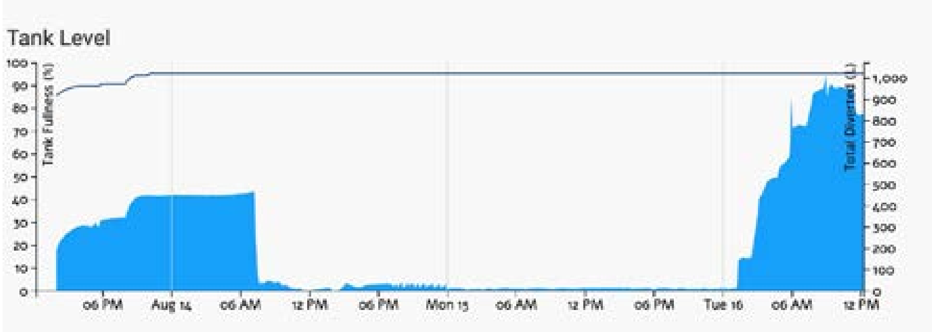

Figure 10. Automated draining capacity based on predicted rainfall (Source: RainGrid)

Figure 10 shows the smart cistern automatically draining the barrel in anticipation of rain. You can see this in the graph shortly after 7am on August 14, when the barrel emptied to around 15% capacity. The barrel begins to fill again on August 16 at 2am, filling first to about 15%, then continuing to fill the barrel to 70% of its capacity. After another short pause in the rain, the barrel fills to 90% just before 12 p.m. The administrator then drained the cistern by a 10% to allow for a 25% capacity for future collections.

Community-based distributed Stormwater Smartgrid utilities, along with smartBlu Roofs, create property-based flood and drought adaptation. Stormwater Smartgrids convert rainfall into a secure water capacity for either individual property or community wide applications, while contributing a degree of climate flood resilience for localized and downstream communities. Private property-based AI/IoT rain harvesting for reuse and/or groundwater recharge is a transformative water security of supply infrastructure offsetting and complementing insecure water and wastewater supply infrastructure. AI/IoT offers highly valuable climate resilience, conservation, demand and/or ecosystem recharge offset data visualization and analytics for water utilities and users.

Private property or institutional distributed AI/IoT rain harvesting is a powerful tool for utilities seeking to meet the baseline goals of SDGs 6.3 to improve water quality by halving the proportion of untreated wastewater, and substantially increasing recycling and safe re-use; and 6.4: to increase water efficiency, ensure sustainable withdrawals and supply of fresh water, and substantially reduce water scarcity.

AI/IoT rain harvesting provides three key climate de-risking modules:
1) Attenuation of stormwater-related chronic (permeability coefficient determined) and seasonal (room for water determined) snow melt, monsoon or wet season peak runoff flood impacts; minor overland flood and sewer system surcharging management.

2) Offset potable water security of supply where variable conditions [restricted/seasonal ground or surface water supply, restricted pump energy, decrepit (non-revenue water leakage or theft) infrastructure] reduces security of supply; or as an ecosystem recharge and drought resilience for sewage infrastructure.

3) Real-time data visualization data and decision-making analytics of micro-climate weather, localized stormwater runoff capture, diversion, and post-harvesting use, and pre-weather

event cistern/rooftop storage operations and management. (Real-time micro climate data management).

This three-tiered benefits structure of Stormwater Smartgrid networks reflects a convergence of AI/IoT-enabled rain harvesting with smart cities strategies, One Water (U.S. Water Alliance, 2018) infrastructure policies, ecosystem protection regulation mandates, community knowledge and resource capacity building, and climate resilience/adaptation; the baseline water elements of the SDGs. Stormwater Smartgrids reflect a delineation of AI as the data interpretive and analytical brain fitted to the IoT operational body of real-time rain harvesting (Kranz, Maciej, Vice President, Corporate Strategic Innovation Group, Cisco Systems, 2017). A Stormwater Smartgrid, like an energy smartgrid, utilizes otherwise isolated distributed rain harvesting. It does so by applying AI analytics (quantitative precipitation forecast algorithms) to the operational automation of IoT managed rain harvesting (for any of the three operational outcomes identified above), which in turn generates property-and city wide data on rainfall, rainwater use, offsets, community engagement (via data and utility communications) linked to the attainment of SDG goals on a local and regional scale.

Building upon this foundational research work RainGrid and a few other utilities and companies globally have pursued AI/IoT stormwater harvesting to resolve two primary social and administrative challenges facing the use of distributed stormwater harvesting on private property: 1) operations and maintenance by the property owners, and 2) the operational reliability, data measurability and operational effectiveness of those cisterns.

The Stormwater Smartgrids are municipality owned on the owner's property – CBP3 (community based public private partnerships) – a rapidly evolving mechanism for the implementation of distributed infrastructure on private property.

Microclimate data
Stormwater Smartgrids also collect detailed 30-second data of rainfall and its intensity. This allows us to make rain maps of the city that detail when and how much it flowed, and where; the actual weather, not a forecast. Over time, this facility will be able to do two very important things – it will be able to cross reference past weather events with predicted weather, and via the weather artificial intelligence (AI) make a detailed analysis of the likelihood that a forecast will actually be realized. Further, it will be able to track climate change dynamics by comparing current to past weather events on a granularity not hitherto available.

3.4 Stormwater Smartgrid Pilot Projects

3.4.1 Oakville, Ontario 2015

RainGrid launched its 2015 Stormwater Smartgrid 1.0 prototype pilot in Oakville, Ontario which successfully demonstrated how a retrofitted RainGrid V1 500 cistern can function to automatically divert runoff from storm sewers during rain events and automatically release stored water prior to subsequent storms. The pilot stored runoff from one downspout draining ¼ of a 1,200 ft.2 detached home rooftop to a 500L cistern, from June-October 2015. In an average rain year, the cistern diverted and detained 14,129L of rain, which was recharged to groundwater via passive irrigation. The automated valve coupled with
RainGrid's quantitative precipitation forecast algorithm automatically drained the cistern 24 hours prior to predicted rainfall to ensure maximum storage capacity.

RainGrid launched its Stormwater Smartgrid 1.0 prototype pilot in Oakville, Ontario in 2015 on one suburban home to test the proof of concept. The original design challenge was to determine how to automate a residential rain barrel. The prototype consisted of a hand built IoT controller consisting of a Texas Instruments development board, with ports for the sensor, electrical valve, and Power over Ethernet (PoE) injector. The PoE cable connected to the household router via a PoE injector linking the controller to a cloud-based server integrated with real-time weather data prediction AI algorithm . The controller operated a pressure transducer sensor and an electrically actuated drain valve connected to the AI cloud via a power-over-ethernet (PoE) controller. The controller and peripherals were fitted to an HDPE 500L RainGrid V1 above ground retrofit cistern. The AI measured the volume of the cistern relative to the volume of the predicted rainfall and subsequent rooftop runoff. The AI measured the cistern volume and determined if storage was adequate to store predicted runoff. If the AI calculates rain event runoff volumes greater than available storage in the V1 500L cistern, the AI directs the controller to open an electrically actuated drain valve until such time as the sensor determines the necessary storage capacity is available.

The pilot cistern stored runoff from one downspout draining ¼ of a 1,200 ft2 (28m^2) detached home rooftop to a 500L cistern, from June-October 2015. In what was an average rain year, the cistern diverted and detained 14,129L of rain, which was recharged to groundwater via passive irrigation. The AI quantitative precipitation forecast (QPF) algorithm converted raw weather data from Weather Underground automatically drained the cistern 24 hours prior to predicted rainfall to ensure maximum storage capacity.

3.4.2 Toronto, 2016

RainGrid embarked upon its 2.0 Stormwater Smartgrid Utility Technology development and implementation in 2016 by successfully building a research and development partnership with George Brown College's Office of Research and Innovation and its School of Mechanical Engineering Technologies and Advanced Prototyping Lab. GBC ORI secured funding support from the Natural Sciences and Engineering Research Council of Canada (NSERC) Green Home program to develop and build RSSUT 2.0 prototypes for the Toronto RainCAP pilot project. A National Science Engineering and Research Council's (NSERC) Green Homes program grant of $35,000 offset the costs to design and assemble 25 2.0 RSSUT systems.

The 2.0 Stormwater Smartgrid Smart Cistern controller switched from a PoE communications and power platform to a wireless solar recharged DC power platform using Zigbee X wireless transmission to a household IoT router. The same Measurement Specialties pressure transducer sensor and electrically actuated valve from the 1.0 prototype were used in this project. The original UI/UX operational visualization and analytics dashboard was significantly upgraded to comprise two UI/UX platforms, one residential, the other administrative. These were:

i)https://my.raingrid.com – desktop-based residential web interface giving property specific microclimate and operational data, cistern water use control, and a VPN platform for messaging), and
ii) https://manage.raingrid.com – a comprehensive administrative backend consisting of: network property & cisterns list, Google map by address and GIS coordinates (capable of integrating municipal sewershed GIS layers), individual cistern and property component status and fault alerts, stormwater diversion & potable water offset data visualization by individual and/or network properties, administrative management protocols and access designations, ability to establish sub-networks by community boundaries, postal code or other characteristics.

Neither site was optimized for mobile or linked to a native app for installation. Participants entered their logon charactersistics for their internet into the my.raingrid.com interface which thereafter auto entered the logon data for their router with every opening of the interface.

Coupled with that development partnership was a successful application by RainGrid to the Commission for Environmental Cooperation's North American Program for Environmental Community Action (CEC-NAPECA). However, as NAPECA funding is only granted to community organizations, RainGrid transferred funding to a local community organization to deliver the project in the Riverdale neighbourhood.

The average residential use of rainwater harvested by the Toronto 2.0 Riverdale pilot project was difficult to calculate due to the technical difficulties of the system. Data from individual systems varied greatly but the 500L cistern systems retained an average for use or recharge in one year of 195,927L.

3.4.3 Riverdale, 2016

In 2016, RiverSides (an independent group) installed and tested 15 of RainGrid's AI/IoT cisterns in the Toronto community of Riverdale. As part of the pilot 15 RainGrid Inc. controller systems were purchased and installed with 500-liter cisterns, located on the properties of 15 participating householders. The following section details the results and lessons learned from this pilot.

Figure 11. Installation of RSSUT system in the Riverdale pilot (Source: Riversides)

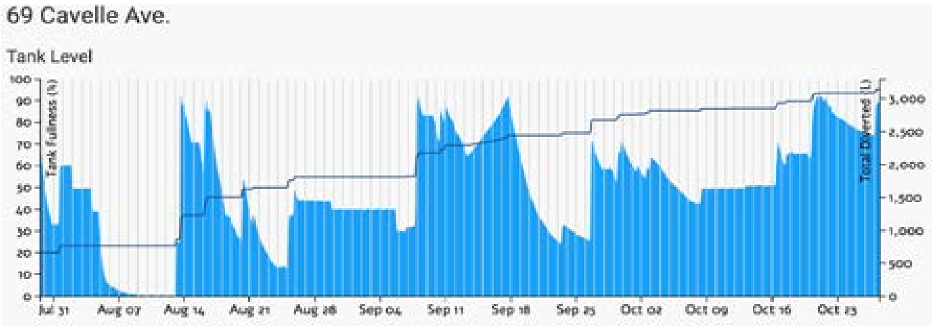

Figure 12. Rainfall collection, tank-level and water-use/drainage metrics for Household 4 (August 28 – October 28)

Table 4. Results and projected water saving estimates from five of the fifteen pilot houses

Pilot details	House 1	House 2	House 3	House 4	House 5
Cistern size	500L	500L	500L	500L	500L
Roof surface	28m^2	46.5m^2	46.5m^2	27m^2	28m^2
Projected annual stormwater collection estimate*	14,000L	18,400L	20,000L	10,400L	18, 500L
Data collection duration	5 months	5 months	5 months	5 months	3.5 months
Average verifiable monthly collection	1,000L	1,440L	1,500L	650L	1,720L
Ave. monthly collection estimate	1,400L	1,840L	2,000L	1,040L	1,850L
Total verifiable stormwater collected, stored and diverted from storm sewers	5,000L	7,200L	7,505L	3,249L	6,023L
Total estimated stormwater collected, stored and diverted from storm sewers	7,000L	9,200L	10,000L	5,200L	6,500L
Amount of collected water used on garden	80% (~4,000L)	0%	80% (~6,000L)	100% (~3,250L)	80% (~5,200L)
Estimated amount of stormwater infiltrated on property	7,000L	9,200L	10,000L	3,250L	6,023L

*Based on 10-month season

While each household in the pilot was provided with the same size cistern (500L), roof size variability, along with other issues detailed below (e.g. high flows, maintenance and internet connection) resulted in a high variability in results for the annual projection for stormwater collection (from 10,400 – 20,000L per year). Despite this, each participating household was able to divert a minimum of 3,249L per month of stormwater, which was used between 80-100% for garden maintenance, reducing the use of potable water required for garden care.

3.4.5 Key lessons learned in this project

Lesson 1 – It was discovered that the system can be limited in storms, as the high low volumes can become turbulent when entering into the downspouts, which can overwhelm the diverter box and the overflow diverter box, leading to a significant reduction in the verifiable volume of stormwater collected, stored and therefore available for the homeowner. To rectify this issue, Riversides custom designed a 'storm funnel', which connects the downspout to the diverter box. This approach focuses the rainwater directly into the diverter value, largely eliminating the overflow issue and more than doubling capture rates.

Figure 13. Riverside Storm funnel in diverter box (left); uninstalled storm funnels (black) and diverter box (green) with filter (white)

2. Secure internet connectivity is essential for ensuring the cistern can function as a 'smart' tool, instead of just as a raintank. When connection is lost the control of the water capacity and storage, and the data-collection opportunities are also lost. This is particularly important for anyone who turns their electricity/internet off when going on away for any period of time. To address this issue, a wireless system and internet service must be considered to ensure the system is not dependent on the homeowner's internet.

3. Manual maintenance is still required to ensure the stormwater smartgrid can function to its highest capacity. For example, clogged filters and storm-surge overflow can result in significant missed collection opportunities. By installing a storm funnel, preparing with early-season filter maintenance and sending automated updates to the customer when a filter appears to bot be working to its full capacity, this issue should be reduced.

Figures 14 and 15 below demonstrates the difference that cleaning of the filters can make to the success of the collection rates. As shown in the graph, the collection rates in July, August and most of September (i.e. when the filters were clean) were very high. After September 18 a clogged filter resulted in a severe drop in collection efficiency.

Figure 14. Rain-fall collection, tank-level and water-use/drainage metrics for House 1 (July 30 – October 27, 2016) [Showing collection when filters are clean]

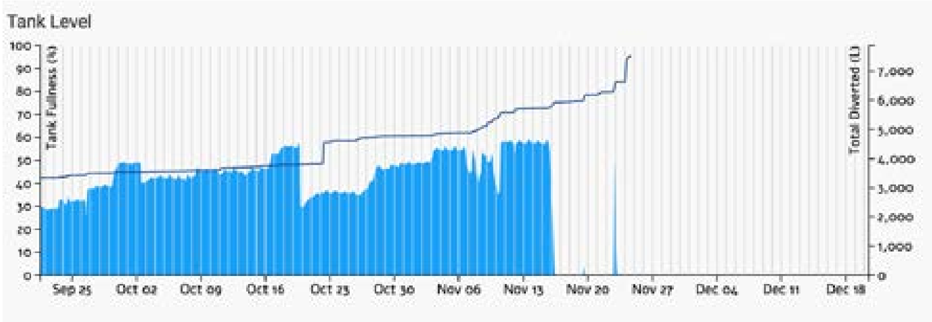

Figure 15. Rainfall-collection, tank-level, and water-use/drainage metrics for House 1 (September 20 – November 16) [Showing collection when filters are not clean]

As shown in Figure 15, collection rates after September 20 through to November 16 were approximately 20-30% that of when the filters were clean. This resulted in a loss of approximately 2,500L of stormwater that could have been collected over the September –November period, showing the importance of maintenance of the tools to ensure the smart element can function as designed.

Box 1. Design, Implementation, Maintenance, Analytics: Community Utility Business Model

Stormwater Smartgrids provide municipal or utility decision makers with intelligent distributed green stormwater infrastructure that seamlessly integrates as asset-managed infrastructure into stormwater runoff/flood or drought resilience prevention and response planning. Stormwater Smartgrid Utility Technology can be optimized and modified to meet a municipality's unique needs.

Tailored Design - RainGrid's highly-trained and knowledgeable staff guide you through a modular technical, regulatory and economic needs analysis tailored to present and future circumstances.

Turnkey Implementation - RainGrid builds community residential and business engagement models to facilitate rapid adoption and implementation. Turn-key installation or training of municipal/third party installation teams make it easy to sale up implementation.

Maintenance - Like any utility, Stormwater Smartgrids require regular maintenance to deliver optimal results, requiring training and maintenance from the team.

Analytics - The true power of the RSSUT lies in the endless opportunities for data collection, visualization and analytics. RainGrid provides cities with advanced analytics to help them better understand how much rain is falling, where, how it is changing over time, and how that may affect asset management planning. Customized analytics reports meet specific needs for planning of climate adaptation, sewer system design, and risk evaluation.

4. Project Inputs

The original input to meeting the challenge of building a distributed network of smart rain harvesting has been a two decade long evolution of municipal residential rain barrel programs. These programs were originally designed to address the systemic design of urban combined sewer systems which collected stormwater in pipes designed to overflow specific wet weather volumes to natural water courses. During the lifetime of Stormwater Smartgrid, a lot of funding and research has been put into the project through numerous grants (e.g. The Green Acres Program as detailed above).

4.1 Enablers and Barriers

4.1.1 Enablers

There are numerous major enablers and barriers to IoT Stormwater Smartgrids but here are the top ones.

Innovation and investment platforms support

The greatest enabler for Stormwater Smartgrid has been the ongoing support from innovation programs and awards. Stormwater Smartgrid was selected for The Water Environment Research Foundation's *Leaders Innovation Forum for Technology Program* (WRF-LIFT) (Water Environment Research Foundation, 2018), which brings together the best scientific minds and industry specialists to accelerate adoption of innovative water technologies. LIFT is a multi-pronged initiative undertaken by WERF and Water Environment Federation (WEF) to help bring new water technology to the field quickly and efficiently. LIFT includes components such as Technology Evaluations, People and Policy, Communication and an Informal Forum for Research and Development to better serve the industry. Being selected for the LIFT program in 2015 was a significant boost to the legitimacy with water utilities of RainGrid, and an incentive to rebrand as Residential Stormwater Smartgrids Utility Technology to give a fuller understanding of the application.

In addition to this, WaterTAP Ontario has been a major supporter of RainGrid's technology and has provided corporate capacity to advance the comprehension and market exposure of RainGrid's distributed stormwater and intelligent rain harvesting.

RainGrid's selection for International Trade missions to water scarce regions of the United States, has also significantly benefitted RainGrid by increasing its profile in new markets, and potentially built partnerships with utilities seeing the opportunities for intelligent stormwater infrastructure on private property.

4.1.2 Barriers

The Public Private Divide

Probably no issue informs the barriers discussion about disturbed stormwater harvesting more than the split between the perception and application of publicly financed, owned and operated infrastructure than the division between private and public land.

There are no shortage of city building or water utility sponsored AI/IoT programs enabling public infrastructure - LED streetlights, smart water metering, leak detection, and numerous state of good repair programs.

Municipalities and water utilities state they cannot install infrastructure on private property, despite installing water meters and electricity meters. However due to the law known as 'eminent domain', the municipality can come in and build whatever they want to build for the 'greater good'. They would therefore be able to maintain the infrastructure. Despite this, municipalities and water utilities are hesitant to own infrastructure on private property, reducing the potential for the scale of implementation required (around 40% of households capturing their own rainwater) to make a real impact at a community level.

While municipalities and utilities would benefit from residential stormwater smartgrids through both reduced stormwater to manage and increased data availability, many may see decentralising stormwater management as dimishing their role in urban water management. Despite this, there is the potential for utilities to invest in this kind of infrastructure (managing the infrastructure themselves, instead of RainGrid managing it), which would ensure they maintained a strong role in the management of the water. This is what is often referred to as Community Based Private Public Partnerships, and could be the answer for households interested in using Stormwater Smartgrids to capture rainwater and open to the idea of sharing the data with the local water utilities.

The business model and economies of scale
Originally we thought it would be developing the technology that would be the challenge, however it was the business model that has created one of the greater barriers. The technology to successfully implement lot-level stormwater management is available, it is the change in the business model to get the technology installed that has been the difficulty, and part of that has been the unit cost. When you produce something for residential application, it has to be low cost because you are putting in thousands of them. Yet, as a private property you cannot start to price things properly when you need a low unit cost. There needs to be one utility or municipality to install 10,000 cisterns to that we can price them at a reasonable cost. To reach the 40% implementation rate you need for a community to have noticeable reductions in stormwater, a sound business model is required. This barrier drove us to using the Community Based Public Private Partnerships (CBPPP) business model. By involving water utilities and municipalities in the investment of the Stormwater SmartGrids we are now able to market the products at an affordable price due to economies of scale, and will be able to see much greater results with higher numbers of households participating in the stormwater capture.

At this stage, the impact in relation to water savings that RainGrid's Stormwater SmartGrids have had is at a very local scale, saving just over 200,000L of rainwater across two pilot cases. As more pilots are introduced, more savings will be possible. To implement more pilot projects, we need to have the initial support through a strengthened business model to ensure we can produce enough Stormwater SmartGrids at a low enough cost to reach the required implementation rate of 40%. Only then will we be able to see the true potential of this technology.

Engineering Firm Engagement
Probably one the most defining barriers to the rapid adoption of smart (AI/IoT) distributed stormwater management relates to the often risk adverse nature of municipalities and water utilities, leading to the continued investment in traditional stormwater infrastructure. This is understandable in one sense as it is part of their role to keep the community safe in regards to water management, however it can also lead to a stronger than necessary hesitation to adopt or trial new and innovative technologies that could support them in protecting their community and enhancing their current stormwater infrastructure and management.

4.1.3 Achievements and impacts
RainGrid has achieved international recognition for its transformative smart water technology and transformative utility business model. In 2015 RainGrid was designated by the Water Research Foundation (WRF) Leaders Innovation Forum for Technology (LIFT) as an Intelligent Water System for demonstration adoption and implementation by municipalities and utilities.

RainGrid has also achieved recognition as a leading social enterprise when it was selected for the 2013 Impact 8 Social Innovation Generation Accelerator by the MaRS Discovery District, and through its successful win at the Toronto, 2014 Challenge Cup-Smart Cities business competition for the most promising, world-changing municipal startups. RainGrid also received a 2016 Best for the World designation as a B Corporation in environmental and best overall categories. This recognition has acted as an enabler in strengthening the interest in the project and in showcasing its potential to a wider audience.

5. Links to the SDGs

Table 5. Links to the Sustainable Development Goals

Sustainable Development Goals and Targets	
SDG 6: Clean water & sanitation **Ensure availability and sustainable management of water and sanitation for all**	
6.1	By 2030, achieve universal and equitable access to safe and affordable drinking water for all
6.3	By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally
6.4	By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity
6.5	By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate
6.6	By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes
6.A	By 2030, expand international cooperation and capacity-building support to developing countries in water- and sanitation-related activities and programmes, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies
6.B	Support and strengthen the participation of local communities in improving water and sanitation management
SDG 11: Sustainable cities and communities **Make cities and human settlements inclusive, safe, resilient and sustainable**	
11.5	By 2030, significantly reduce the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations
11.B	By 2020, substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change, resilience to disasters, and develop and implement, in line with the Sendai Framework for Disaster Risk Reduction 2015-2030, holistic disaster risk management at all levels
SDG 13: Climate Action **Take urgent action to combat climate change and its impacts**	
13.1	Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries
13.3	Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning

Sustainable Development Goals and Targets	
SDG 6: Clean water & sanitation **Ensure availability and sustainable management of water and sanitation for all**	
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6.5	By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate
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13.3	Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning

AI/IoT rain harvesting creates decentralized stormwater utilities. Similar in form and substance to distributed energy utilities of solar or wind, these ***Stormwater Smartgrids*** seamlessly integrate residential and commercial private-properties into a network of smart, asset-managed distributed water infrastructure. In doing so, AI/IoT rain harvesting closes one of the major gaps in a city's ability to successfully address so many interconnected Sustainable Development Goals through

- Security of drinking water supply (via groundwater recharge) (SDG 6.1)
- Protecting ecosystem water quality by reducing pollutants in stormwater (SDG 6.3)
- Optimizing sanitary sewage infrastructure (SDG 6.3)
- Increasing water efficiency through household reuse (SDG 6.4)
- Restoring environmental flows damaged by urbanization (SDG 6.5 & 6.6)
- Implementing rain harvesting, recycling and reuse technologies (SDG 6.A)
- Supporting community-scale participation in water and sanitation management (SDG 6.B)
- Reducing the potential for urban flooding (SDG 11.5)
- Increasing climate variable flood and drought resilience (post loss recovery) (SDG 11.B)
- Reducing energy use through decentralisation (SDG 11.B)
- Increasing urban resilience to climate related flooding (13.1)
- Enabling community participants to be better informed about their local climate and rainfall data (13.3)

6. Lessons Learned

Throughout these pilot projects we have learned a range of key lessons. These include how to improve the AI/IoT technology to make it more robust, to build-in additional time to test and adjust the systems in the field and the importance of community social-marketing from the beginning of the project. The follow section outlines these findings in more detail in the hope that these lessons will assist similar start-ups to get started on the right foot when introducing their innovative smart technologies to the market.

6.1 Technical lessons learned from the field

2015 1.0 Oakville

The technical lessons we learned from the proof of concept pilot were that residential scale AI/IoT rain harvesting could be designed to optimize smaller scale cisterns as stormwater management. Our early UI/UX dashboards were rudimentary but effective at illustrating the data of cistern levels, microclimate and simple operational parameters. Locating the pressure transducer sensor in a T-configuration with the electrically actuated drain valve resulted in pressure fluctuations that the sensor read as inflow, thus skewing the data.

The social engagement lesson drawn from this pilot was also very useful. The homeowner for whom the system was installed was happy with the installation but disliked the PoE cabling and PoE injector and the obvious connection to her interior household modem, situated in a second floor bedroom/office. This negative feedback prompted a rethink of the design a decision that significantly set back the development of the project, yet will benefit the project in the long-term.

2016 2.0 Toronto

In an effort to provide a lower property owner engagement footprint, we significantly modified the design of this pilot. The bulk of the R&D funding for this pilot came from an NSERC Green Homes research grant secured by our R&D partner institution, George Brown College Mechanical Engineering Advanced Prototyping Lab. The community social marketing engagement, installation, communications and half the maintenance costs of the installed RainGrid 2.0 systems were to be covered by a grant secured from CEC-NAPECA. This grant was conditional on it being spent by an NGO partner; so we contracted with two local NGOs. Unfortunately, the main NGO partner managing the funding were unable to deliver the most important elements of the engagement and community social marketing, to the extent that no formally recorded engagement, communications or replicable processes were instituted. Unfortunately, this resulted in a very limited evaluation of the pilot. What RainGrid can deduce about this pilot is tied to our analysis of the prototype technology's utility. In response to the push back received to the simple, functional PoE design, the 2.0 system was a very ambitious design, custom built on a limited timeline that precluded field tested prior to installation.

One significant improvement to our 1.0 and 1.5 proof of concept versions was a significantly upgraded UI/UX data visualization and analytics platform, divided between a residential and an administrative dashboard, the latter of which provided significant peripherals monitoring and fault assessment.

6.2 Prototypes take time to develop, test and get right

During our research and development stage we were warned to expect all of our field installations installed in the first two to three prototypes to not work as expected. While we were hoping this would not be the case, unfortunately many things did not go to plan.

In the first pilot we had issues with the sensors being damaged in harsh winter conditions, and when our communications software were replaced it required modifications to translate the signal to work with the household modem. For example, to eliminate the flow pressure reduction reading of the Specialties U7139 pressure transducer sensor, we modified the V1 500L cisterns with a separate port. This had the effect of subjecting the sensor directly to the water column which, when conditions turned cold, exposed the sensors to freeze-thaw conditions that damaged most of them the very first winter. The PoE communications and power platforms were then replaced with Zigbee wireless to household internet, which required a Zigbee modified TPLink TL-MR2030 router to translate the signal to the household modem.

In the second prototype the 2.0 system shortcomings mostly derived from having a limited budget, which significantly reduced our options to test and upgrade the technology when issues arose. For example, when the Zigbee radio transmitter specifications of signal strength range had difficulty with building mass and heavy rainfall, we determined that the units needed external antenna however without additional resources and support we were unable to fund this upgrade.

In addition, due to unexpectedly low sun exposure throughout the year the otherwise very energy efficient NiCad DC/solar power package failed to generate an adequate charge for the 4 AA NiCad batteries. This meant the rechargeable batteries failed entirely in cold temps as solar panels were not receiving the three hours of sunlight required to recharge them.

In Prototype 3, the electrically actuated valves turned out not to be weather proof (not ideal for a rainwater cistern) and many seized thereafter draining the power packs and the entire system failing. Once seized even the manual override couldn't drain the cisterns. Lesson learned, electrically actuated valves must fail 'open' but achieving that state requires constant energy inputs we could not install at the time due to the low power design.

In addition to this, as the system was dependent on residential internet access, low internet signals of loss of internet connections resulted in loss of data. Therefore wireless internet connections must be introduced with high power signal that cannot be disconnected to the internet.

These examples show the importance of taking the time to research, develop, test, and adjust smart technologies when developing prototypes, and also of the importance of the financial support needed to enable this time for research and development. Despite our many setbacks, we have learned a lot throughout this process and are eager to keep designing and testing our technology until is it robust enough to test on a much larger scale.

6.3 Strong community engagement is worth the effort

Limited community engagement with the pilot participants led to some challenges as well, as while most of the participants stated that they liked the technology, many disconnected their system (either intentionally or accidentally when disconnecting their internet service), earlier than expected.

Not surprisingly, participants linked their receptivity to use their SmartGrid to their interest in efficient watering of their gardens, or an interest in the technology itself. Technology early adopters were the majority of the participants with those interested in protecting the environment next on the adopters list. Unfortunately the lack of a formal community engagement with the pilot users reduced the wider community receptivity and interest in adopting the technology.

Based on the community engagement we were able to undertake, we do know that constant engagement and follow-up was necessary to ensure the users understood how to use the technology, were checking their systems regularly and knew how to use the systems to their advantage.

6.4 External support from the beginning of the project is essential for successful implementation

With regard to local water utility and political decision-makers their support was quite mixed. Though the Water utility managers were not as interested in participating in the pilot, the Toronto Sustainability Office endorsed it. This lead to municipal support through the city councillor's, however this support led mostly to further engagement and recognition and not to financial support for the pilots.

Local city councillors and federal members of parliament supported the project's demonstration of direct citizen engagement in flood and drought awareness, infrastructure and clean-tech climate change adaptation. National members of parliament (MPs) were the most supportive due to the positive signals the project disseminated about clean-technology, climate policy and public engagement.

The most significant lesson learned about engagement was not to be deterred by the reticence of first pilot adoption of the system.

7. Conclusion and Next Steps

7.1 Conclusion

The five-year evolution of the Stormwater Smartgrid technology and business model for residential properties illustrates how complex it will be to realize the flood and drought adaptation possibilities that distributed AI/IoT rain harvesting holds for households, water utilities and builders. While the AI/IoT technology will rapidly evolve, and an out of the box product will arrive in the market similar to irrigation controllers, there remains much work to make intelligent rain harvesting a green building standard for flood and drought infrastructure, a secure water supply and the standard bearer of community climate adaptation. Rooftop runoff needs to be seen as a resource rather than a drainage problem. This is the least acknowledged but definitive One Water utility infrastructure frontier, and it offers the best hope that water utilities, in developed and developing economies, have for making progress toward normalization of the sustainable development goals.

In North America, institutional reticence about utility-owned AI/IoT rain harvesting infrastructure on private property is slowly being addressed. Utilities uncertain about adopting a full scale utility-scale approach can use a 'hybrid market-based' approach by distributing smart controllers as an integral element of their existing rain harvesting rebate programs with centralized real-time date visualization and analytics control within the utility.

The degree that utilities utilize residential smart rain harvesting is partially based on how well they see the potential to build a comprehensive One Water utility. Few can ignore the 40-60% of gross impermeable area represented by residential and small commercial property rooftops but the litmus test is whether they *integrate* those properties or simply *serve* them.

To capture relatively clean rainwater where it falls is relatively low carbon, highly integrated and comparative low capital input oriented solution compared to post property runoff conveyance LID and certainly centralized stormwater storage facilities.

7.2 Next steps for RainGrid

In light of water utilities or a critical mass of households not yet being willing to adopt smart distributed rain harvesting, RainGrid will meanwhile pivot to focus on its visibility for residential property developpers and smart city designers. To do this we will focus our work on development of a commercialized out-of-the-box technology for retrofit applications on existing rain harvesting systems or full home and commercial rain harvesting systems. By reducing the costs for the product, this could enable greater uptake by households and improve results seen at a community level.

In a related development, RainGrid has been actively engaged with the Mississauga-based Credit Valley Conservation Authority, and the Region of Peel, to establish the parameters for what is termed the smartBlu Roof feasibility study. In response to the discovery that the rain water harvesting system that was installed at the City of Mississauga's newly built headquarters was sized solely for toilet flushing (providing no attenuation benefits for the subsequently released City of Mississaugua stormwtaer utility fee), RainGrid and other partners were engaged to determine the feasibility of developing a real-time automated blue roof to offset the inability of the CVC HQ building to meet stormwater retention goals required to offset the Stormwater Utility Fee.

Supported by a substantial grant from the Federation of Canadian Municipalities, Municipal Climate Innovation Program (FCM-MCIP), and endorsed by Peel Region as a water efficiency strategy deployment, this study seeks to advance the blue roof design and implementation process with AI/IoT automation. Similar work is underway in Amsterdam hosted by the WaterNet utility. The objective of each project is to demonstrate at-scale systems for commercial rooftop runoff reduction for reliable, measurable and effective reductions in peak stormwater flow, enhancement of potable water offsets, and a vital tool for urban climate adaptation and resilience.

In addition to this, we are currently in the process of our third pilot, the 2018 Collingwood Smart Stormwater Pilot Project, involving 10 homes. This pilot is a demonstration of the seasonal flood prevention possibilities of the RainGrid Stormwater Smartgrid, and the Safer Sump IoT sump pump. This FCM funded pilot has taken its lessons from the challenging 2.0 & 2.1 versions and returned to the reliability of a PoE power and communications platform. However, the pressure transducer sensor has been replaced by an ultrasonic sensor. Once again this R&D was generously supported by an NSERC funded research partnership with George Brown College as a three project enhancement of the original design.Based on the findings from this pilot, we are looking to gain support for larger pilots.

The potential future of RainGrid's Residential Stormwater Smartgrid is most likely to be found in water scarce regions such as California and Texas – to which RainGrid deployed in 2018 in an effort to secure at scale demonstration partnerships. Significantly it was determined, specifically in Southern California, that AI/IoT rain harvesting's greatest potential lay in its application as a groundwater recharge technology in support of indirect potable reuse projects for water security, and desalination efforts resulting from aquifer overdraft.

Appendix

Stormwater Smartgrid: A Defining Technology and Business Model Challenge for Water Utilities

RainGrid's ongoing research and development (R&D) into residential-scale Stormwater Smartgrid technology parallels a body of R&D into business models concerned with the financing, implementation and operation of utility-scale distributed water infrastructure; what is more frequently being referenced as Community-based Public-Private Partnerships (CBP3). What RainGrid Stormwater Smartgrids bring to this R&D into decentralized asset-managed rain harvesting is a focus on residential property infrastructure. In that regard, our research and development has been focused on using AI/IoT as a means to overcoming institutional reticence about owning, installing and operating networks of rain harvesting on residential private property.

While at RainGrid we believe distributed networks of residential AI/IoT rain harvesting will be one of the defining characteristics of sustainable water utilities, that is still a highly marginalized market niche. The AI/IoT rain harvesting market is rapidly gaining ground however in commercial building construction and retrofit that uses AI integrated sensors and IoT automated systems to reduce their carbon footprint by managing lighting, AC/heating, parking, bicycle sharing, and now blue/green roofs, rain harvesting and potentially water treatment. The potential for being self-reliant means being insulated to the risks inherent in under-capitalized, low operational investment scenarios associated with large centralized utilities increasingly unable to meet optimum service levels. Water utilities that embrace AI/IoT distributed infrastructure will avoid the challenge of stranded assets they are increasingly unable to maintain. The challenge of climate change and the evolving information management capacity represented by the simple ownership of a smartphone, represents a tectonic shift for water utilities.

The decision-making advantages that property-specific, microclimate data offer in terms of flood and drought resilience are unprecedented. In an industry that utilizes models due to the challenge surrounding the collection of data, the opportunity for utility planners and policy decision makers to gain functional outcomes (e.g. stormwater runoff source control and retention, potable water demand management offsetting) as well as microclimate, property-specific data on wet weather events and their impacts would be an ideal situation.

TEXT BOX

National validation guidelines for water recycling: Comprehensive Bayesian recycled water validation

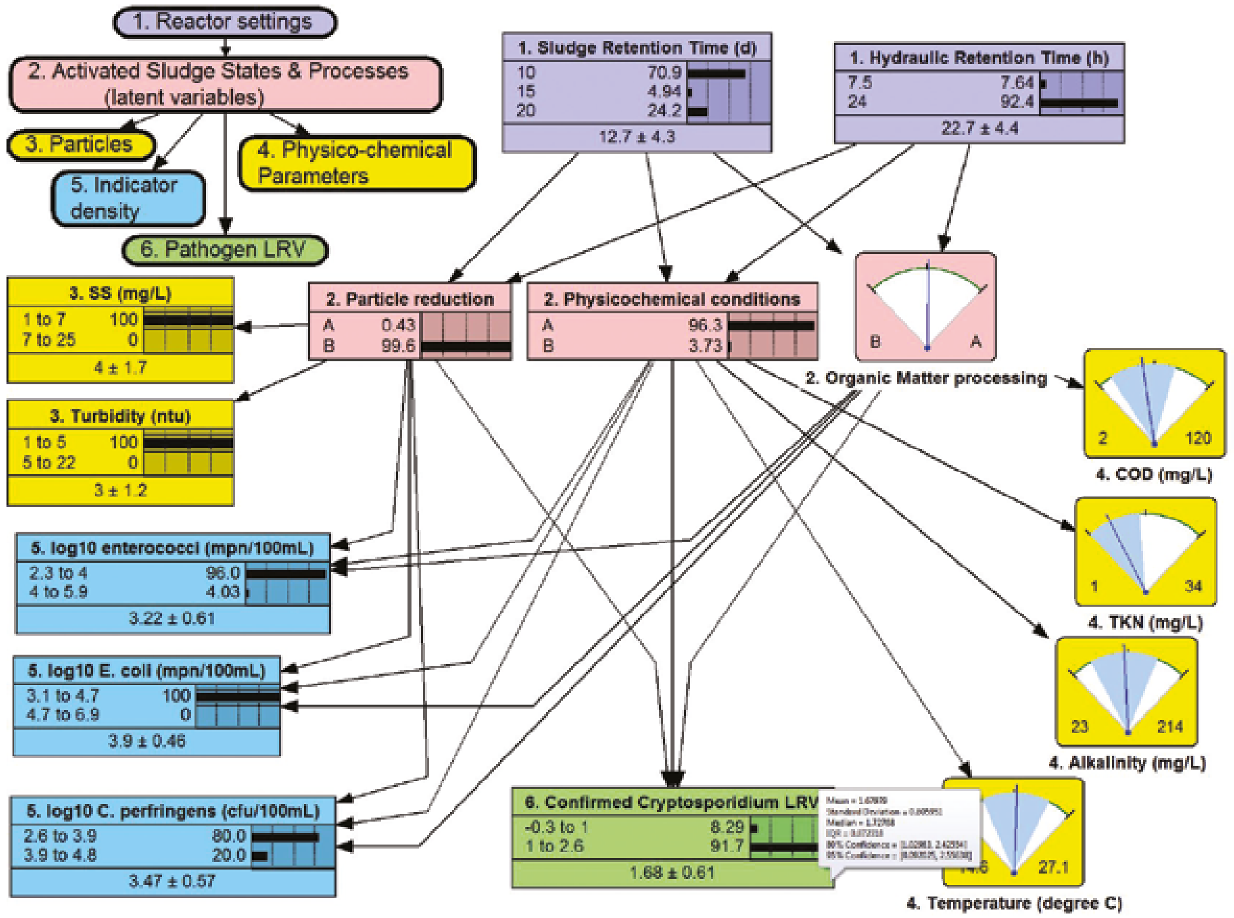
Country: Australia

City/region where project is based: Multiple Australian urban centres

Population (of area where the project is based): Approximately 20 million

Key organisations /stakeholders involved in the project: Australian Water Recycling Centre of Excellence's NatVal Project Stakeholders see:
https://researchdata.ands.org.au/australian-water-recycling-centre-excellence/267239
http://www.waterra.com.au/project-details/44

Authors: D. Roser, G. Carvajal, B. van den Akker, A. Keegan, R. Regel and S. Khan



Case Study: Smart tools for water quality data management and interpretation: Bayesian frameworks for recycled treatment process validation

Wastewater is increasingly recycled in Australia and globally for both direct and indirect potable use. To ensure its safety, it is essential to validate the technologies used to treat the water (i.e. assess reliability) over many months during process validation and plant commissioning. Due to the extreme risks arising if a system fails, ongoing monitoring is required to ensure a system shuts down in the unlikely event of hazardous contamination. As monitoring technology has advanced, constraints on data interpretation have been highlighted (e.g. the unclear relationship between online surrogates[1] such as turbidity or pH and risk benchmarks), resulting in increased institutional interest in improving interpretation of real-time water quality data.

This awareness reflects the need to relate all measurements to formal risk assessment metrics (e.g. treatment process Decimal or Log_{10} Reduction Values (LRVs) credits, targets and benchmarks), which are increasingly used by regulators. To support the use of these metrics, a consortium of Australian water researchers and managers developed NatVal, a 'national framework for validating water-recycling technology' (1) to improve confidence in treatment methods and the use of real-time water quality monitoring.

As part of the NatVal framework, our group was charged with identifying a process validation 'Framework' consistent with ISO 31000/31010 Risk Management principles and operational tools. To this end we investigated methods for quantitatively and conceptually relating measurements from surrogates, to monitoring indices (e.g. coliform counts) and then to contaminants of primary concern e.g. *Cryptosporidium*, whose LRV and µDALY risk metrics can be estimated experimentally in smaller trials.

To relate monitoring data to risk metrics in an operational setting, we chose Bayesian Belief Nets (BBNs), a type of artificial intelligence which capture human 'cause and effect' reasoning algebraically to facilitate 'reasoning under uncertainty', were trialled. BBNs are 'directed acyclic graphs' which visually look like flow charts. Unlike the latter though, nodes (e.g. a normal distribution function) and links (causal node inter relationships) are defined mathematically. BBNs proved remarkably adaptable and ideally suited to 'Smart' treatment performance analysis.

1. Online surrogates is the term used to describe water parameters (e.g. turbidity) when they are used as substitutes for direct pathogen monitoring

For example BBNs can 'learn' from databases and probabilistically relate online measurements (especially turbidity, sludge retention time and nitrate) to *Cryptosporidium* LRVs (see reference 2), and indicator (e.g. enterococci) behaviour to pathogen reductions and risk (Figure at left). Combined with another AI approach (neural network Perceptrons) BBNs can integrate disinfectant concentration, contact time, turbidity and pH measurements to estimate disinfection LRVs in real time (see reference 3). By using Bayesian inference we were also able to put uncertainty estimates on risk estimated using surrogate measurements.

While Smart monitoring collects enormous amounts of treatment process data (i.e. big data) and supports real-time equipment management, one issue faced is that current data outputs are often incompletely interpretted. In particular, they provide a lot of data but do not transform this into useful information. Through our research we have shown that BBNs, Bayesian inference and statistical analysis can address this gap operationally, auditably and in real time. It also provides a framework for risk inference suited to regulators and water utilities.

Based on our subsequent trials the greatest challenge to widely rolling out this Smart technology for water utilities and regulators appears not to be a programming constraints, but getting water managers to view their activities from a Bayesian perspective and understand Bayes reasoning and how it provides powerful prioritization mechanisms.

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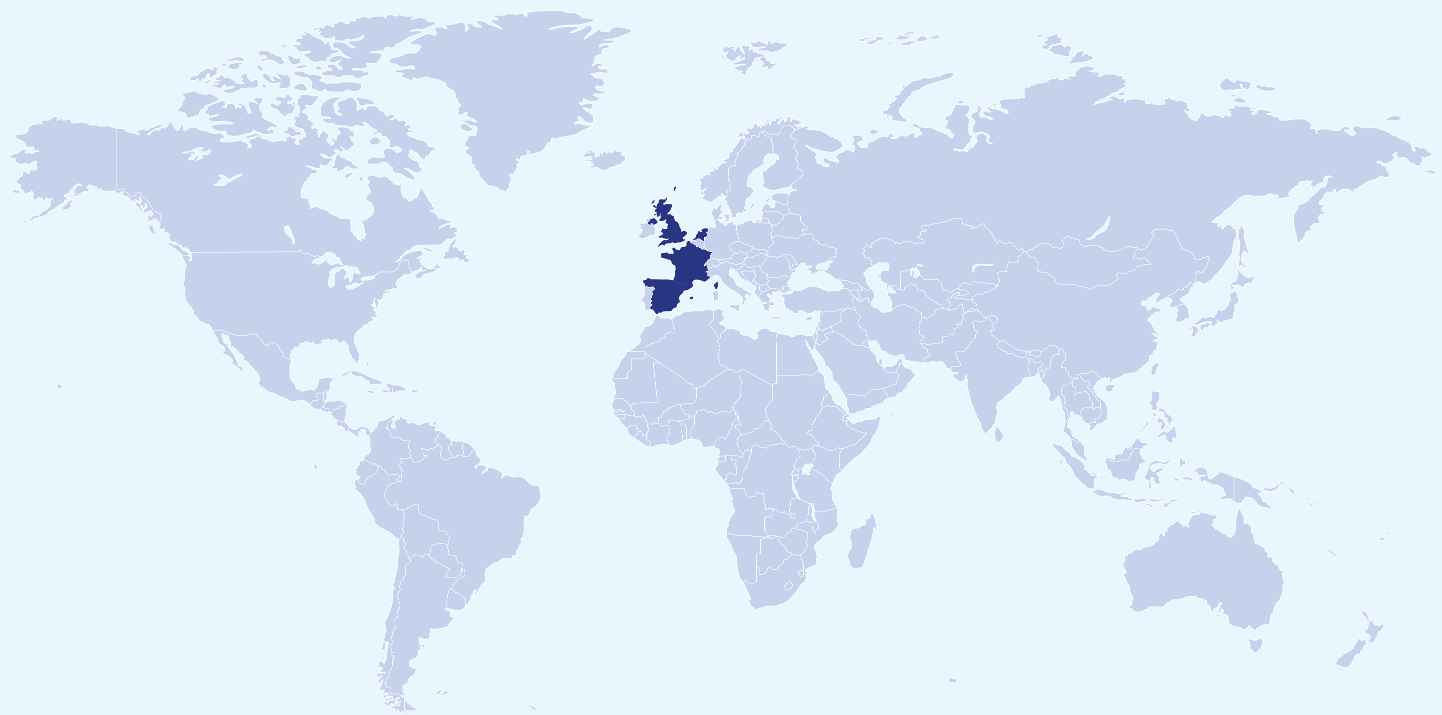
Demonstration of Sensing, Information and Communication Technology (SICT) Solutions for Smart Water Management: The Smart Water for Europe (SW4EU) Project

Eelco Trietsch and Renske Raaphorst, VITENS, Lead Organization of the SW4EU project
Dr. Silvia Tinelli and Prof. Ilan Juran, W-SMART, Lead organization for Outcome Dissemination



Spain, Netherlands, United Kingdom, France, in Europe

Executive Summary of the EU-FP7 Sponsored SW4EU Demonstration Project

Index

Note: *The Executive Summary of the SW4EU project has been adapted by the authors in order to share the project objectives and key lessons as part of the IWRA/K-water report. A more comprehensive Project Description including the main results, outcome analysis and impacts assessment, has been prepared by the authors with contributions of the owners of the SW4EU Demo-sites for publication in the upcoming UNESCO Book on Smart Water Management. The Publishers, UNESCO and W-SMART on behalf of SW4EU, have agreed to grant IWRA authorization for adapted replica of few sections and figures included in this Executive Summary.*

Project Summary

The Smart Water for Europe (SW4EU) Project was developed to contribute to the European Innovation Platform (EIP) Water by accelerating demonstration and thereby deployment of innovative smart water network technology solutions for upgrading the reliability, efficiency, quality control, sustainability and resiliency of metropolitan drinking water supply services. Its outcome is expected to support significant improvements of the utility's capacity to respond to societal challenges and increasing public concerns, while enhancing European SME's competitiveness and effectively promoting economic growth in the emerging sector of Sensing, Information and Communication Technology (SICT) for smart water network applications. Furthermore, the project intent is to bring together the SICT industry experts and water operators to accelerate acceptance of innovations and accelerate their market penetration.

While the technology to implement smart water management is readily available, there are several hurdles that currently impede the successful implementation of smart water management for water distribution networks. Typical to the case of industrial innovation these include lack of: 1) integrated and open solutions to meet industry's standards; 2) ability to comply with all users' requirements; 3) validated demonstration cases for water utilities to implement future projects; 4) business intelligence awareness with an industry's motivation to change traditional water management approaches; and 5) political and regulatory support to address public water security and sustainability concerns.

To address these barriers, the SW4EU Project objectives were to develop and demonstrate integrated smart water management solutions for water distribution networks across four demonstration sites (in the Netherlands, Spain, the United Kingdom and France). The water challenges addressed as part of this project include: water quality management (focused on early bio-contamination detection), leak detection and management, energy optimization and customer interaction, as those issues have been identified as the areas of greatest concern and interest for water distribution networks in Europe.

This case study provides an overview of the SICT solutions developed and/or demonstrated through the SW4EU project, along with lessons learned and recommendations for their integration in the selected applications towards preventive water systems management. These applications have been selected due to their high potential for creating business cases of substantial savings and improvement of resource efficiency. It is expected that sharing the outcome of this case study will contribute to engage water utilities and policy makers in accelerating their deployment and thereby support the competitiveness of European SICT SMEs.

1. Project Objectives – Responding to the European Water Challenges

Currently, 3,500,000 km of water distribution networks exist in Europe. Water utilities face a number of challenges related to these distribution networks. In the next 10 – 30 years, large parts of water distribution networks will need rehabilitation, which is estimated to require considerable budgets. For example, Thames Water anticipates the spending of € 1 billion/year and Vitens (in the Netherlands) anticipates spending € 270 million/year to upgrade infrastructure during this time. By extrapolating these figures to Europe and by taking into account the state and performance of distribution networks, Vitens and Thames Water estimate that € 20 billion/year will be needed in Europe to upgrade the distribution networks. It is therefore accepted that prioritization and optimization of these investments are urgently required.

Furthermore, in many countries water quality also needs improvement. Frequently, the European directive on drinking water is not met with respect to microbiological and chemical parameters, thus posing a threat to human health.

Finally, resources for water production and water distribution need to be used more efficiently. Mostly, the water distribution networks and assets are not managed actively on a real time basis. Production, pressure management, water quality and leakage events are dealt with in a reactive way based on laboratory analysis, complaints from customers and signals of health authorities. Continuous optimization does not take place and hence, resulting in the following challenges: 1) high water leakages (ranging from 5 – 50 % of total water produced); 2) sub-optimal asset management and water production; and 3) sub-optimal pressure management.

These challenges need to be addressed to ensure more efficient, reliable and cost effective management of water resources and upgrading the security, safety and sustainability of the water distribution systems.

The EU sponsored SW4EU project was developed to address the European Innovation Partnership (EIP) concerns and recommendations responding to the challenges water utilities currently face while promoting innovative SICT developments of EU SMEs. While the EIP addresses the European concerns the project objectives can be also related to the UN-SDG framework and more specifically in the European context to the goals of: i) clean water and sanitation (Goal 6); ii) ensuring sustainable energy for all (Goal 7); resilient infrastructure and sustainable industries (Goal 9); sustainable cities and communities (Goal 11); sustainable consumption (Goal 12) and climate action (Goal 13) as they are supported by science and public education (Goal 4).

This chapter provides an executive summary review of the SICT solutions developed and/or demonstrated as part of the SW4EU Project to address the challenges of: i) water quality and ii) leak detection. It also briefly outlines several key points explored by the SW4EU team with regard to i) energy optimization and ii) customer interaction.

The SW4EU Project was implemented across four demonstration sites in Europe, in the Netherlands, Spain, the United Kingdom and France. The project involved 21 partners who provided expertise and innovative technology solutions including:

- 12 SMEs bringing in their sensors, data processing, modeling and ICT technologies for the solutions to be demonstrated;
- 3 Water utilities who have created their own demonstration sites;
- 4 Research organizations and universities of which 1 owns a demonstration site;
- 2 Platform organizations representing water utilities and providers and users of contactless technologies.

The site-specific project objectives and key lessons are briefly described in this executive summary. A more comprehensive Project Summary including the main results, outcome analysis and impacts assessment, has been prepared by the authors with contributions of the owners of the SW4EU Demo-sites for publication in the upcoming UNESCO Book on Smart Water Management.

2. Description of the SW4EU Demo-sites

The 4 demo-sites participating in the SmartWater4Europe project (as shown in Figure 1) are briefly described below.

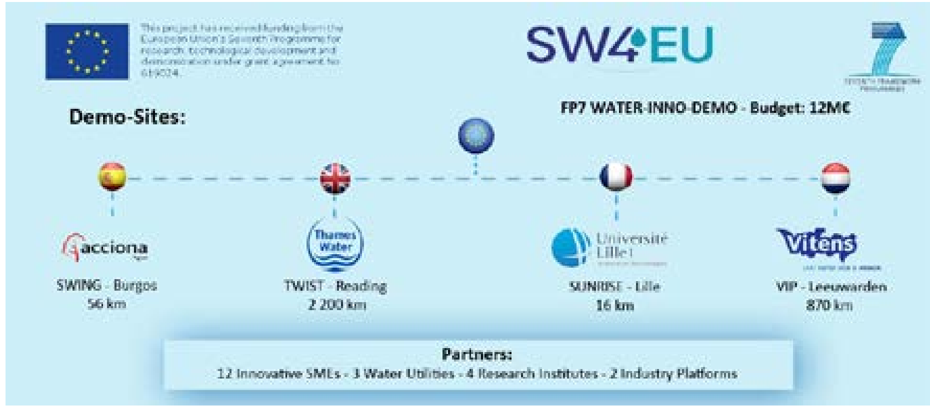


Figure 1. Demonstration site of the SmartWater4Europe project

2.1 The Vitens Innovation Playground (VIP) demo-site

is located in the Northeastern part of the province of Friesland. The supply area of Noardburgum is selected as the demo-site, and has both a rural and an urban character. It consists of 100,000 household connections and 2,200 km of pipe length. Leeuwarden, capital of the province of Friesland and cultural capital of the EU in 2018, has 96,000 inhabitants and is the larger city in the demo-site area. The selected SWM applications and demo-site instrumentation are summarized in Figure 2.

Figure 2. Vitens Innovation Playground (VIP) demo-site

Installed sensors - site monitoring for water quality included 45 Optiqua EventLab sensors, 10 S::CAN sensors, 5 intellisonde sensors and 1 Bactiline sensor, which were installed throughout the demonstration site. To demonstrate the accuracy, robustness, service level, maintenance, effectiveness and automation aspects Vitens placed the Eventlab, S::CAN and Intellitect sensor at 3 production plants and a reservoir to evaluate and compare the sensors.

2.2 The Acciona's SWING (Smart Water Innovation Network In the city of BurGos) demo-site

is located at the City of Burgos, which is the capital of, the Castille and Leon region in the northern half of Spain. The city, founded in 884, has an approximate current population of 180,000 inhabitants and a municipality and city area of 107.08 km² (41.34 sq mi). Aguas de Burgos Inc. the municipal society in charge of the Entire Water Cycle Management in the city of Burgos, has actively participated in the project as the demo-site owner. The selected SWM applications and demo-site instrumentation are summarized in Figure 3.

Installed sensors - Site monitoring included three selected urban areas:

1. Traditional city center area with its parks, restaurants and business sector, with a network total length of 9.081 km. For water flow monitoring the instrumentation included 442 remote water meters, one water flow meter and one piezo-resistive pressure sensor in the supply manhole.
2. Residential area of the west of the city with a 20.667 km long network that has been renewed recently. Its instrumentation included 911 remote water meters, one water flow and one piezo-resistive pressure sensor in the supply manhole.
3. Industrial area with several warehouses with a 25.692 km long network, which is covered with 177 remote water meters, one water flow meter installed in the supply manhole and three piezo-resistive pressure sensors.

For the purpose of water quality monitoring ACCIONA Agua has installed six water quality analyzers manufactured by two project partners, including five EventLab® from Optiqua and one Nano::station® from S::CAN. Each analyzer is located in a different place of the city to evaluate the water quality in the network.

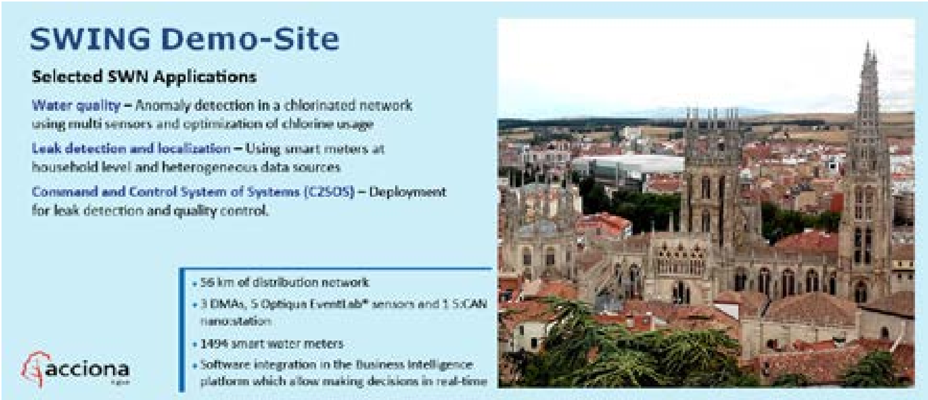


Figure 3. Acciona's SWING demo-site

2.3 The Thames Water Innovation and Smart Technology (TWIST) demo-site

is situated in Reading, England, in the Thames Valley, at the confluence of the River Thames and the River Kennet, and on both the Great Western Main Line railway and the M4 motorway. The demonstration site is approximately 71km² in area. It comprises 686 km of distribution mains and 179 km of trunk mains located in and around the city, which has many pipes over 60 years old, serving 89,000 commercial and domestic properties. The majority of these mains are of ferrous material at varying levels of degradation, with plastic (PE) mains now used as a standard for full replacement, and ductile iron generally for larger diameters. The trunk mains network consists of 172 km of mains, which convey about 45 Ml/d of chlorinated potable water from the treatment works into the distribution network. They include installations varying from 4” (100 mm) up to 32” (800 mm) in size, with majority of larger diameters constructed of iron. The selected SWM applications and demo-site instrumentation are summarized in Figure 4.

Figure 4. Thames Water demo-site

Installed sensors - the site monitoring included 2102 smart AMI water meters, 80 Network meters 14 Incertameters, and 20 Syrinix Instruments. The demonstration site is made up of four flow-monitoring zones (FMZs), split up in district meter areas (DMAs), which are bounded by closed valves or district meters for measuring the flow of water entering and leaving the DMAs.

2.4 The SUNRISE Demonstration Site

Lille at the Campus of the University Lille, which is close to the city of Lille in the North of France. The campus was constructed between 1964 and 1966. It represents a small town of about 25,000 users. It includes 145 buildings with a total construction area of about 325,000 m2. Buildings are used for research, teaching, administration, students' residence and sports. The drinking water network is around 50 years old. It is composed of 15 km of grey cast iron pipes with a diameter varying from 20 to 300 mm. It includes 49 hydrants, 250 isolation valves and a set of air valves. The selected SWM applications and demo-site instrumentation are summarized in Figure 5.

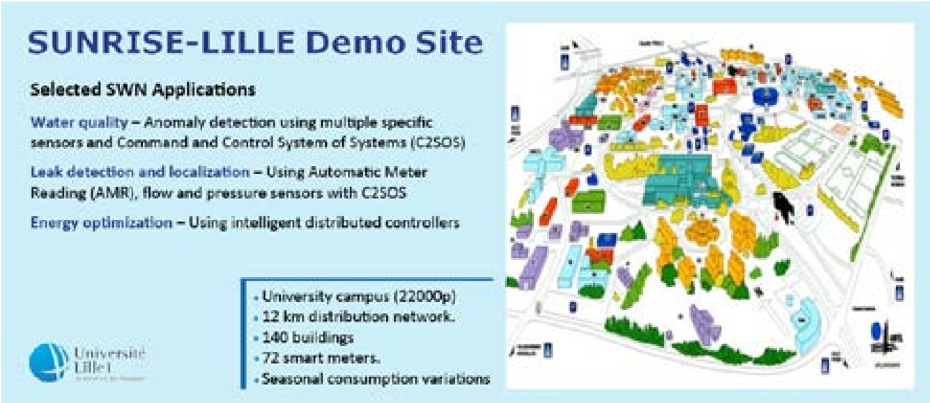


Figure 5. SUNRISE-Lille demo-site

Installed sensors - The SUNRISE demo-site instrumentation included 100 Automatic Meter Readings (AMR) installed at the galleries of the building connections to evaluate consumption patterns in different zones of the campus as well as 5 pressure cells to monitor the pressure in the network nodes. For quality monitoring both EventLab and S::can sensors were installed in two locations of the Campus. In each building, the sensors were installed in the operational control room. To ensure reliable results, the sensors were pre-tested and calibrated in a lab setting.

3. The Demo-sites Results

3.1 SICT Solutions for Water Quality Control

The demonstration program included three solutions for water quality:

1. Detection, back-tracing and forward tracing of water quality events by using multiple generic sensors, specific sensors and detailed modeling (Vitens).
2. Detection of water quality events using generic sensors (Acciona).
3. Detection of water quality anomalies using generic sensors (i.e: S::CAN and Optiqua), laboratory pilot models of bio-contaminations, and Artificial Intelligence algorithms for bio-anomaly detection and geo-location (University of Lille).

The following section outlines the main results obtained from the field demonstration and associated laboratory studies for the development and/or assessment of the SICT solutions in the three demonstration cases, including the VIP, SWING an SUNRISE demo-sites

3.1.1 Vitens Innovation Playground (VIP) Demonstration Site (The Netherlands)

During this project, multiple solutions were tested, from sensors almost ready to market to newly developed sensors. The tested solutions were the following water quality sensors:

- EventLab sensor (includes server Optiqua): Generic sensor, based on refraction index;
- Nano::station sensor (S::CAN): specific sensor for turbidiy, nitrate, colour, TOC, DOC based on (UV) absorption;
- Intellisonde water quality sensor (Intellitect): Specific sensor for temperature, O2, pH, O2-Reduction Potential, conductivity;
- Bactiline water quality sensor (Mycometer): specific sensor for bacteriological activity.

One of the demonstration objectives was to assess the performance and optimize the configuration of these sensors. Beside the demo-site a large-scale model (7m by 3m) representing the Vitens Innovation Playground (VIP) was used. The model enabled to perform experiments, which are not feasible in real-life, simulating the hydraulic network flow and potential scenarios to assess the behavioral response due to transport processes.

The key lessons derived from the VIP demonstration of the selected SICT solutions may be summarized as follows:

- Using both generic and specific sensors enables optimization of the monitoring system to achieve the highest probability of detecting changes in water composition or bio-anomalies;
- The most critical task is to ensure real time reliable data pre-processing and quality control. The water analyzed with sensors should be representative for the water quality in the main pipe. Placing sensors in the District Metered Areas (DMAs) could provide additional information about the propagation of water quality changes in the network itself;
- With regard to instrumentation, placing the sensors in households is an effective measure as they are frequently refreshed. This means that these sensors are mostly representative of the water quality in the local distribution network.

3.1.2 Smart Water Innovation Network in the city of BurGos (SWING) Demonstration (Spain)

For real-time water quality monitoring, a network of 5 Optiqua EventLab and 1 S::CAN Nano::station sensors were deployed in the Burgos distribution network. The SWM solution, including both generic and specific sensors, is developed and tested to confirm the high quality and stability of Burgos water. Dosing of chlorine has not been optimized due to a limitation in the devices used for this purpose.

With regard to water quality control, the main objective of this study was to establish the correlation(s) between refractive index measures (a general and not selective parameter related to water quality) with other spectroscopic and physical measurements (specific and selective ones). The sensors employed were the EventlabTM (Optiqua), a single optical sensor based on a Mach Zender Interferometer (MZI), and the Nano::station (S::CAN) with several selective probes: i::scan (for color, FTU/NTU, UV254 nm, TOC and DOC measurements), condu::lyser (for conductivity measurements), pH::lyser (for pH measurements) and chlori::lyser (for free chlorine measurements).

The site demonstration illustrated that the refractive index measurement is a useful generic indicator of water quality and can be used to monitor water quality changes. The Eventlab could also be combined with other sensors for a better determination of the nature of changes detected.

3.1.3 SUNRISE Demonstration Site at the University of Lille (France)

The water quality is monitored using EventLab and S::scan sensors, which are installed in 2 campus buildings. Before this installation, these sensors were tested in a pilot Lab, which enabled to inject chemical and biological substances at control density and duration and to follow upon the responses of sensors to injections.

Facing the lack of recorded bio-anomalies data, in order to simulate the laboratory's experiments and create a numerical database for the assessment of selected Artificial Intelligence algorithms (Kohavi & Provost, 1998) for bio-contamination detection the complex reactions between multiple chemical and biological species (e.g. E.Coli with Chlorine) were modeled through the use of EPANET-MSX, an extension of EPANET (Rossman, 2000). The EPANET-MSX was used to analyze the Chlorine decomposition in the presence of E. Coli. The numerical simulations were found to be consistent with the experimental results of laboratory pilot model testing (Abdallah, 2015; Tinelli et al. 2017).

The water quality monitoring devices, used in the SUNRISE demonstration site, were found to be sensitive to environmental and operational conditions. A continuous observation of the devices as well as a regular maintenance of these devices and calibration re-adjustment is continuously needed. Data analysis requires crossing all the available data, recorded by the sensors, as well as the data related to the water usage.

An Artificial Intelligence based risk assessment model was developed (Tinelli et al, 2017) by integrating i) data processing of water quality parameters (e.g. chlorscan data or numerical data), ii) statistical tools, iii) artificial intelligence algorithms training, testing and validation, and iv) a GIS platform for spatial visualization of the bio-contamination likelihood propagation in the network. It yields a quasi-real time spatial variation of the likelihood indicator for early detection of bio-anomalies in a generic Water Distribution System (WDS) and the visualization of its spatial variation enable to identify the geo-localization of the bio-anomaly source. To improve the accuracy and efficiency of the anomaly detection and minimize false alarms Artificial Intelligence algorithms for signature recognition such as Support Vector Machines (SVMs) (Cortes & Vapnik, 1995) and Artificial Neural Network (ANN) (Girolami, 2002; Smola, 2004; Jafar et al., 2010) were used, adapted and demo-illustrated using a numerical database established from the EPANET MSX scenarios simulations.

This case illustrated that machine learning-based risk assessment methods are useful decision support tools for non-specific bio-anomaly detection and geo-localization. However the future development and deployment of AI based anomaly detection systems will require significant testing data under a variety of operational conditions in order to establish a reliable database for their site-specific calibration raising the challenge of data availability for bio-contamination in water distribution systems.

3.2 SICT Solutions for Water Network Leak Detection

Several leak detection and geo-localization systems and data analysis algorithms were developed and/or demonstrated in the demo-sites under a diversity of operational conditions. The main results are briefly presented below:

3.2.1 Vitens Innovation Playground (VIP) Demonstration Site (The Netherlands)

While District Metered Areas (DMAs) have become useful tools for detecting and locating leaks at a DMA scale, they are far from being a common configuration in the Netherlands. Six DMAs were created in the city of Leeuwarden by installing so called ‘measurement streets’: boundary mains containing 3 sensors that measure **flow** (into and out of a DMA), **pressure**, **conductivity** and **temperature**. The conductivity sensor is built into a PVC pipe and, together with the flow and pressure sensors, installed directly in the ground. The sensors have a wired connection to the roadside kiosk. The data is transmitted every 5 minutes and stored in a data historian.

Several algorithms were developed and/or demonstrated and the key points of their performance evaluation are briefly summarized below:

- KWR’s algorithm of Comparison of Flow Pattern Distributions (CFPD – KWR, 2014) – using on-line monitoring of flow data to recognize different types of changes through continuous comparison with the same timeframe data exactly one year before. The CFPD method (Van Thienen & Montiel, 2014) provides valuable insights into the state of the network, which enables to distinguish between different types of events. However attempts to apply the CFPD method for real time event detection have not been successful. Its reliable application requires integration of operational data and assets’ deployment (valves, flushing, etc.) records.
- VITEN’s Dynamic Bandwidth Monitor (DBM) – this forecasting algorithm for water usage in a District Metering Area (DMA) was developed to enable detection of any deviations and distinguish events (e.g. leaks, pipe bursts, flushing) from predictable water consumption changes (e.g. unmetered water flow between two DMAs, warm weather, holidays). The DBM filters the predictable events that can be correlated to similar events in neighboring areas and creates a real-time forecast by comparing for a specific timestamp the monitored data with the data of the past 12 weeks. It yields upper and lower thresholds and finally compares the actually measured water usage to the forecasted value. The DBM algorithm was implemented in an operational dashboard to be used in daily operations. Its deployment illustrated that in several cases, the DBM could support the detection of a leak or pipe burst several hours before a customer called or an operator detected the event, especially when leaks occurred in the night or when the water usage was predictable.
- KWR’s Flow Step Analyses - Flow Step Testing is a robust method of leak detection, which consists of closing and opening valves according to an established protocol to ensure that there are no sections without pressure at any time. The method was tested and proven very useful in one case where Vitens suspected a leak but was unable to locate it.
- Quasset’s Leak Localization Detection Algorithm - This algorithm was designed to detect (and eventually predict) sudden bursts. The leak localization analysis includes behavioral pattern analysis of the flow and pressure sensors throughout the DMA’s networks. However, at this stage, only one event was applicable for full analysis and further events field data are required for the assessment of this method.

3.2.2 Smart Water Innovation Network in the city of BurGos (SWING) Demonstration (Spain)

The leakage detection is based on 3 different algorithms, whose combination results in a likelihood assessment of water leakage within the demonstration site network. SWING demo site includes 3 out of the 26 Burgos City DMAs. 1,496 smart water meters have been installed in order to provide the demo-site with the appropriate equipment for leak detection and smart management. The assessment of several leak detection algorithms can be summarized as follows:

- Consumption Prediction Algorithm (CPA) - This algorithm was developed by ACCIONA to identify possible leakage using a predictive methodology based on a multiple linear programming model. It allows comparing the estimated flow within the DMA with the actual flow, warning of a possible leak if the difference exceeds the confidence interval. Its performance was evaluated by monitoring the hourly forecast error, illustrating that the error was less than 1% in the urban DMA (0.70%) during the first nine weeks of 2017.
- Other useful algorithms tested included Minimum Night Consumption Monitoring (MNCM) and Hydraulic Balance Algorithm (HB) designed to distinguish the causes for differences between incoming water and consumption by costumers in DMAs and thereby differentiate non-accounted water due to consumption and unaccounted water due to leakage.

3.2.3 Thames Water Innovation and Smart Technology (TWIST) Demonstration Site

The demonstration site is made up of four flow-monitoring zones (FMZs), split into 61 DMAs, which are bounded by closed valves or district meters that measure the flow of water entering and leaving the DMAs. The sensors installed included: 1 PipeMinder-T, 2 TrunkMinder, 14 Incertameters located in 4 DMAs, 17 Burstminders (PipeMinder-S) located in these 4 DMAs. Additionally, 3000 smart meters installed in household were available.

Thames Water distinguishes different kind of leakages: on the customer side and within the distribution network, operated by the water company. Automated Meter Readings (AMRs) are installed both at the edge of the curtilage of the property customer (underground) and also inside properties. In both circumstances, there are physical challenges to achieving reliable radio communication between the meter and a receiver. The algorithms used for leakage detection at a DMA scale included:

Customer-side-Leakage Discrimination Algorithm (CSL-CDA) – This algorithm is designed to analyze water consumption data from Automated Meter Readings (AMR) and to detect anomalous patterns, distinguishing CSL, for which the minimum night flow rate either remains constant or increases with time, from wastage, the pattern of which is more variable. Its accuracy was evaluated illustrating a satisfactory performance when challenged with a dataset of mixed CSL and wastage, achieving an 80% correct inference rate.

Aura BED alerts and data mining (University of Sheffield) - **AURA-Alert** (Mounce et al, 2014) was developed as an online service for SW4EU. The automated selection of training data is conducted by using n previous weeks in order to capture the current data profile at a network measurement point (for example the diurnal hydraulic pattern). This event detection system is adaptive, as it is retrained continually, at regular intervals and completely automatically, so that training is scalable and not subjective. AURA-Alert processes each time step independently. Therefore its output (of AURA-Alert) can be sensitive to isolated anomalous timestamps. As the water network operator is primarily interested in periods where many outliers occur in close temporal proximity a Binomial Event Discriminator (BED) was developed for aggregation of outliers to arrive at the probability of an event occurring for each time step. However its performance at this stage is variable with the system being able to detect up to 58% of known events on the network under certain conditions, but these conditions lead to a significant increase in false positives.

Syrinix algorithms (Mounce et al, 2017) – The PipeMinder-S and T, which measure and record pressure within the pipe, are capable of measuring up to 128 samples per second. They serve two purposes: i) Detection of pressure changes directly due to bursts and identification of transients induced elsewhere that pose a threat to the network; ii) Predicting the pressure at a PipeMinder using a number of PipeMinder sensors. The algorithm considers the differential arrival times of the transient (change in pressure) at one or more PipeMinder units. The field demonstration illustrated encouraging results, which warrant further investigation to enable a greater length of trunk main to be protected using the Syrinix algorithms.

3.2.4 SUNRISE Demonstration Site at the University of Lille (France)

The SUNRISE site represents a DMA unit model. The EPANET hydraulic model was used to create 3 virtual DMAs and establish a numerical demand driven database of the flow parameters using the off-line AMR data, which included both water supply at the inlets to the campus and AMR consumption data at the building connections.

The Smart Water System at Lille Demo Site is operational and used by the technical staff. Concerning leakage detection, all the components of the system (sensors, communication, software) work well. The system proved to be performing in the detection of water leakage at the Campus. The major problem concerned the communication system of some sensors, which required technical intervention. The system and data processing could yet be enhanced using machine method to recover lost data or to detect leakages at the buildings level.

Several leak detection algorithms were developed, tested and/or demonstrated, including an Artificial Intelligence Application for early leak detection and geo-localization.

An Artificial Intelligence based risk assessment model was developed (Mamo et al., 2014; Cantos et al, 2017) integrating: i) data processing of water flow parameters (e.g. AMR measured data, aggregated inflow and outflow through the campus network, as well as numerical flow velocity, flow and pressure data obtained with EPANET hydraulic simulations), ii) statistical tools to identify thresholds for leak likelihood assessment, iii) artificial intelligence algorithms training, testing and validation, and iv) a GIS platform for spatial visualization of the leak likelihood propagation in the network yielding a quasi-real time spatial variation of the color-coded likelihood indicator for early network leak detection and geo-localization.

The feasibility of using Artificial Intelligence algorithms for leakage signature recognition such as Support Vector Machines (SVMs) and Artificial Neural Network (ANN) was illustrated as well as their ability to evaluate the percent misclassification error and thereby reduce false alarms. The algorithm used, trained and tested using a numerical database, which was established through EPANET scenarios simulations on the SUNRISE demo-site, provides a rather reliable leak detection and geo-localization tool with misclassification errors in the order of $6^{0}/_{00}$ for the testing scenarios, when multiple pipeline parameters were considered (e.g. Flow, Velocity, Unit Head-Loss). However, the development, adaptation and reliable integration of such AI based leak detection systems will require a significant database represnting a variety of operational conditions.

3.3 SICT Application for Energy Optimization

The goal of this research is to identify SICT solutions and tools for reducing energy consumption when distributing drinking water to customers.

3.3.1 VITENS VIP Site

Vitens yearly electricity consumption is around 77,000,000 kWh. Its aim is to reduce its consumption of electricity in 2020 by 20% relative to 2010. The main contributor to energy consumption within the supply of drinking water is the continuously needed pump pressure within the network. The preliminary conclusions of the research conducted could be summarized as follows:

1. Water transport at a low pressure implies that customers should preferably not be connected to the transport mains during or after installation.
2. For the VIP site, using Dynamic Pressure Regulation based on instrumentation in the ‘capillaries’ could result in an energy saving of up to 8%. This requires process automation to prevent peak pressures, which may cause pipes to break.
3. In general, the distribution pressure within VITENS’ network is more or less based on “worst case” situations. Tighter control would allow VITENS to reduce the distribution pressures by 0.1 bar without leading to complaints.
4. The results illustrate that a customized approach needs to be applied for energy optimization per situation taking into account the dynamic balancing at the zone scale. Furthermore, the savings are not cumulative due to potential interdependency among the measures used.

3.3.2 THAMES WATER TWIST Demo-site
Thames Water developed an Energy Visualization Tool (EVT) to display the energy distribution within the water distribution system. The algorithm enables to estimate energy loss not only in the pipes but also at the demand points and display the results obtained on a GIS platform. It allows identifying highly energy inefficient areas due to unnecessary over-pressure and/or high frictional losses. More specifically, the tool is useful for detecting areas where pressure is lower or higher than required and hence for the assessment of opportunities for optimizing the energy flow balance.

Harvesting energy could be considered as an alternative when the reduction of pressure is not possible and therefore the energy is wasted. However, the cost and complexity are two important factors to consider.

The purpose of the companion demonstration project conducted by CALM Water using the off-line data of the SWING demo-site was to assess the feasibility and illustrate the development, adaptation and deployment of a GIS based algorithm, designated 'Power-Log' algorithm, for early detection and geo-localization of a power deficiency in the water distribution system as well as for its mitigation control. The results demonstrate the feasibility and conceptual development of the 'Power-Log' algorithm application for early detection and geo-localization of a power deficiency in the water distribution network.

3.4 SICT Application for Customer Interaction
The goal of this research is to promote SICT solutions for engaging public education initiatives and customer interaction. It involved VITENS and Thames Water.

3.4.1 VITENS
focused on two activities: i) development of an events dashboard and ii) interactive game to stimulate costumers to reduce water consumption.

VITENS Events Dashboard - a geographical events dashboard for the Central Operations and Dispatch Department (CODD) where real-time customer data (e.g. tweets and phone calls) and sensor data (e.g. pipe bursts and water quality events) were geographically displayed. Events can be detected more easily due to the combination of the data; i.e. suspected pipe bursts confirmed by customer phone calls in the same area. The events dashboard, which is currently used daily, has demonstrated its value in several cases and user experience is presently used for its development.

Waterbattle Game - An interactive game/app was developed based on the actual water consumption within households. Players could score points for reducing water consumption or using water outside peak moments. The aim was to make the customers more aware of their water consumption stimulating them to explore the feasibility of consumption peak shaving patterns, in order to reduce energy consumption and minimize CO_2 emissions. The two pilots of community engagement in the Waterbattle game and app. involved several schools, 485 children and 216 households.

This experience illustrated that the most active app participants have effectively modified their water usage behavior. Up to 60% of participants who had the monitoring system installed used the Water battle app. The app could contribute to behavioral change of the customers and the game, bringing together parents and children, seems to create a "social pressure" motivating the parents to adjust and minimize their water consumption

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3.4.2 Thames Water
has conducted customer interaction experience with installed Sensus 640 volumetric water meters at over 3,000 metering points around Reading SWING site. Thames customers were invited to participate in a scheme that rewards them with points for reducing the amount of water that they use on a weekly basis. Using smart meter data, customers' household consumption is compared to historical averages, and if the amount of water used is less than the average, customers receive points, which were available for various rewards, providing incentive to save water and educate oneself on water efficiency. The results suggest that a subset of households responded well to the incentives, however the larger majority did not see a consumption reduction. The benefit of the smart AMRs became evident as it enables near immediate notification of a likely burst or leak in the home, particularly when combined with actuated valves that can restrict flow into a household and may therefore significantly contribute to water saving goals.

4. Key Lessons

This case study demonstrated the high potential of SICT solutions for creating business cases of substantial savings and improvement of resource efficiency. It is expected that sharing the outcome of this case study will contribute to engage water utilities and policy makers in accelerating their deployment and thereby support the competitiveness of European SICT SMEs. The key lessons may be summarized as follows:

4.1 Water Quality Control
- Current practice of non-specific bio-anomaly detection can be optimized using both generic and specific sensors for monitoring and identifying the highest probability of the bio-anomaly/contamination or the change in water composition. The most critical task is to ensure real time reliable data pre-processing and quality control.
- As demonstrated by ACCIONA, Refractive index measurement is a useful generic indicator of water quality and can be used to monitor water quality changes. Eventlab could be combined with other sensors to better determine the nature of the changes detected.
- The water quality devices are sensitive to environmental and operational conditions. The experience led to some practical recommendations:
  - Use several water quality devices and make cross testing control of recorded data,
  - Conduct regularly monitored data comparisons with laboratory analysis and devices calibration re-adjustment,
  - Ensure regular maintenance and probe cleaning,
  - Share experience with sensors manufacturers and integrate the latest development;
- Data analysis requires crossing all the available data, recorded by the sensors, as well as the data related to the water usage.

This SUNRISE demonstration case also illustrates that machine-learning based risk assessment methods are useful decision support tools for non-specific bio-anomaly detection and geo-localization of their sources. The current results demonstrate the feasibility and benefit of such system in real time monitoring for early leak detection and geo-localization filtering false alarms. However their future development and deployment will require significant testing under a variety of operational conditions in order to establish a reliable database for their site-specific calibration raising the challenge of data availability for bio-contamination in water distribution systems.

4.2 Leak detection

Several data analysis algorithms were developed and/or their performance assessed in the four demonstration sites at a DMA scale.

These methods are developed to: i) enable detection of any deviations of flow patterns by monitoring hydraulic parameters (flow velocity and pressure), ii) distinguish events (e.g. leaks, pipe bursts, flushing) from predictable water consumption changes (e.g. sensor flaws between two DMA, weather changes, holidays etc.), iii) monitor variation of minimum night flow or comparing actual flow parameters with their historical time series to detect behavioral changes at a DMA scale (Montiel et al., 2013; Farah & Shahrour, 2017). Among these methods Consumption Prediction Algorithm (CPA) developed by ACCIONA to identify possible leakage using a predictive methodology based on a multiple linear programming model seems to provide a reliable leak detection tool with a forecast error smaller than 1% in the urban DMA (0.70%). The field demonstration of the pressure monitoring based Syrinix algorithm illustrated encouraging results, which warrant further investigation.

The feasibility of using Artificial Intelligence algorithms for leakage signature recognition and geo-localization, such as Support Vector Machines (SVMs) and Artificial Neural Network (ANN), was illustrated at the SUNRISE demo-site as well as their ability to evaluate the percent misclassification error and thereby reduce false alarms. The application of such AI based algorithms, integrated with statistical data analysis of spatial time series of the flow parameters (i.e. Flow, Velocity, Pressure) and a GIS platform for spatial visualization of the leak likelihood propagation in the network enables to pin-point and geo-locate the leakage pipe within the network. However, the development, adaptation and reliable integration of such AI based leak detection systems require a significant leakage signatures database under a variety of operational conditions.

4.3 Energy Optimization

The challenge is the continuous pump pressure management within the network. The tools developed and/or demonstrated focused on energy distribution visualization to enable identifying highly energy inefficient areas due to unnecessary over-pressure and/or high frictional losses. More specifically, the tools developed using a GIS platform have illustrated the benefit of detecting areas where pressure is lower or higher than required. Focusing on areas with high demand, gives opportunities to optimize the energy demand. The results illustrate that a customized approach needs to be applied for energy optimization per network attributes, situation, customers demand and other parameters taking into account the dynamic demand-supply balance at the zone scale. Moreover, savings are not cumulative due to potential interdependency among the measures used.

4.4 Customer interaction

The customers interaction experiences undertaken by VITENS and Thames Water illustrate the potential benefit of SICT deployment for public education using educational games and customer interaction measures to promote public awareness for water saving and reduction of CO_2 emission, which are among the core targets identified by the EIP and the UN SDGs.

5. Conclusions - Potential Impact of the Project Outcome

The SW4EU demonstration project provided and exceptional platform for the development and, more specifically, demonstration of State-of-the-Art SICT solutions developed by European SMEs. Dissemination of the results can greatly contribute to create intelligent business cases for accelerating the market penetration and deployment of these solutions in responding to current water industry challenges and growing customers concerns. They are also expected to encourage Government and Industry to mobilize the investments necessary to engage the development and testing of such innovative solutions in order to address the critical need for real-time preemptive rather than reactive drinking water systems management. Typical to innovation challenges this future development entails financial risks and further technical challenges, which has to involve:

5.1 Creation of a new market for smart water solutions

The project demonstrates innovative solutions for smart water solutions. This demonstration ensures cooperation of SMEs and water utilities in the value chain on jointly creating innovative and integrated solutions for water utility challenges (instead of a regular client-supplier relationship). The project was visible for relevant target groups through large-scale demonstrations. These aspects are vital to SMEs and will facilitate market uptake and stimulate the demand side of the market to adopt innovative solutions. The success of the project already resulted in a significant investment of an extension and replication of the Vitens demonstration site to a 5 times larger area called Friesland Live. Again, this will serve as a great example for SWN implementation and it is expected that more water utilities will follow.

5.2 Public health risk reduction, improved water quality and preemptive assets management

The successful demonstration of water monitoring technologies results build the case for paradigm changing of water utilities from laboratory analyses, which is reactive by its nature, to preemptive Smart Water Management using online sensors. Online water monitoring enables water utilities to react earlier to water quality events, thus reducing public health risks, and undertake preemptive leakage management, thus reducing pipe bursting risks. SWM practice will therefore contribute to improve service reliability, effectiveness, safety and sustainability leading to customer appreciation of the upgraded performance of the water service.

5.3 Change of investment approach

The project has proven that the implementation of Smart Water Networks results in more than just financial benefits. While a fully executed transformation of a whole network to a SMW might even cost more than the direct short term financial benefits other benefits and long term impacts on service performance, safety and sustainability are expected to be generated, which may significantly affect customers reaction towards such modernization efforts. For example, improved customer interaction in the water system management, as an involved 'human sensor' to detect water quality anomalies or leakage, incentives for reduced peak consumption or other information based customer interactive anomaly mitigation measures could contribute to a new cost effective business model(s). Secondly, the increase in customers' knowledge about the distribution network, its performance and weaknesses would gain insight in optimization its management and ensuring the security, safety and sustainability of the network. Investors believe these benefits will strengthen their position in the future and would contribute to a resilient strategy of the drinking water network with respect to climate change, increase in population and protection with regards to terrorism and/or natural disasters.

6. The Next Step

The demonstration of the selected SICT solutions under real operational site conditions enabled the SW4EU project to support business cases for the selected applications and promote their deployment through outcome dissemination of the project results. With an estimated savings potential of about € 10 billion worldwide annually (source: Sensus; Water 20/20, Bringing Smart Water Networks into Focus) Smart Water Management is a major challenge for society and offers an enormous market potential to industries and innovative SMEs. As the water networks face rehabilitation challenges over the next 10 – 30 years, with an estimate of approximately €20 billion/year needed in Europe to upgrade the distribution networks, smart health monitoring of the water networks becomes essential for the risk-based prioritization and optimization of the required investments.

Integration of SICT solutions in engineering and management practice of drinking water systems is critical today as it is essential to move towards preventive management of aging infrastructure; cost efficient upgrades to improve the reliability, safety, security and sustainability of the complex urban networks; interactively integrate consumers in the management of water demand to address growing climate change impacts; and promote public education and awareness to support the required modernization and upgrade of the water distribution systems.

It is therefore imperative that European governments and water utilities support innovative European SMEs in the future developments, demonstration and reliable integration of SICT solutions in engineering and management practice of drinking water systems. Towards this goal the next step of the follow up on the SW4EU outcome is expected to involve:

- Integration Feasibility Assessment and Adaptation studies, under operational conditions, for early deployment monitoring in 'beta' sites of water utilities of the SICT solutions demonstrated in the SW4EU project, as well as other SICT solutions becoming available;
- Public education and awareness building to interactively integrate the consumers in the management of the water demand towards new business models and public culture that supports innovation and understands its strategic and operational needs;
- European governments' commitment through regulations that will effectively support SICT innovation and promote its deployment to address growing public concerns, accompanied by the development of industry driven functional and operational standards;
- Follow up EU sponsored SICT demonstration projects co-sponsored by the Industry, at a 2-3 years frequency, to provide a continuous demonstration platform for innovative solutions;
- European support to innovative SMEs competitiveness by stimulating the market growth for upgrading the efficiency, quality, reliability, safety and sustainability of the water systems;
- Industry-Universities Research and Development (R&D) partnerships to continuously engage the development and demonstration of innovative SICT solutions and professional education of future water experts to support and accelerate their integration in engineering and management practice.

By moving forward in this way we anticipate that SICT solutions will significantly contribute to improved water management approaches in Europe and around the world.

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Appendix

Links to the Sustainable Development Goals

The SW4EU Project and solutions provided by the project also provide links to SDG goals 6 (clean water and sanitation), 7 (ensure sustainable energy for all), 9 (resilient infrastructure and sustainable industries), 11 (sustainable cities and communities), 12 (sustainable consumption) and 13 (climate action). The targets linked to the project are listed below in Table 1.

Table 1. A list of the SDGs and their specific targets that relate to the SW4EU Project

Sustainable Development Goals and Targets	
SDG 6: Clean water and sanitation Ensure availability and sustainable management of water and sanitation for all	
6.1	By 2030, achieve universal and equitable access to safe and affordable drinking water for all
6.4	By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity
6.5	By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate
6.B	Support and strengthen the participation of local communities in improving water and sanitation management
SDG 7: Ensure sustainable energy for all	
7.3	By 2030, double the global rate of improvement in energy efficiency
SDG 9: Build resilient infrastructure and sustainable industries	
9.4	By 2030, upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries taking action in accordance with their respective capabilities
SDG 11: Sustainable cities and communities Make cities and human settlements inclusive, safe, resilient and sustainable	
11.B	By 2020, substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change, resilience to disasters, and develop and implement, in line with the Sendai Framework for Disaster Risk Reduction 2015-2030, holistic disaster risk management at all levels
SDG 12: Ensure sustainable consumption and production patterns	
12.3	By 2030, achieve the sustainable management and efficient use of natural resources
SDG 13: Climate Action	
13.1	Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries

Samuel Zeller

CHAPTER 3. Discussion and policy recommendations

Contents

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3.1 Core elements of Smart Water Management

The broad benefits of SWM projects are made clear by the case studies in this report (see Box 1). While financial investments in most SWM provide medium- to long-term financial returns, non-financial benefits such as environmental, social, governance and technical benefits are all seen within the short-term and should be equally valued as a return on investment, as evidenced in most of the case studies in this report. Many of the activities that utilize SWM relate to improving water quality, access and efficiency, which have a significant role to play in reaching the Sustainable Development Goals (SDGs). Other activities utilizing SWM focus on ecosystem protection, planning and decision-making for increased climate change resilience, which will improve the environment and livelihoods for the people living in rural as well as urban areas.

Box 1. Benefits of Smart Water Management Implementation

Social benefits

- **Access to clean water and sanitation** through water treatment and monitoring
- **Health improvements** through increased access to clean, safe water
- **Improved livelihoods** through job creation, greater opportunity for further education, higher productivity and other opportunities
- **Increased training and capacity building** for the local community and staff
- **Increased sharing of solutions** to support sustainable development
- **Increased decision-making opportunities** through increased engagement and knowledge-sharing
- **Greater collaboration with community** through engaging with local stakeholders at the beginning of the project
- **Greater security** by improving water security and increased resilience to climate change
- **Increased trust** in water suppliers and the safety of water sources
- **Improved access to data and information** through real-time data sharing with all water users
- **Increased gender equality** through increased opportunities for capacity building and further education
- **Reduced conflict over water access** leading to increased trust and willingness to engage in collective action

Economic benefits

- **Increased efficiency** in irrigation systems and wastewater treatment systems
- **Reduced waste** by the reduction of water loss through leakages
- **Job and opportunity growth** through job creation through SWM project research, design, development and implementation
- **Improved capacity** in water systems improving their capacity to manage flows and reduce damage during storms/floods
- **Reduction in future infrastructure costs** by integrating smart technology tools to improve capacity/efficiency, resulting in less need for additional infrastructure
- **Mobilisation of funds** from public and private sources, as well as international funding sources

Environmental benefits

- **Improved water quality** through reduced pollution and contamination in waterways
- **Improved ecosystem health and protection** through improved water quality and quantity
- **Reduction in groundwater depletion** through reduced over abstraction
- **Reduced land degradation** through flood and drought management and reduced nutrient loss in the soil

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- **Reductions in CO_2 emissions** through energy optimisation and reduced energy consumption
- **Reduced water consumption** through leak detection and reduced demand and increased reuse

Governance benefits

- **Improved management and knowledge,** as measurement is critical for effective management
- **Improved accuracy of data,** as real-time data should also be SMART (specific, measurable, actionable, relevant and time-bound) data
- **Increased community-led decision-making opportunities** as water users can make decisions based on real-time water use and information
- **Improved transparency** as water users have access to water use and quality in real-time

Technology benefits

- **The opportunity to test and develop** new and innovative tools for water management
- **Innovative technologies created** with the potential for commercialization
- **Identification of the remaining gaps** in technology adoption (e.g. standardisation of software and tools to make it easier to adopt the 'right' mix of tools for each situation
- **Showing the potential for SWM tools** to deliver successful outcomes and in turn lead to significant social, environmental, governance and financial impacts

A common thread across all SWM projects in this report is the need for infrastructure such as integrated systems, sharing of automated data and collaborative decision-making and learning processes. This applies to rural and urban areas in both developing and developed countries. However, as each country and region has its own context, and as institutional or industrial end-users require a different approach to individual end-users such as households or irrigators, a one-size-fits-all approach is not suitable for Smart Water Management. Instead, each region must assess how smart technologies can support them to better protect their water sources, to improve efficiency and to help to build resilience for the future. To assist with this, each region needs to select the appropriate policies for its own situation to drive and support SWM implementation. The research, development, testing and maintenance of SWM systems should be a priority for both public and private investments, with the government and institutes particularly able to support successful SWM in a number of ways.

3.1.1 Environmental factors

Most of the projects included in this report began with a shared desire among the government, civil institutions and the people living in these regions to improve human interactions with natural resources, including water, land and energy. Across the case studies, government policies and regulations put in place to improve water quality standards, protect groundwater resources and improve efficient use of water have acted as a driver for these projects to adopt innovative measures to protect the environment.

These case studies have demonstrated examples of environmental indicators that have resulted from collaborative efforts among governments, municipalities, research institutions, local agencies and communities, farmers, industry and the private sector:

- Significant improvement in water quality (e.g. Paju, France, Mexico, Canada, SW4E)
- Ecosystem protection (e.g. France, Canada)
- Reduced land and soil degradation (e.g. K-HIT, Africa, China, FDMT)
- Efficient energy consumption (e.g. SW4E, China, Canada)
- Flood management (e.g. K-HIT, Canada, SW4E, FDMT)
- Drought management (e.g. K-HIT, FDMT)
- Groundwater protection (e.g. China, Canada)
- Efficient use of water resources (e.g. Africa, Seosan, France, China, SW4E, Mexico)

This shows the potential for policies to support the protection and restoration of our environment and natural resources through Smart Water Management projects such as the ones shown in this report.

3.1.2 Economic factors

In many of the case studies, long-term investment in SWM led to a higher chance for successful implementation of SWM projects and increased benefits, including benefits that are both financial (e.g. increased efficiency and job opportunities) and non-financial (e.g. improved water quality, building trust in the community and opening opportunities for collaborative decision-making).

Support from governments and institutions (such as universities and international agencies) was also shown to be essential for many of the projects, which relied on initial financial inputs to support research, development, testing, technology acquisition and implementation. As SWM technology is a relatively new field, the evolving nature of SWM tools also leads to projects upgrading existing technology as it becomes available, requiring secure sources of funding. As shown in many of the case studies, financial return on investment is likely to occur in the medium-term (e.g. in Paju Smart City the recovery period is anticipated to be achieved in 8 years). Despite this, short-term return on investment is possible, as seen in Africa where investments in monitoring tools provided noticeable financial benefits to irrigators within one year. For projects that require medium-term cost recovery, as often seen within the water sector, short-term non-financial benefits (see Box 1) play a key role in securing the interest in SWM implementation and replication. With banks and governments focusing on short- to medium-term budget cycles, this is a challenge that must be considered.

Future cost saving was also considered a key driver for many of the case studies, as integrating SWM technologies and systems into current infrastructure enabled many of the projects to reduce future augmentation/investment in new infrastructure. By supporting the existing infrastructure with SWM technology the Paju and Mexico cases were able to reduce future augmentation costs, and by integrating the current systems together SIAAP (France) was able to both increase cross-sector network decision-making and avoid significant future capital costs. In the case in Africa, by adopting SWM tools and an innovative governance scheme (the AIP), water extraction was significantly improving overall supply reliability and easing the pressure on existing infrastructure and reducing conflicts over water access increasing the willingness to pay for water and participate in maintenance work. In the Flood Drought Management Tools (FDMT) case, SWM tools were used to assist water users and decision makers to develop resilience plans to manage/avoid future risks caused by floods and drought, reducing the future impact and costs of future land degradation and disaster management for local communities and agencies.

Job creation and increased opportunities were noted in several of the case studies, with new roles being developed both in the design and implementation phases of the SWM technology and systems. In the case of Paju, the project led to the creation of a new 'Clean Water Environment Project Team', which included a total of 98 workers working in waterworks, sewerage, environmental facilities and cityscapes. The Paju Smart City project also involved the hiring of a local construction company, resulting in 238 jobs in water related fields being established during the duration of the project. Other projects saw reductions in the time required to work (e.g. through increased irrigation efficiency), however as the profit remained the same (if not increased) this reduction in work lead to increased opportunities to use that time for other activities, including further education and training. In agencies such as the SIAAP, major teams are dedicated to the development and management of the SWM systems, creating new roles providing opportunities for staff to increase their capacity in research and opportunities to discover and develop new and innovative SWM solutions for water management.

Strong business models were also shown to be important to ensure the uptake of tools and to improve the potential for replication and scalability possibilities. For example, the Africa case team were aware that despite the positive outcomes already seen in the project, distribution of free equipment to farmers does not guarantee longevity of use and continuing impact. In the Canada case, the current business model has faced challenges as it involves high costs for individual systems (with limited financial return on investment for users, at least initially), resulting in an inability to scale up despite the potential for the technology to have a strong environmental, governance and social benefits. Hence, developing a strong business model that can sustain the production and implementation of the tools will be the focus for both of these cases in Phase 2 of the African project. Collaboration with governments and industry, and developing co-payment schemes, are two options that can lead to improved business models to ensure the longevity of the projects and to enable the possibility of replication and upscaling.

Finally, most of the case studies indicated a high level of cooperation among the public and private sectors, institutions, and individual interests to adopt SWM technology. While additional policy support will only strengthen the value of the contributions from each sector, partnerships among all stakeholders, especially local agencies and community, are essential for the successful adoption of SWM strategies.

3.1.3 Social and community factors

The benefits of SWM go beyond increased access to, and improved efficiency and quality of, water. The social and community benefits associated with these outcomes are significant. By increasing access to clean drinking water and sanitation, communities in rural and lower socio-economic areas are provided with the equal rights to basic services, improving health and well-being in the community. By increasing irrigation efficiency, farmers in Africa have more time for other opportunities. As irrigation is predominantly the role of the women in the family, this opens up the potential for women to have greater access to further education and to consider other work opportunities which are of interest to them, bringing more equality into the farming practices in Africa. By increasing the quality of water and the information provided on the quality of the water, communities begin to gain trust in their water suppliers and governments, resulting in changes in behaviours from relying on bottled water to drinking tap water, significantly reducing the costs for the community for drinking clean water.

In addition to these benefits, SWM can support communities with awareness raising, learning/education and decision-making. This can be done through information sharing tools (e.g. Canada, Mexico, Paju), education tools (e.g. Africa) or decision-making platforms (e.g. FDMT, China). By increasing the awareness in the community about water-related challenges, it opens up the opportunity for them to make decisions based on this information, and to act accordingly. This increases the trust placed in the community and the role that individuals play within their community to work together to resolve these water challenges. By enabling communities to contribute in this way, trust builds and motivation to support implementation and adopt new ideas/technologies is secured. By involving local stakeholders, solutions for the fair use and allocation of water can be reached more easily.

SWM tools can also be used for learning, as seen in Africa, where farmers were encouraged to test and understand the equipment themselves to identify the patterns they were seeing. This led to their increased understanding of their land and water resources, which enabled them to make decisions based on what they had learned, instead of acting based on information provided to them. This builds capacity, knowledge and skills in these communities, where farmers can now better understand how to get the best results for their farms while still protecting their natural resources. Other areas where capacity building has benefited from SWM tools include the transboundary basin project in Africa and Thailand, where SWM tools assist in building the capacity of local agencies to plan for and adapt to the changing climate. This builds resilience in areas where climate change will have some of the greatest impacts. Involvement of local communities in SWM approaches improves the environment and livelihoods, and encourages social cohesion and resilience.

3.1.4 Innovation and technology factors

SWM technological solutions can increase water availability through water savings (e.g. increasing efficiency and detecting leaks), and increased water quality (through contamination control). They can improve the environment through flood and drought management and ecosystem protection. They can improve livelihoods and opportunities in local communities through reducing costs, building trust, and increasing engagement and decision-making potential for users. In addition, innovation and new technology can also create business and job opportunities.

A wide range of SWM technical solutions are available to support these changes, including water quality monitors and sensors, efficient irrigation systems, groundwater modelling, satellite data for forecasting and planning, GIS mapping, sensors and controls for leak detection and reduction, rainwater cisterns for the reduction of stormwater, (sub) district metering areas for increased accuracy of data, energy optimisation tools, and engagement platforms to support water user decision making. Each of these tools can be used to address current water challenges in regions trying to implement water demand/consumption management, improve water and sanitation quality, plan for the changing climate/increase resilience, improve community decision-making and build trust in the community.

To better support the implementation of SWM technology, several key factors for success are addressed throughout these case studies. These include:

- long-term investment to ensure research, development, testing and implementation can be completed successfully;
- external funding support to enable projects to be successfully implemented in the short-term; value placed on non-financial benefits of SWM technology (as described above);
- policy support for standardisation of technology systems to ensure all technology and its software is compatible to enable users to build the 'right mix' of tools for their context;
- transparency of new technology updates to ensure users can choose the right time to invest;
- improved business intelligence awareness to shift water utilities and users from traditional approaches to data sharing and integrated systems.

These changes can be addressed though improved policy support, regulations and cross- (and within) sector collaboration and engagement.

3.1.5 Governance factors

There are many aspects of governance that can benefit from increased data and knowledge sharing. With measurement playing a critical role in effective management, improving the accuracy and access of data can provide new opportunities for governance and community-led decision-making. Smart technologies also offer improved transparency as water users have access to water use and quality in real-time, allowing for decisions to be made based on current conditions. Governance and policy factors are discussed in more detail in section 3.3.1 below.

3.2 How to adopt the lessons learned from the case studies

Case studies are interesting and often inspiring examples of what works in a particular region within a particular context. They can also be used as valuable lessons for policymakers interested in further supporting the causes presented. A brief analysis follows highlighting how policymakers who are motivated to support SWM may wish to move forward. It is important to note however that every project and context is different, and therefore replicating a project exactly as it has been done in other regions without adapting it to local conditions nor gaining local stakeholder support and engagement is not recommended. There is no one SWM technology or solution that will solve every challenge. Instead, SWM technologies should be considered as a range of options that can be adopted and adjusted to suit the needs and challenges of each situation.

3.2.1 Possibility of scaling up or down

Many of the projects shown within this report (e.g. Mexico, Canada, SW4EU, China) have started on a smaller scale with the aim to scale up as the benefits were shown and more participants showed interest to come on board. In the African project the SWM tools and processes were piloted within six schemes in three countries with the intention to scale out and up once the tools have been taken to proof of concept. E.g. in the Africa case proof of concept was achieved in phase one which generated funding for the out and upscaling in phase 2.

To enable the scaling of projects both up and down, once the technology has been tested (i.e. when the results and benefits have been seen), the government should support projects to extend their projects to other areas/regions to test out the possibility of replication and scaling. International organisations can also take lessons learned from pilots and test them in other areas and countries to support cross-nation knowledge sharing and solutions, while NGOs can assist in sharing information and knowledge about these projects to support future implementation.

Some of the larger scale SWM projects (e.g. France) are quite ambitious and have been implemented over a long timeframe. Therefore, the complexity of such large projects should be taken into consideration when considering replication. It is recommended those interested in implementing similarly advanced projects seek advice from/consultation with the project managers of the original projects to gain a better understanding of the exact approach taken and what might need to be adapted to implement it successfully in your region.

As the implementation cost of SWM projects can be high, in many cases it might be considered best to start small and scale up as successes are seen. However, as shown in the Canada case, starting too small can lead to reduced government support/funding, as legitimacy of smaller projects is not as evident as in larger projects. Therefore, it is best to ensure that the scale of the pilot will provide sufficient benefits can be shown during the pilot phase, to attract sufficient support for ongoing success and up and out scaling.

3.2.2 Possibility of replicating in the same or similar regions

As demonstrated in the Mexico case, replication in the same or similar regions is not always simple. Even within a short geographical distance, considerable differences (e.g. socio-economic, infrastructure, policy support) can occur completely altering the context in which the initial project succeeded. To address this, collaboration is needed between the organisations implementing the project and governments within the original implementation region and the receiving region to ensure that technology and skills transfer can be seen in regions where it is needed most. In contrast, projects that have been successful in a particular country or region may be easily adopted in similar regions (e.g. Africa, FDMT, China) although, this will depend on the interest level and support from local stakeholders and decision-makers, including the community. Major SWM infrastructure (e.g. France) could be replicable in other major cities of a similar development status, with the right support and guidance (and if given the same amount of time to implement it properly).

3.2.3 Transferability to different regions

While transferring SWM solutions across regions presents more complexity than within regions, it can be achieved. This has been demonstrated by K-water who are currently replicating their Seosan project in Bali, Indonesia. Despite the circumstances of both regions being vastly different, K-water have partnered with the Indonesian government to ensure on-going policy and financial support to drive interest in the project. Creating this kind of transfer can be challenging, however by engaging the right stakeholders early in the project and with policy support and accessible resources, it is possible to transfer SWM projects across regions.

3.2.4 Conclusions

Each case study has its own specific context, based on its scale, geographic location, policy support, socio-economic status and the water challenges faced. While it is important to recognise the context of these project successes and challenges, with the right political commitment, stakeholder engagement and enabling conditions these projects can act as examples for other regions interested in replicating the benefits seen using SWM technology.

3.3 Proposed policy recommendations for successful SWM implementation

Throughout these case studies the importance of political support has been evident. This has been through both regulations ensuring targets for improved water quality, access or efficiency were achieved, or policy support for providing increased funding and resources to agencies looking to develop innovative solutions to water challenges. It is therefore important to reflect on policy as a key driver for successful SWM implementation, and to provide a direction for policy makers to move towards to support future SWM implementation in both developing and developed regions.

3.3.1 Overview: Policy, planning and governance

The following factors were key elements to the successful implementation of SWM in many of the case studies:

- **Long-term investment from outside funding** (both governmental and institutional) as it allowed on-going research, development and testing of new technologies
- **Funders valuing non-financial short-term benefits** (e.g. environmental, social, governance, and technical benefits) of SWM, with the awareness that financial-benefits (return on investment) can be seen in the medium- to long-term (i.e. willingness to pay was high from supporters) (e.g. France and Mexico)
- **Engaging within and outside of their sectors/institutions** to implement a collaborative project/network, including the sharing of data and capacity to improve outputs
- **Support from the top-down** (as well as engagement from all stakeholders and levels) enabled the enthusiasm of the project to continue throughout the development and implementation stages
- **Promoting the potential for SWM** to reduce the need for additional infrastructure (e.g. France)
- **Engagement and collaboration with all stakeholders** from the beginning, especially local agencies, of the project to ensure the complexity/context of the project was well understood and all stakeholders are on board with the SWM implementation and decision-making
- **Policy and government support** and incentives/regulations to drive the project
- **An understanding that SWM technology approaches vary** depending on who is implementing the tools (i.e. institutions, individuals or mixed), with additional support (e.g. engagement, governance or business models) required for successful individual adoption
- **Trust built in the community** through the use of and engagement with real-time data improving awareness of water conditions, decision-making and positive behaviour change (e.g. Mexico, Paju)
- **Building strong business models** and creating new jobs and opportunities for the water users and community
- **Using a two-pronged approach** to SWM by including engagement tools, governance networks and business models to strengthen the potential for successful long-term SWM implementation

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- **Training and capacity building** for locals to ensure on-going successful management of the SWM tools and systems
- **Short-term results** (e.g. reduced water consumption, increased water quality, more efficient management, reduced conflicts over water access) lead to more enthusiasm for continued SWM implementation

Cross-cutting challenges faced by the case studies included:

- **Lack of standardisation** of SWM technology, leading to users being restricted to technology from the one manufacturer
- **Technology evolving rapidly** so it is challenging to know when there is a new technology coming out that might be better suited to their context
- **Time delays and loss of data** when stakeholders were not willing to share information/ data or community/water users were not supportive of the project (due to lack of initial engagement)

Based on these findings, Table 1 presents a suggested policy framework for successful SWM implementation.

Table 1. Policy recommendations for Smart Water Management implementation

Strategies	Policy direction
SWM for an improved quality of life (Society)	**1.** Facilitate adoption of SWM tools, especially in developing countries, to support access to basic services, and to support equality for poverty reduction, public health and quality of life. Include capacity development, technology sharing, collaborative business models and community governance and decision-making opportunities.
	2. Build trust and community engagement using SWM tools in areas where the community feel unsafe using the local water sources
	3. Empower people in developing countries with smart tools to reduce the time spent on water management and increase farm income and time available for other activities (e.g. further schooling, and additional work opportunities)
Investment in SWM for improved resilience and sustainable development (Economy)	**4.** Strengthen collaboration across and within sectors to provide opportunities for networks to share information and data to assist with effective and efficient water management
	5. Value non-financial benefits (e.g. environmental, social, governance and technical benefits) as equally important as financial benefits for SWM implementation, as they contribute to building resilience to the effects of climate change and increasing populations
	6. Support long-term investments for SWM implementation to enable adequate research, development and testing
SWM for protecting and conserving water resources and ecosystems (Environment)	**7.** Introduce policies, regulations and incentives to drive environmental and ecosystem protection through use of SWM.
	8. Encourage SWM solutions to increase water quality, manage demand and use, water reuse, reducing groundwater depletion and increase energy efficiency, etc.
	9. Introduce SWM solutions for climate adaptation plans for flood and drought planning and management and major storm events
Support evolving smart technology development and adoption (Technology)	**10.** Develop standards to ensure all SWM technologies are compatible (can communicate) with each other to enable tools to be purchased across various suppliers to enable those implementing SWM to create the right set of tools for each context
	11. Support on-going research, testing and development of SWM tools to advance them to a point where they are robust and require minimum maintenance and are ready to be commercialized (Government policies that support taking SWM tools from R&D to market)
	12. Support technology to assist in regions without built infrastructure or the adequate resources (e.g. electricity), as currently SWM infrastructure is (almost always) reliant on built infrastructure
Building capacity and networks for increased resilience and collaboration (Governance)	**13.** Empower people, especially those in developing countries, by providing them with SWM tools, data and capacity development and education to enhance/support local decision-making
	14. Strengthen the capacity to adapt to climate change by adopting SWM planning and operational technology
	15. Plan for water disasters in advance by creating proactive policies instead of reactive policies

Box 1. Smart Water Management Implementation Types

Implementing SWM technology by itself will not always resolve the water challenges faced by a project. In some cases, a two-pronged approach is necessary to address the complex nature of each challenge. The second element of the two-pronged approach can include community engagement, governance schemes, learning processes and business models, and is equally as important to the success of many of the projects as the SWM tools themselves.

Based on the case studies presented within this report we have categorised SWM technologies into three different types depending on who is using/adopting the technology. Each type requires a different approach to ensure the technology achieves its potential benefits.

Type 1 – Institutional users

Type 1 addresses technologies aimed at major institutional users such as water suppliers, water managers, mines, water treatment plants, etc. (e.g. France, K-HIT, China). The implementation of these technologies is mostly straightforward as industries and utilities can be encouraged to adopt SWM through incentives (improving efficiency, environmental benefits) or drivers (meeting regulations or targets) introduced by governments or the agencies themselves. Regulations and policies that encourage these institutions to develop and implement SWM technologies are relatively easy to introduce (depending on the government), and the institutes will more easily fund the necessary research (often with government support) to develop and successfully implement SWM.

Type 2 – Individual users

The second type is the technologies aimed at a large number of individual users such as household users and farmers (e.g. Africa and Canada). These are far more complicated to implement, as they require a very large number of individuals to change what they are doing, and they do not often respond in the same way to economic incentives. Often the main benefits are to the society at large, rather than the individual. The savings from introducing smart technologies in homes might be small compared to the cost and inconvenience of adopting it, however the total impact might be significant and therefore the societal benefit high. In this second type, a two-pronged approach is more critical in order to see a total societal benefit.

Type 3 – Institutional and Individual users combined

The third type involves a combination of both the institutional and individual user. This is seen when an institution develops and implements the SWM technology but the success of the technology partly relies on the individual user (e.g. Mexico and FDMT). This approach requires some engagement, but is less dependent on a second-prong than Type 2, due to the implementation being conducted by the institution.

3.4 Economic lessons: Ensuring support and investment for SWM

3.4.1 SWM as a long-term investment

Projects with long-term government, industry or institutional support and investment appear to have the best chance for on-going success in SWM implementation (see France, K-water, SW4E, China, Africa case studies). One reason for this is the time required to successfully implement SWM. In the case of France, it took 20 years of investment in research and engineering in the field of real-time control to implement the MAGES system. Other projects required 3-10 years for development, with many considering it an on-going process. This shows the importance of allowing time for on-going research, design, development and testing, and providing the opportunity to innovate as technologies evolve. This is especially important for large-scale projects that involve integrating SWM technology with current technology, infrastructure and networks.

As it is an emerging field, SWM technology and tools are rapidly changing. This necessitates ongoing research and development to ensure the best tools are used for each context and challenges faced. By encouraging on-going long-term funding, it allows the evolutionary nature of SWM technology and tools to be an advantage instead of a disadvantage to any SWM project. In contrast, the projects provided with limited or short-term funding and government investment (e.g. Mexico) show excellent initial success, but begin to face difficulties when looking to replicate in regions where the benefit could be even greater, as increased resources (both financial and human) are needed for research and to invest in new technology and maintenance of the current technology.

In the early stages of any SWM project, funding for maintenance and adjustments is required (including funding for staff and the training required to upkeep the technology). This can be an unexpected additional cost for some projects (see Mexico), and therefore should be included into the initial budget. Despite the initial maintenance requirements of SWM technology, it is expected that as more projects test and adopt SWM technology in different contexts, the technology and systems will continue to advance or evolve to a point where they become more robust and require less maintenance. Longer time frames also provide greater opportunities for stronger stakeholder engagement (which has been shown to be one of the keys to successful SWM implementation) and for long-term impact assessments. While developing and adopting a new SWM system can take time, innovative solutions can result in significant change (e.g. see Africa) in more areas than just sustainable water management (see links to the SDGs).

For projects that are independently funded (e.g. Canada), limited financial resources and support can become a barrier to implementation, as long-term financial input is typically required to test ideas on a large scale. Without this support the successful implementation and demonstration of the potential for the technology is hindered. This highlights the importance of government funding, which often has the opportunity to provide long-term support.

3.4.2 Outside funding support for successful implementation

Due to the medium- to long-term nature of successful SWM project implementation, most projects relied on funding from either governments or institutions to ensure the successful implementation of their projects. This government support and investment also played a major role in ensuring short- to medium-term financial return on investment. For example, in the Seosan Smart City case they will see the return on investment in 8 years, while other projects may rely on longer-time frames to see the financial benefits.

Government funding came from both municipal (e.g. Seosan city) and central budgets (e.g. Seosan, France and China), through drought budgets, water management plans and ministries. This funding was predominately provided for research and development, technology investment, operating and maintenance costs to be used within the region it was provided for.

Institutional funding came from a range of sources (e.g. universities, national research agencies and international funding bodies). This funding was provided with a stronger focus on research, innovation and understanding how SWM could work to address various water challenges, with the aim to share knowledge and to replicate/upscale the project to other regions where the needs were equal or greater (e.g. Africa, FDMT, SW4Europe and Mexico). Financial support is also appreciated as large-scale demand or production of smart meters (and other smart technology) has not yet been achieved in some countries, and therefore the production costs are still currently higher than traditional water technology. As with any technology however, as interest in/demand for SWM technology increases, it is anticipated that economies of scale will reduce the production and installation costs of SWM. This is already the case in Korea, where large-scale water facilities are planning to update their traditional water systems with smart technologies, increasing the demand rapidly.

3.4.3 Cost recovery

While early input costs occur, a financial return on investment is likely to occur in the medium to long-term, as water costs reduce (e.g. through identifying and reducing non-revenue water, reducing consumption, and improving efficiency), or as water prices are increased slightly to recapture costs (e.g. K-water). In addition to this, like most technologies, once smart tools evolve and the market expands, costs will likely decrease and there will be more opportunity for short-term cost-benefits of SWM to be seen.

In terms of recovering costs through reduced water tariffs, it was acknowledged that for some countries (e.g. Mexico and Korea) the tariffs for tap water are often quite low (or in the case of UNAM zero) and therefore reducing the water use in these countries does not necessarily lead to reduced costs in the short-term. However other benefits, such as reduced infrastructure costs in the future will result in financial benefits. Despite the delay on the return of financial investments, each of the case studies appears confident that SWM was the right decision for them and that it will pay off in numerous ways, including financially, in the future.

3.4.4 Moving beyond cost benefit analysis when assessing the value of SWM

Despite the initial financial deficits seen in many of these projects, the funding bodies supporting them are willing to invest in SWM due to the other benefits it achieves, such as improved quality of life, natural resource protection and climate change adaptation (e.g. Paju Smart City). In the case of Paju the government realised it was more important to have indirect benefits (e.g. reduced bottled water consumption and increased community health and well-being), than to have short-term direct financial benefits.

Many of these projects have shown the importance of moving beyond a cost-benefit analysis approach to determine whether SWM is a sound investment. In the France case, there has been no assessment as to whether a financial return on investment has been achieved at this stage, due to the on-going investment in evolving technology and maintenance. Despite this, the non-financial benefits (e.g. increased efficiency, capacity, data availability, collaboration and decision-making capabilities) and impacts (e.g. safer water for the greater Paris region and ecosystem protection) have been strong enough drivers for SIAAP to actively promote the continued use of SWM as the core of their operations.

This has been shown in the other cases as well with non-financial benefits including:

- Increased community awareness and decision-making opportunities for water uses (e.g. Mexico, Africa, FDMT)
- Improved customer satisfaction (e.g. Seosan, SW4Europe)
- Improved water quality, natural resource management and ecosystem protection (e.g. Mexico, France, Canada)
- Reduced land degradation (e.g. FDMT, China)

- Increased food productivity and capacity for planning and resilience to climate change (e.g. K-HIT, Africa, FDMT)

For projects where it is likely that short-term returns on investment could be seen (e.g. Africa), it is interesting to note that this has not been the focus for assessing the success of the project. Instead increases in productivity, efficiency and increased decision-making capacity have been the strong drivers for the project to continue. With this in mind, sustainable return on investment may be a better measure for these projects, as it encompasses social and environmental returns on investment as well as the economic benefits.

3.4.5 Future cost savings (infrastructure and planning)

One way that financial returns on investment have been seen in these case studies is through the reduced future costs of building new infrastructure (by supporting existing infrastructure instead with SWM technology). This was seen in the France case where they used SWM to co-ordinate the current networks to adapt current infrastructure instead of building a new facility, saving significant future capital costs. This is also the case in Africa, where implementing major infrastructure is often the approach taken for improving agriculture. By implementing smart tools and the Agricultural Innovation Platform to support the current infrastructure instead, the need for major infrastructure projects is removed saving implementation significant costs along with unwanted maintenance costs. In the FDMT case, smart tools are instead used to help water users and decision makers to develop resilient plans to manage floods and droughts, reducing the future impact of climate change on the land and water resources and saving damage costs in the future.

3.4.6 Willingness to pay for or adopt SWM

From a water user perspective, willingness to pay for SWM technologies and tools also appeared to reflect non-financial benefits when the costs of the tools were low, as shown in the case in Africa where farmers were most interested in improving their productivity (by reducing nutrient leaching and increasing nutrient availability), efficiency (reducing time required to irrigate) and opportunities (increased time available for other purposes, including education), than in financial gains. Willingness to pay also increased when the farmers understood and saw the results of the tools and saw the potential for the tools to increase their knowledge and understanding of their land, helping them to save time and also increase their income.

In the case where the costs were initially higher (i.e. in the Canada case), the willingness to adopt the technology remained relatively high, with participants in the pilot case stating that they were interested in the non-financial benefits (e.g. rainwater capture for irrigation, reduced pollution in waterways, etc.). Due to the high cost of producing any technology on a unit scale, in order to expand the project enough to have the desired impact, the willingness to adopt the technology must also come from the municipalities and water utilities who could support the project through providing grants or rebates (or other incentives for residents).

For a government (or other funding agency) to support this type of residential project the evidence of its impact would also need to be shown at a larger scale (beyond a small pilot study). This is a task which typically constitutes one of the key challenges that the project faces with getting the technology off the ground. Context is also important when assessing the willingness and ability to pay for SWM implementation, as shown in the Africa case, where the willingness to pay varied across the schemes. In this case, 70% of farmers in two of the schemes (Tanzania and Zimbabwe) showed a high willingness to pay for the tools, in comparison to only approximately 40% in Mozambique.

3.4.7 Strong business models for long-term sustainability of SWM

Strong business models are required to ensure the uptake of tools and the potential for replication and scalability is possible; this is particularly the case for 'Type 2' SWM implementation (where individuals implement SWM, see Introduction). For example, in the Africa case the project team is aware that, despite the positive outcomes, distribution of free equipment does not guarantee longevity of use and continuing impact. Hence, one of the objectives of Phase 2 for the project is to develop a business model that can sustain the production and spread of the tools. Business models include: the public sector paying for the technology, private sector paying and loaning the technology, co-payment of the technology, developing a payment scheme to return the costs, rebates for the technology, etc. In the Canada case study, the current business model did not succeed as it involves high costs for individual systems (with limited financial return on investment for users, at least initially). The business model for this type of project will likely involve collaboration with the municipalities who will benefit from the technology if 40% of community implement the systems (rebates are an option for this, as used for solar PV implementation). This involves strong collaboration with municipalities and could lead to potential financial support for the project.

3.4.8 Will SWM replace jobs or create jobs?

While some projects resulted in the reduction in staff needed in particular areas (e.g. in manually metering water use), other roles were found for these staff including managing the remote meter readings and customer service (see Seosan). In Paju, the SWM project lead to the creation of new jobs, with a 'Clean Water Environment Project Team' established which included waterworks, sewerage, environmental facilities and cityscapes and included a total of 98 workers. In addition to this, Paju City has hired local construction companies for the implementation of the project, which has resulted in 238 jobs in water related fields being established for the duration of the project. In the Africa case, while the time required for the farmers to irrigate their farms was reduced, and therefore the time required to 'work' on the farm was reduced, the profit made by the farmers remained the same (if not increased) due to increased productivity of the crops, resulting in the farmers having increased opportunities to take on additional work elsewhere or to continue with further education (or other opportunities) as desired.

While many of the case studies boast of efficiencies in the technology requiring fewer staff to manage the water system, which can result in reduced job opportunities, other cases have shown the benefits to increased efficiency and technology use, including new jobs, increased skill capacity and opportunities for education and additional work. For example, the Mexico and France cases show that SWM implementation can result in the creation of new roles and collaboration across otherwise separate sectors, leading to increased opportunities for integrated management. In addition to this, the France case showed that major teams are dedicated to the development and management of the SWM systems, describing working on new SWM technology as a great opportunity for them to discover the innovation potential for SWM tools and technology and to gain new skills in the area. In the Africa case study the SWM technology both reduced the time required for farmers to irrigate their land while also increasing the productivity of the crops. This resulted in a positive benefit particularly for women, who are traditionally in charge of managing the irrigation. These women now have more time for other opportunities such as accessing education or gaining additional income from alternative activities. If SWM can maintain income levels while reducing the need for staff, then staff can be retrained for other roles, ensuring loss of jobs is minimised, as seen in the K-water case studies where employees who were carried out manual monitoring were retrained into customer service roles. However it is important to note that retraining of skills is not always a simple process and opportunities for staff whose positions will be replaced should be considered carefully.

3.5 Social: Increased engagement, knowledge and decision-making

3.5.1 Engage with stakeholders early in the project for successful adoption

Working with the community and other stakeholders was seen to be one of the best approaches to ensure a successful uptake of technology. Including them in decision-making and training them to use the tools and to understand the information provided by the tools led to even greater success (e.g. Mexico, France, Paju, and China). For example, in Mexico community participation was considered of the upmost importance to the implementation of the SWM technology. While water leakages could have still been detected without the school community's support, the increased use of water fountains, improved water efficiency and better treatment and management of water were all-reliant on behaviour change. Community engagement was achieved through a two-pronged approach, both through the Water Observatory and also through in person workshops and training. The option for water users in the university community to have access to real-time updates on the water quality provided assurance that the water was safe, while community workshops used the knowledge gained by the smart technology to develop behaviour change. By partnering the two, the university community made significant changes to their behaviour, including reducing bottled water consumption considerably. For SIAAP (France) it was the engagement with all of the stakeholders in the joint water network that was essential from the beginning of the project to ensure they would all still be able to use their own platforms once the SWM was implemented instead of creating a new platform. Significantly reducing the retraining time for each stakeholder, and also ensuring the motivation for the project continued throughout its development.

In Paju, community engagement and information sharing played a major role in increasing tap water drinking rates. One of the key factors K-water attributes this is involving the community in the public activities of the project from the beginning of the project. The other two are the community's belief in the visible results shown during the project, and the open-access to real-time data via the community electric signboard (which will be discussed more further down). In contrast, the China case study shows what can happen if you do not engage with stakeholders from the beginning. In China it was the farmer's cooperation that was the most important for the smart systems installation and functional operation. In the beginning of the project the farmers were not initially consulted which led to substantial challenges as farmers removed or damaged the smart technology assuming it was being installed to charge them higher prices for water. This resulted in a meaningful delay in the results and loss of reliable data that had been collected. The team now acknowledge that the successful operation of the metering system and water saving facilities will rely on the farmers' cooperation. They are therefore working with the farmers, providing them with more information about the SWM tools and how they can benefit from them (along with compensation for their initial attempts to install without consulting them). This shows that collaborating and building trust with local stakeholders first before starting this kind of project can also lead to shared data, willingness to develop the best tools with you, on-going maintenance in the future.

3.5.2 Bringing the right stakeholders together at the beginning

It is not only important to bring all of the stakeholders together at the beginning of a SWM project lead to successful implementation of SWM technology, but bringing the 'right' people together (usually referring to local agencies) at the beginning can effect the most rapid change. For example, in the Africa case, engagement with the farmers and local agencies is essential from the beginning as they have been living with these issues for a long time and know what has and has not worked. In the same case, the crucial nature of the first phase of stakeholder engagement was highlighted by the initial 'visioning' step as it enabled participants to be confident that their issues had been heard and explored sufficiently. This takes time and care needs to be taken when options to consider the streamlining of the process are considered. For

France, strong stakeholder relationships with the partners were essential to ensure the shared objectives were being met. This resulted in a strong network of water professionals all working towards the same ambitious goals.

For the FDMT project in Africa and Thailand, engaging with local stakeholders in these regions prior to the implementation of the project was stated as one of the greatest enablers for the project's success. This ensured the local stakeholders were involved from the beginning of the project and could be part of the decision-making process from the beginning. For projects where strong stakeholder relationships need to be developed at the beginning of the project, time should be given to allow for this to develop to ensure trust can be developed between the stakeholders. Involving local stakeholders in the development and the dissemination of information was also shown to be a benefit (see FDMT, Africa, Mexico). For the Africa case, a local facilitator for the Agricultural Innovation Platform (AIP) was a critical component of the AIP. The project found that a local facilitator should ideally be someone with natural facilitation skills and with sufficient incentive to maintain the momentum and motivate and coordinate the breadth of stakeholders. Facilitation may then in the future become the new role for extension officers in Africa creating future job opportunities.

3.5.3 Local stakeholder engagement and support essential

The Paju case highlighted the importance of community-based organisation involvement in order to reflect the various needs at the local level. This kind of local stakeholder engagement and support is even more important when looking to replicate a smart urban water scheme in a new region, as each context is different and there is no 'one size fits all' solution. SWM projects could be successfully adopted in other regions around the world by working with a local and diverse stakeholder engagement group to ensure appropriate solutions are developed with local circumstances in mind. The case in Africa demonstrates that this kind of engagement can take a lot of time and resources, and is only sustainable in the long term if run by locals for locals. Therefore it is important to ensure that local stakeholders who will be trained as part of project are involved in the decision-making from the beginning of the project to ensure motivation and engagement is sustained once the initial implementation is completed. Working with non-traditional stakeholders and partners can also be beneficial as it allows new ideas and solutions to come into the discussion (see Africa case study).

3.5.4 SWM for community awareness raising and decision-making

Canada, Mexico, FDMT, Africa, Paju and China all highlight the potential for SWM to be used for community awareness raising and decision-making. This can be done through information sharing tools (Canada, Mexico, Paju) or decision-making platforms (e.g. FDMT, China) or a combination of the two (Africa). In Africa the value of the SWM monitoring tools has been recognised beyond improving efficient irrigation and farming practices, but is now also see as essential for building a learning system that supports the irrigation schemes. The awareness raised due to the data reported by the monitors has been disseminated to stakeholders outside of the project, benefiting an even greater number of people. In the FDMT case the satellite data acts as a decision-making tool for basin agencies when addressing potential future scenarios for climate change related floods and droughts. Already, the Thai stakeholders within this project have used the platform to start to develop their strategies for the basin.

3.5.5 Increasing community trust through SWM

Several cases showed the link between SWM and increased community/water user's trust in water quality (e.g. Mexico, Paju, SW4Europe). While real-time technology is often implemented in order to have reliable and constant information on water quality and consumption, it can also help to build trust in users who express concerns that manual monitoring is irregular with potential human inaccuracies. In Mexico, the university community showed a significant increase in trust when the water quality was monitored using automated technology, than when it was manually monitored. This resulted in a considerable increase in the community drinking tap water (which they could now see was clean in real-time) and in turn drinking less bottled water. Through the Mexico project, it was found that people are much more trusting of automated data than they are of people manually monitoring and updating data. This became evident throughout this project as people started to trust the drinking water quality when they knew the monitoring was automated, and when they could see the results for themselves on the Water Observatory platform. This was also observed during talks with the UNAM community, where all community members responded positively when informed that real-time automated data was available for the water quality of UNAM water taps every 5 minutes. This shows that people appreciate having access to real-time data for water quality as it assures them of the safety of the water. Automated monitoring plays a role in increasing trust in water quality in comparison to the manual monitoring of data, which is incapable of providing updated, accurate data on water quality every 5 minutes.

This approach could be adopted by the governments in Mexico (and other regions) to improve the community trust of water resources in the community, with the aim to increase tap water consumption (in areas where it is safe) and decrease bottled water consumption. In some cases (e.g. Paju) it was not the water quality itself that was the issue, but the trust in water quality. SWM helped to build this trust and now many more people drink the tap water. This trust was built as water users can directly check the quality of water coming from their taps using real-time status monitoring. Initially only 1% of the population in Paju was drinking tap water (5% on average in Korea), despite high water quality. Compared to Japan (52%). At end of project, drinking rate up to 36.3% (a significant increase). This raises the possibility for utilities in developing countries to use SWM as a way to develop trust in the water supply in their communities.

3.5.6 Engagement and learning as an on-going process

Community engagement and learning need to be on-going processes in SWM implementation, both for the water users and those implementing the technology. While initial implementation of the tools can be a quick process, for water users to truly understand the potential for the tools they are using it can take time. The case in Africa demonstrated one approach where water users were encouraged to learn the potential for these tools by themselves to ensure they are driving their learning about the technology. Mexico, Paju and FDMT (and SW4E?) trialled another approach where training and capacity building workshops were developed to ensure the users of the tools understood how to use them and the benefits they would get from them.

3.5.7 Engaging with stakeholders you usually would not engage with

Smart water tools can become a benefit for many water users. It is therefore suggested that those wishing to implement smart tools in a community think broadly about who could benefit from the SWM implementation and what information they may wish to know more about. This might include talking with farmers about soil moisture, efficient irrigation and groundwater, or universities about water quality and consumption. In the Africa case, this involved talking with youth and women (two groups not usually part of the discussion about farming), and brought them into the decision-making process. This opened up many opportunities for these groups and increased the opportunities for women in these areas to have a say on the decisions for the farm.

3.5.8 Engagement tools using various tools and approaches

Various engagement tools were used throughout the projects to provide the community with real-time updates of the water conditions, to increase interest and trust, to support behaviour change and to support decision-making and planning. Examples of the smart technology used include:

- The **smart phone app and signboards** used in Paju Smart City. These smart tools were installed to make real-time data accessible to the public and to ensure any barriers (e.g. such as those unable to install or unaware of the app) were removed so the public had access to the quality of the water in real-time.
- The **Water Observatory online platform** in UNAM, Mexico City. This platform provides an accessible tool for the water users in UNAM (and anyone else with an interest and online access) to check the water quality of the water devices in the main campus. The platform also acts as an internal data storage and analysis site for PUMAGUA.
- The **Agricultural Innovation Platform** (AIP) in Africa. This governance tool brings stakeholders together to develop a vision for what they would like to achieve using smart tools and approaching it together. It was developed to ensure local farmers would have a strong, self-sustaining network to make decisions with and a strong business model to ensure the project continues sustainably in the long-term.
- The **Flood Drought Management Tool portal** developed by FDMT and DHI provides a planning tool for climate change adaptation and planning for water utilities and transboundary decision-makers using satellite data.
- **Real-time water quality data water fountains** installed in apartments and schools in Paju act as a trust building and engagement tool as well as increasing access and incentives for water users to drink the tap water.
- **Mobile phone games** were used within the SW4EU projects to raise awareness of water consumption and efficiency in the community and schools.
- **A groundwater mobile phone game for farmers** in China. The app will be developed for farmers to better understand the use of water and electricity when pumping from the wells, and the impact it can have on the groundwater levels. This 'game' is intended as an engagement and education tool for farmers to increase their interest and understanding about the project
- The **RainGrid online platform** in Canada. This platform provides real-time updates for SmartGrid users to assess their current water collection and predict their future water collection, enabling them to adjust their behaviour as necessary.

3.5.9 In the long-term local management of tools should be supported

In the two cases based in Africa (e.g. Africa and FDMT) initial support was provided by external agencies. However, both of these cases have developed to ensure that the management of the tools and supporting platforms will be run by locals. Deploying monitoring tools across countries can be a challenge and local production of these tools can help address this. This can also help to boost local economies and reduce reliance on external manufactures. As is the case with many new technologies, particularly those with sophisticated components deployed across multiple national boundaries, there have been some challenges in regard to delivery and keeping pace with demand. However, increased team support and movement of production to within the region will enable these issues to be addressed (see Africa). The context of the SWM project is also important in determining how tools should be chosen and utilised. Typically only local stakeholders have the knowledge and experience to most effectively adapt a SWM project successfully, but externally provided technology and capacity development may also be required at least initially to ensure all skills are available for successful implementation.

3.6 Environment: Protecting our natural resources and ecosystems

SWM tools are often developed with the goal in mind to address a particular water challenge. In these cases, it was shown that SWM tools and systems can also assist with supporting and protecting the environment and natural resources beyond what they initially set out to achieve. The SWM tools to address these challenges are described below.

3.6.1 Water quality

Water quality was the most prominent challenge addressed within the SWM case studies, with over half providing solutions to address water quality using various approaches. In the Paju, Mexico and SW4EU projects, the quality of potable (drinking) water was addressed and monitored to both increase the safety of drinking water through early detection of bio-contamination, and to improve community receptivity to drinking tap water. The Canada case addressed the quality of stormwater, looking to reduce non-point source pollutants entering the waterways and ecosystem by reducing stormwater flow at the local level. In France, SIAAP addressed water quality through monitoring and controlling water quality in the sanitation treatment system.

3.6.2 Ecosystems

Smart water tools have the potential to provide ecosystem protection through reducing pollutants entering the waterways and groundwater. In the Canada case, by collecting water at the source (i.e. from the household roof) pollutants collected from roads and pathways are no longer collected with the rainwater, reducing the level of contamination reaching the groundwater and waterways. SIAAP in France have shown that reducing contamination in sanitation can also protect ecosystems: Now that the MAGES project is able to provide higher quality water for the river Seine fish species are returning and fish population sizes are at an all-time high.

3.6.3 Land degradation

By reducing nutrient degradation the Africa efficient irrigation case study was able to return the soil to a healthy state, reducing land degradation and ensuring improved production of crops on the land. The Flood and Drought Management Tools project in Africa and Thailand and the K-HIT project in Korea looked to reduce land degradation by managing floods and droughts to ensure the land was protected from extreme weather events. In China, the reduction of groundwater abstraction also supported improved land protection along with groundwater resources.

3.6.4 Efficient energy consumption

Alongside improving water resource efficiency, smart tools also have the potential to improve energy optimisation. This was shown through the SW4EU project, where (explain project). Energy consumption were also reduced indirectly in the China and Canada projects through reduced use of water abstraction (China) and reduced pumping of water when collected at the source (Canada). Energy conservation plays a major role in reducing the impact of climate change, and therefore by adopting smart water management tools that can also assist in energy optimisation and reduced consumption we can improve the use of two of our most essential resources, water and energy.

3.6.5 Flooding

Flooding was addressed at the national and regional scale both through integrated operational solutions (e.g. K-HIT) and through flood management and planning solutions based on predicted weather patterns (e.g. FDMT), and at the local scale (e.g. Canada) through reduced stormwater runoff.

3.6.6 Droughts

In addition to addressing floods, both the K-HIT and FDMT projects showed the potential for smart tools to address droughts through storage of water and planning. Droughts could also be addressed through many of the technologies, which provided solutions for increased water access, water quality and reuse as improved water efficiency supports water access in times of drought.

3.6.7 Groundwater

Groundwater over abstraction is an area of great concern in many countries, and an area which can be addressed through the use of modelling using real-time electricity and water data as shown in the China case. This kind of technology provides the opportunity for countries where groundwater has become a key source of water for irrigation to ensure accurate reports on the current levels of groundwater are current and can also engage with the local farmers to show the importance of efficient groundwater use.

Groundwater depletion was also addressed through the Canada project with stormwater collected at the household scale then returned to the groundwater.

3.6.8 Efficient use of water resources

With over 40% of water supply in most cities being lost to non-revenue water (i.e. water leakages), the Mexico, SW4EU and Seosan city projects have shown the importance of smart technologies for the efficient use of water uses. Community engagement was also used to support the community to reduce water overuse.

3.7 Governance: Decision making and collaboration

3.7.1 Interdisciplinary collaboration leads to successful SWM

Many of the projects showed the importance of interdisciplinary teams and collaborations as one of the keys to their success. In the Mexico case study, PUMAGUA consists of scientists, engineers, regulation experts, maintenance staff, teachers, and communication experts, with each team essential for understanding the issues that were being addressed, and for implementing the project. The PUMAGUA team also found it highly beneficial to have the support of the whole university, as it ensured support water provided when the teams needed it.

This interdisciplinary nature was also highlighted in the French case study, were SIAAP worked closely with the other water agencies in Greater Paris to integrate their current networks and operation systems, instead of building a new facility and operation network. This enabled each of the teams to continue working with the systems they were familiar with, while also increasing their capacity. Similarly the SW4EU project involved the collaboration of more than 20 stakeholders, enabling the partners to test and develop new technology, different sites, to identify which tools worked best for which contexts, and to learn from one another.

In both the FDMT and the Africa case studies, external agencies in water management, technology and research (e.g. universities and international NGOs) supported local agencies (e.g. water utilities and basin authorities) to develop and implement their smart projects. In these cases, the knowledge from the local agencies was deemed crucial to the success of the project. In Korea, the K-HIT project involved internal collaboration of several interdisciplinary teams within K-Water to develop the technology and tools for floods, droughts, hydro and planning, alongside external collaborations with the government for support.

In contrast, a lack of collaboration was also shown to cause major delays if not stalled starts all together. In the China case study the lack of collaboration between the project team and the electricity sector resulted in major delays for the project. As the electricity sector would not share electricity data, the project team relied on collecting their own electricity data from meters installed in local wells. When the electricity readings were found to be inconsistent, it took several months until the two teams collaborated together and were able to realise that the electricity meters had not been installed correctly. Reinstallation of the meters was ultimately required, resulting in significant delays. This highlights the need for close cooperation with the electricity sector, not only for technical expertise support and their ownership of the technology, but also for their knowledge and access to the data, which was required for successful implementation of the project. Similarly in the Canada case, had the project created strong collaborations early in the project with water utilities and municipalities, it would have built a stronger business model, strengthening the future potential and opportunities for the project and the trust from future participants in the project. Lack of this collaboration at this early stage seems to have caused the project to stall.

3.7.2 Understanding the challenges from the beginning leads to success

One of the key lessons that many of the projects learned throughout their projects was the importance of having a strong understanding of the challenges and context of their location prior to implementing SWM technology. Having this understanding enabled the most suitable tools and technology to be selected from the beginning.

For example, prior to PUMAGUA (Mexico case study) a baseline assessment had never been performed at UNAM, resulting in the team having very little understanding of the key issues related to water at the university, or the extent of these issues. To address this PUMAGUA conducted a full diagnosis of the situation including water quality assessments, water consumption and surveys of the university community. A key outcome of this diagnostic stage was the conclusion that smart technology (i.e. sensors and monitors) would provide them with the most comprehensive understanding of their current challenges while also helping to direct the project to achieve tangible solutions to these challenges.

Now that these SWM tools have been implemented for the past 8 years, PUMAGUA has an even better understanding of what is needed for the future and which technologies and tools they would like to implement to improve the system even further. This shows that as SWM technology evolves, regular reassessment of the situation and context of the project is necessary to ensure the correct suite of technologies are being used for each situation.

This staged approach was also shown in Seosan, where stage 1 involves an assessment of the challenge; stage 2 analysis of the data and diagnosis; and stage 3 adjustments are made to ensure the tools work to the best potential. This staged approach is particularly important in developing regions where baseline assessments of the issues unique to that region are often not available.

3.7.3 Concrete outcomes and objectives increases motivation and funding

To guarantee on-going support and motivation both SIAAP and K-water found it important to have concrete outcomes agreed between all stakeholders. For example, the MAGES project (France) started with two concrete outputs for all the parties: 1) rainfall data treatment and 2) setup of a real-time data sharing platforms between the SIAAP and each one of the partners, leading to increased motivation to reach these outcomes. K-water was required to improve the water supply network and stability of tap water supply using ICT. These concrete outcomes/outputs were requested in return for mid- to long-term budgets, which significantly supported the success of these projects. The Mexico case study provides an example of how setting specific targets can help deliver results: In their case, a target was set to reduce water consumption by 50% from 2008 values, and has so far decreased it by 25% despite the university community increasing by 37% in this time.

3.7.4 Choosing the right tools for the context of the project

The diversity of these projects and the challenges they have faced and overcome demonstrates the importance of understanding the context of the project to implement SWM successfully. The following factors have been shown as important to consider at the beginning of a SWM project to gain the most comprehensive understanding of the context and how best to approach SWM implementation:

- Technical capacity and knowledge of all stakeholders (especially the water users who will be using the tools)
- Access to technology and tools locally, or reliant on external partners
- Maintenance capacity (both financial and human) for the tools
- Financial capacity (and for how long will this support be available)
- Regulations and policies in place (including incentives and disincentives)
- Community engagement potential (and tools that might help the community to engage fully with the project)
- Collaboration potential (which stakeholders will be interested and how willing will they be to collaborate)
- Access to resources (e.g. internet access, electricity, infrastructure to monitor, data storage capacity)

By considering these factors, a better base understanding can be developed at the beginning of the project, which can in turn assist in identifying any early barriers that may occur or opportunities that can support the project.

3.7.5 Involving water users in decision-making

In addition to involving water users through engagement and awareness raising, SWM also offers the opportunity to involve water users proactively in decision-making. These decision-making processes can be seen by involving the water users in the discussion from the beginning (e.g. the farmers in the Africa case) or by providing them with decision-making tools once the system is in development (e.g. FDMT, Mexico) or once the project has been developed (e.g. Paju). By providing these tools to water users with real-time data and the information required to make informed decisions, they can feel more in control of their actions and decisions as a water user. This demonstrates the potential for SWM tools to be used to increase decision-making opportunities for water users and could be easily replicated and adopted in regions were there is interest for water users to make their own decisions in regards to water use.

3.7.6 Project management and roles must be determined from the beginning

SWM projects are often developed and implemented in collaboration with several partners. These partnerships are often made up of external partners (those from outside the area of implementation) who assist with the initial development and implementation, and local partners who continue with the project once it has been implemented. As SWM projects and technology tend to require ongoing maintenance (at least in the short-term) it is important to identify at the beginning of the project who will be in charge of this management and maintenance in the future, and also to ensure a budget is available for the future management of the project. It is also important to clarify at the beginning of the project how often upgrades are likely, when or if scaling of the project will occur, if replication is a consideration and who will manage these stages of the project.

For example, in the case study in Africa it was essential to identify early in the project who would be responsible for each part of the SWM tools and their maintenance. In the Africa case it was also important for the irrigation association of each scheme to develop a clear mandate to enable the farmers to ensure the governance of the project continued smoothly and sustainably in the future. In the case of SIAAP, strong commitment from the top management of each partner ensured everyone knew who was managing each part of the system, and how it would be managed in the future. This is particularly important for projects where funding partners are involved only during the first phases of the project, i.e. where the local partners must maintain and pay for future augmentations of the project in the future to ensure the projects are sustainable.

3.8 Policy: Policy support for SWM implementation

3.8.1 Policy support and regulations a major driver for SWM implementation

Throughout these case studies is was clear that many SWM projects are driven by regulation requirements (e.g. water quality in Mexico and Paris, efficiency targets in Paris and depleting groundwater resources in China). For example, Mexico's regulations on water safety were a significant driver for PUMAGUA to assess drinking water and wastewater quality. While the regulations did not stipulate that real-time technologies were required to meet the requirements, having the requirements in place created the driver for PUMAGUA to assess their situation, which may not otherwise have become a priority. In Paris, the increased regulations on water quality in the Seine resulted in SIAAP having to advance their systems, and as smart technologies had been part of their management approach for over a decade, integrating their smart networks with other water agencies enabled them to meet the increasing regulations. It is therefore important for regulations (e.g. to increase water use efficiency, reduce leak detection or improve water quality) to be introduced in areas were further drivers are needed to support future SWM implementation.

In countries where SWM has become a priority for governments (e.g. Korea), having strong policy support for SWM has also made implementing successful SWM much easier and has acted as a driver for SWM developers (such as K-water) to participate in the development of projects such as Paju Smart City. Policy support also often includes significant funding for research and development (R&D) into SWM, with funding for SWM in Korea expected to reach 8.7 million (USD) by 2020 in Korea. The planning and execution of the drought policy, existing laws and systems played an important role in the implementation and support of the Seosan project. In addition to this, government budget support for the project facilitated its implementation.

Local plans and policies can also play a role as a driver for SWM implementation. The Seosan Smart City project was initiated on request from the City of Seosan, who requested smart technology implementation as a drought measure when national drought plans were introduced, with financial support provided by the national government. This shows the potential for policy support to act as a major driver for adopting SWM projects, when coupled with supportive funding to meet the targets. Governments supporting major SWM projects also drive interest and support for SWM (see K-HIT, Korea).

In contrast, when government support is not provided it can hamper the implementation of SWM project. For example, in the Canada case study, municipal support could have enabled the use of rebates for the SWM technology to encourage the 40% of the population to uptake the technology to ensure the results could be seen. As this type of technology also supports the actions the municipal governments are aiming for (e.g. improved stormwater management and improved water quality), rebates or other financial support from municipalities or water agencies would be a great first step in supporting the successful implementation of household and site-scale SWM project.

It is also worth considering the other types of policies which could support SWM implementation. With SWM technology offering a number of opportunities for community engagement and decision-making, introducing policies requiring improvements in these areas could also increase interest in smart tools.

3.8.2 National acts also play an important role in government support

Along with policies, national acts also play an important role in government support. In Korea, the *Framework Act on The Management of Disasters and Safety* encouraged the government and public institutions to plan drought measures and the *Countermeasures Against Natural*

Disasters Act enforced the federal government and local governments to restrict water supply and electricity generation and to maintain drought-overcoming facilities. Without these government Acts in place, this project may not have been supported.

3.8.3 The importance of standardisation and integrated solutions

Some of the key barriers reported by the case studies were a lack standardisation and integration of SWM technologies and a lack of transparency from manufacturers on future technologies. As standardisation is not currently regulated, future policies can also assist in supporting SWM implementation by addressing some of these challenges currently faced by these projects. Due to the lack of standardisation, current SWM systems are often not compatible, which leads to projects being 'locked in' to one manufacturer or supplier and reduces the potential to use the 'best fit' of tools for the context of the project. Standardisation of technologies on the market to make them compatible with one another would therefore reduce the reliance that many projects have on one manufacturer. Standardisation would also support future projects, as it would encourage manufacturers to work with SWM project managers. This would increase transparency about upcoming technology to ensure large investments are not made using technology that is soon to be upgraded, and would benefit the manufacturers with real feedback from the project implementation team to ensure the most important upgrades to the technology are made.

3.9 Technology: Supporting the evolution and adoption of SWM technology

Countries with ready access to SWM technology and capacity (e.g. Korea) will have the 'easiest' transition to SWM implementation (e.g. Seosan, France) however countries without these resources can still benefit from SWM through collaboration with these countries (if only to learn from them).

3.9.1 Planning for successful SWM technology implementation

When planning SWM projects and technology installation, a few key factors were shown to assist with successful implementation.

Firstly, project managers must ensure all installation requirements are met (e.g. inlet pressure, flow-rate, data connectivity) prior to investing in the technology. This includes understanding logistical challenges such as underground installation which can be solved but require additional technology or equipment. It is also important to understand how the technology will integrate with the other systems used in the project and whether the systems are compatible across the technologies, or require different systems or platforms. Real-time data becomes far less useful if it is provided in several different units that cannot be easily converted and integrated.

Care should be taken in order to prevent the use of SWM technology creating a dependence on one particular commercial product or manufacturer. It would be desirable for companies to have products compatible with each other in order to have different options. Compatibility would also likely accelerate their response time to project inquiries and issues.

If selecting a range of technology from various manufactures, integration of the data sent by different systems to one data platform can be a challenge. Often different manufacturers require different software to read the data from the signals, and for reading the incoming data. In some cases, metering companies will make their money from installing meters at a low cost and then provide paid services for the customers after installation (see China case study). This results in the data being sent to the companies servers, and can reduce access to the data. It can also result in the data being collected in different formats, resulting in a challenge

when integrating it to provide an overarching picture of the data. Having a full understanding the challenges faced and how SWM technology can assist with these challenges will help to ensure the right mix of tools are selected for the context of the project. The tools used in a project in one country or region may be useless in another context. It is essential to understand which suite of tools suit the scale, location and challenges faced in the project area.

For projects where location accuracy of the data is essential, the implementation of District Metered Areas (DMAs), or Sub District Metered Areas (SDMAs) can assist in improving the data accuracy of the region as it separates the area into subareas (see SW4Europe, Seosan, Indonesia text box).

There are standard issues which need to be considered and prepared for across all SWM projects, such as clogging of filters, drop out of Internet service, and maintenance requirements still impact SWM technology. For example, interrupted Internet connections can result in missing data and loss in trust in the data collected. It is therefore essential that a secure and reliable connection is established for all real-time technology. Communication networks are also important for SWM implementation. If traditional communication networks or electricity are not available, other options can be found (e.g. data uploaded to the cloud when the mobile is connected to the internet as shown in the Africa case study, or solar power used to support irregular electricity supply as seen in the Uganda aquaponics project).

3.9.2 Evolving technology can be both a disadvantage and an advantage

As SWM is an emerging field, smart technology for water management is constantly being updated and as a result can become out-dated quickly. It is therefore important to study which technology will be the most suitable, and also to conduct research on whether there are any new technologies soon to come on to market that might be more effective than the technology currently available. For example in the PUMAGUA case, sensors that use radio frequency were chosen, requiring additional infrastructure to ensure the radio waves reach the entire campus. Mobile frequency sensors are now available that do not rely on additional infrastructure, that may have been more cost effective in the long-term. This evolution can also be seen as beneficial for new projects starting to implement SWM, as the constant evolution of technology provides new solutions and opportunities to create the 'right mix' of tools for the context of the project.

3.9.3 Various approaches to implementing SWM

While many projects introduce new SWM technology infrastructure as part of their project (e.g. Canada, K-HIT), SWM technology can also be used as a retrofit or upgrade to current infrastructure (see Mexico and Seosan), or as an alternative to introducing new infrastructure (see Paris and Africa cases). By combining the existing water management in Seosan City with Smart Water Management tools, the efficiency was significantly improved. SDMA (Sub District Metering Area) system technology, which subdivides existing DMA systems into smaller units to improve the revenue water ratio, is one example of this. These cases also provide an example of SWM complementing traditional infrastructure by enriching the results and validity of the information. The Paris and Africa case studies further demonstrate that SWM technology can greatly reduce the need for future infrastructure, resulting in significant future cost savings.

3.9.4 Monitoring tools can be used as an education tool

Many case studies have also shown the potential for SWM tools to be used as engagement and educational tools. A good example is provided by the Africa case study, from which the farmers gained a stronger understanding of the benefits of efficient irrigation through the use of the real-time soil monitors. Instead of informing the farmers that reducing irrigation could provide a range of benefits, the tools allowed the farmers to come to this conclusion on their own, building their knowledge of how their land works and increasing their capacity to better manage their farms. The case study in Mexico also demonstrated the use of real-time water quality and consumption as an education tool for the university community, with students learning how they could make a difference through changing their water use behaviour, and seeing the results in real-time.

3.10 Replication and scalability: the potential and challenges

Based on the successes seen in many of the SWM projects, the potential to replicate the projects or scale them up or down in other regions is an area of great interest for many of these projects.

3.10.1 Early successes and knowledge sharing can support replication and scaling up

In the Africa case study, once the farmers recognised the value of the SWM tools, demand for the tools increased. Farmers involved in the project have expressed interest in scaling up the project and trying out SWM tools on different crops, and many other farmers are now interested in SWM tools. This interest provides strong incentives for project partners and potential new partners to help with scaling up the project and distributing the SWM tools more widely. As a result irrigation practices are changing faster than expected, and this knowledge could be expanded into other areas if the project was to be replicated elsewhere.

It is also important to recognise that initial excitement and enthusiasm for a project does not guarantee long-term success. The provision of long-term results, continued comparisons and feedback from other projects, long-term learning goals and in some cases continued evolution or expansion of the project may all be necessary to maintain stakeholder interest.

3.10.2 Challenges in replication and scalability

Each of these projects has shown interest in scaling up or replication in some way. However, it is important to note that what is a challenge in one context may not be a challenge in another context, and vice versa. Challenges faced by the projects so far are described below.

3.10.2.1 Lack of basic infrastructure reduces options for SWM implementation

In the Mexico case study, PUMAGUA demonstrated the difficulty of replicating pilot projects into regions with a highly varied context. In the case of PUMAGUA, the SWM tools that were successful in a university setting faced instant barriers when introduced into a lower socio-economic area of Mexico City. While both sites were within the same city, they faced very different water challenges. The university faced issues with water quality and leak detection, the areas in Mexico City faced limited infrastructure or infrastructure of low quality, and irregular water access. Concluding that it was near impossible to implement effective monitoring systems where there is little to monitor, PUMAGUA used the SWM technology and approaches they had developed to focus on monitoring the houses that did have a reliable water connection. At the same time a long-term goal was set to expand upon and replicate this project in other areas.

3.10.2.2 Lack of resources to support replication in some regions

The success of most of these SWM projects has been in part due to funding support from governments. While K-water is looking to replicate their successes in other regions (see Bali text box), they acknowledge that not every country will have the strong governmental support for SWM offered in Korea, and therefore that investing in this kind of project can be a challenge in other regions. Beyond financial support, many regions looking to introduce SWM technology into their regions face barriers of access to the technology, resources (such as electricity or Internet access) and capacity. Therefore it is important to assess what would be needed for each project to be successful elsewhere, and what support would be needed for a project that

was successful in a large city in a developed country to be successfully replicated in a small city in a developing country.

3.10.2.3 Economies of scale and evolving technologies

As shown in the Canada case study, there can be challenges in scaling up a project to improve the economies of scale prior to the technology reaching high-demand in order. Therefore, scaling up is considered challenging unless external support is provided at least in the short-term. In addition to this, as technology is in a constant state of evolution, many of the case studies commented on the difficulty of knowing the right time to purchase and install SWM technology, especially if in purchasing the technology results in the project becoming locked in to one supplier or manufacturer.

Despite these challenges, each of these projects is interested in upgrading, replicating, scaling or sharing their knowledge to support future projects. The more SWM projects are developed and implemented around the world, the more can be learned about which technologies work best for each context to best support every region with implementing SWM to assist with resolving their water challenges.

3.11 Sustainable development: How SWM can assist in addressing the SDGs

The case studies presented in this report show the considerable potential for Smart Water Management to contribute towards reaching many of the Sustainable Development Goals and their targets. These projects show the potential for SWM to assist with the SDGs beyond SDG 6 (to provide clean water and sanitation for all). For example by moving towards zero poverty and hunger, improving quality education, supporting sustainable cities and the consumption of clean energy, implementing sustainable consumption and climate action, alongside supporting partnerships to reach these goals together.

The following section details how the projects presented in this report can assist in addressing these goals. While the number of targets these projects are able to assist is already substantial, the diversity of SWM projects around the world leads to potential for SWM to assist with meeting an even greater number of SDG targets through future implementation.

SDG 1. Towards zero poverty

The projects in southern Africa, Mexico and Korea each provide assistance for moving towards zero poverty through supporting equal rights to economic resources, control over land, natural resources and new technology (target 1.4); through building resilience and reducing exposure and vulnerability to climate-related extreme events and other shocks (target 1.5); and by supporting policy frameworks that are based on pro-poor or gender sensitive development strategies (target 1B).

Each project approaches this in a different way. In southern Africa, the project shows the potential to move towards zero poverty through identifying and improving institutions that reinforce inequity with a particular interest in gender, youth, end-users, social capital, access to natural resources, economic well being and agency in decision-making. As the farmers also have direct use and control of appropriate technology, this strengthens their control over their land and increases their decision-making potential, increasing their resilience for the future crop production and income potential. This project also aims to build resilience through enhancing individual and community capacity (knowledge, empowerment and agency), reducing conflict, building strong networks and advocating for policy change through the African partners of the project (an element of the project which will be accelerated in Phase 2). In the Mexican case study, this support is shown through its efforts to enhance water availability for the next generations of UNAM's community, as well as for the inhabitants of Mexico City where equal rights to water is currently an issue in many regions. In Seosan City, Korea resilience is built through ensuring access to water in all regions, including those which have had limited access in the past and rely on it for drinking purposes and sustainable irrigation.

SDG 2. Towards zero hunger

As shown in the Africa and China case studies, SWM technology can be used to improve irrigation practices, leading to increased crop productivity and income. The Africa case study has shown this through increasing agricultural productivity and incomes of small-scale food producers, access to land and other resources (target 2.3) through increasing the farmers incomes and yields. Farmers have also increased their awareness of sustainable irrigation practices and reduced water and fertilizer use, moving towards sustainable food production and resilient practices (target 2.4). In the China case study the use of an irrigation calculator and web tool enables the farmers to calculate irrigation water demand, providing a plan for sustainable agriculture through ensuring equitable water for irrigation and improving crop productivity (targets 2.3 and 2.4). The project in Uganda (see page *), also shows the potential for SWM to assist with aquaponics projects in regions where food sources are scarce, and fish sources act as the main source of protein for the community.

SDG 3. Good health and wellbeing for people

With clean water playing a major role in human health, improving the quality of water sources through SWM techniques has the potential to substantially support *reducing the number of deaths and illness from water pollution and contamination* (target 3.9).

SDG 4. Quality education

One of the surprising benefits of SWM implementation has been the increased opportunities presented for further education and capacity development, leading to *an increase in the number of youth and adults who have relevant skills, including technical and vocational skills, for employments, decent jobs and entrepreneurship* (target 4.4). This was shown in the Africa case study, where the reduced time required for women to irrigate crops led to available time for further education. In addition to formal education, acquiring vocational skills in technology design and development, community engagement and water and agricultural management has become one of the great social benefits to SWM implementation throughout these projects.

SDG 5. Gender Equality

Women's participation and equal opportunities for leadership at all levels of decision-making (target 5.5) was shown in the case study in Africa providing women with key roles in the government scheme (Agricultural Innovation Platform). The role of real-time community engagement tools also increases the role women can play in decision-making at a local level, as shown in the Paju case study. Another benefit as shown in the Africa case study was that as women's incomes have increased, joint decision-making and female decision-making has increased, and household conflict has reduced.

SDG 6. Clean water and sanitation

While the link between SWM and SDG 6, to improve access to safe water and sanitation and to improve sound management of freshwater ecosystems, may not be surprising, the variety of ways in which SWM can assist the achievement of this goal are worth noting.

To achieve universal and equitable access to safe and affordable drinking water for all (target 6.1) the Mexico case focused on improving water quality and education for the water users to increase receptivity to drinking tap water. In the Paju project, water quality was already safe, however the perception of the water quality led water users to buy bottled water. By using real-time data and communication approaches, Paju City was able to increase awareness and trust in the community, and as a result the increase in water users drinking tap water increased from 1% to 33% over three years.

To achieve access to adequate and equitable sanitation and hygiene for all (target 6.2) SIAAP integrated their sanitation networks and introduced real-time monitoring and mesh networks to treat the wastewater as it moved from one treatment facility to the next, resulting in increased water quality and improved ecosystems. In Mexico, the treatment of wastewater using real-time monitoring increased the safety of the water.

The use of SWM to improve water quality by reducing pollution (target 6.3) was addressed in numerous projects, including to treat wastewater (see France), reduce non-point pollution from fertilizers and stormwater runoff (see Africa and Canada), capture and treat rainwater (see Canada), and monitor and reduce contaminants in drinking water (see Mexico, SW4EU). One of the main goals of the MAGES project (France) was to reduce the pollutant loads discharged into the receiving water, especially during rain events. By monitoring and adjusting the levels of these pollutants in the Seine, SIAAP is able to contribute to improved water quality in the Greater Paris region. On a global scale, SIAAP is sharing knowledge on the technologies they have developed, providing the potential for these technologies to be replicated elsewhere in the world in the future.

To substantially increase water-use efficiency (target 6.4), SWM was used to improve efficient irrigation (see Africa), reduce leakages (see Paju, Mexico, SW4EU), reduce consumption (see China, Seosan, Mexico, SW4EU), capture and reuse rainwater (see Canada), increase storage of water (see K-HIT). In the case of China, water meters were installed to evaluate water saving methods, giving valuable annual feedback to decision-makers to enable them to adjust irrigation plans. In addition to this, by increasing the farmers' awareness of their water use and savings using real-time data, they were able to adjust their irrigation practices to irrigate more efficiently.

To implement integrated water resources management at all levels (target 6.5), K-water developed K-HIT, to integrate the management of numerous river basins and dams to provide a holistic action plan for water management in Korea, and to support rivers upstream and downstream with flood and drought resilience and improved water quality and quantity. In France, the SIAAP implemented integrated water and sanitation networks across Greater Paris (France), the Africa case study integrated water-use efficiency across the schemes using SWM tools and knowledge sharing platforms. For the FDMT project, integrated water resources management is one of the key management processes incorporated into the FDMT applications, including transboundary basins.

To protect and restore water-related ecosystems, including rivers (target 6.6), SIAAP reduced pollutant loads by treating the wastewater to a high quality to improve water quality in the Seine, restoring the ecosystem of the Seine, which has seen the return of over 30 fish species since the implementation of SWM in the Greater Paris sanitation network (see France).

To expand international cooperation and capacity building to support developing countries (target 6A), the case studies have shown that both planning and operation support and capacity building can be achieved. For example, the FDMT project equips transboundary agencies with the information and tools required to complete comprehensive assessment and plans to prepare for flood and drought disasters using satellite data, while K-water is currently supporting Indonesia with replicating their Seosan project to reduce leakages and improve water quality. The potential for further international cooperation and capacity building is also strong for SWM, though the context of each project must be taken into consideration, and local stakeholders engaged with from the beginning to ensure successful adoption and implementation of SWM.

Many of these projects show the potential for supporting and strengthening the participation of local communities in improving water and sanitation management (target 6B). This has been demonstrated through involving local authorities and the community in the projects from the beginning (e.g. Africa, FDMT, and Mexico) and learning from their experiences for how best to proceed (e.g. China). By supporting and engaging with local agencies and communities, these projects also empower local organisations and stakeholders to be better informed and to engage in decision-making.

SDG 7. Affordable and clean energy

As shown in the SW4EU case study, energy optimization can be implemented using SWM technology, increasing the efficient use of electricity and reducing energy use, supporting the target to *double the global rate of improvement in energy efficiency* (target 7.3). Treating water also uses a considerable amount of energy, therefore each of the projects introducing approaches to use water more efficiently and to reduce leakages (see Mexico, Paju, Seosan, France, SW4EU, Canada) in cities play a major role in improving energy efficiency.

SDG 8. Decent work and economic growth

Many of the case studies show the potential for increased jobs and economic growth through their SWM projects. Namely, K-water has shown within each of their case studies that by introducing SWM projects in Korea the job market has increased (for researchers and developers, project managers and construction) (target 8.1 and 8.2). In the Africa case, it was shown that household incomes have increased during the duration of the project, and reductions in irrigation time have led to opportunities to establish new small businesses or to undertake additional labour work for other farmers (target 8.5). There has also been an increase in youth farming in the schemes in Africa (target 8.6).

SDG 9. Industry, Innovation and Infrastructure Resilience

SWM links closely to targets 9.1 to *develop quality, reliable, resilient infrastructure to support economic development* and 9.4 to *upgrade infrastructure for resource efficiency.* One example of this is the MAGES system as demonstrated within the France case study. By introducing MAGES to SIAAPs traditional infrastructure, SIAAP was able to enhance the performance of the whole system to make it more adaptable to changing situations, enhancing resilient wastewater infrastructure in Greater Paris. The MAGES system also reduces energy and reagent consumption, contributing to making the system more sustainable. In the Mexico case study, PUMAGUA upgraded their disinfection system and wastewater treatment plant infrastructure to improve resource efficiency, sustainability and resilience.

SDG 10. Reducing inequalities

SWM implemented in developing countries can go a long way to reducing inequalities. This can be by providing support and income growth for the bottom 40% of the population (target 10.1; see African and Uganda), *empowering and promoting social, economic and political inclusion for all* (target 10.2; see Africa, Argentina), and *promoting equal opportunities* (target 10.3; see Africa, Uganda, Argentina) for women and youth.

SDG 11. Sustainable cities and communities

To build sustainable cities and communities, cities and human settlements must be made to be inclusive, safe, resilient and sustainable. Several of the case studies have shown how SWM can contribute to building these types of cities and communities through protecting natural and cultural heritages sites (target 11.4; see FDMT case study) and reducing the number of deaths and economic losses caused by flood and drought (target 11.5; see K-HIT, FDMT, France and Canada). For example, K-HIT demonstrates this through efficiently supplying water to drought using integrated SWM systems and by minimizing damages caused by water disasters in preparation for floods.

The protection of human settlements is also supported at various scales within the FDMT and China projects, through *strengthening national and regional development and planning* (target 11A; FDMT), and *increasing cities integrating plans, resources efficiency and adaptation to climate change* (target 11B; see FDMT, China, SW4EU and Canada). In addition to the informative tools and research that the China project provides the government for decision making and planning for resilience to extreme weather and emergency situations, their findings also enable policy recommendations to be made to the government to assist other developing nations to implement smart tools and technology.

SDG 12. Responsible consumption

To ensure sustainable consumption and production patterns, SDG 12 requires *strong national frameworks integrated into national and sectoral plans, practices and consumer behaviour*. Sustainable management and efficient use of resources (target 12.2) is addressed by several of the case studies (see Paju, Seosan, France, Mexico, SW4EU, China, Canada) through efficient water use, leak reduction, energy optimisation and reduced reagent consumption. To *ensure relevant information and awareness for sustainable consumption and development* (target 12.8), many of the projects placed a high importance on education and information dissemination (e.g. Paju, Mexico, SW4EU, China), insuring water users have the relevant information for sustainable consumption.

To *support developing countries to strengthen their scientific and technological capacity to move towards more sustainable patterns and consumption* (target 12A), programmes such as UNAM's PUMAGUA act as a model for developing countries by sharing the scientific and technical lessons they have learned while implementing SWM, building the capacity for developing countries to leapfrog any challenges they have faced throughout their implementation. Other projects look to develop capacity by providing training (see FDMT, Africa) and scientific experience (see Indonesia text box).

SDG 13. Climate action

Every country in the world is affected by the climate change and its impacts. As a result all countries need to strengthen their resilience to climate-related hazards and natural disasters (target 13.1), such as floods and droughts. Three of the case studies directly address this target by optimizing infrastructure to manage crisis situations (e.g. see France), reducing pressure on centralised infrastructure in the case of flooding (e.g. see Canada) and by integrating SWM into adaptive planning and forecasting (e.g. see FDMT).

In order to integrate climate change measures into national policies, strategies and planning (target 13.2) the FDMT case uses climate data and forecasting to integrate plans for future flooding and drought events in developing regions. The planning tools utilized through the FDMT platform, encourage improved preparations and effective decision-making based on climate data and forecasting of hazards to be incorporated into national plans, especially in least developed countries such as those in the Volta and Lake Victoria pilot basins (target 13.B). Furthermore, the stakeholder training and information dissemination conducted throughout the FDMT project contribute to target 13.3 *in improving human and institutional capacity to handle climate change impacts*.

Increasing awareness of climate change adaptation has also been a key focus of the case studies in Mexico and SW4EU. A significant aspect of the PUMAGUA program was in education and information dissemination, through the Water Observatory and several communication campaigns, in order to increase awareness and participation. This aligns with several targets within the SDGs including 13.3 (to improve capacity for climate change impacts). The Canada and SW4EU projects both enabled community participants to be better informed about their local climate and rainfall data. The projects also showed the potential for SWM projects to raise capacity for climate change management in developing countries (target 13B, see FDMT and Mexico).

SDG 14. Life below water

While SWM often focuses on water for irrigation, human consumption, industry and sanitation, we must also consider how it can support our oceans, seas and marine sources. One way in which SWM is already doing this is through reducing marine pollution (target 14.1). By increasing irrigation efficiency, nutrient leaching reduces leading to reduced nutrient runoff and non-point source pollution into our rivers (see Africa case). By collecting rainfall at the source and reducing stormwater, non-source pollution from roads and footpaths is reduced (see Canada case study). By reducing contaminants in sanitation and returning the water in a clean state to our waterways, ecosystems can be restored, including fish stocks returning to their former numbers (see France). In this way, SWM is already providing considerable assistance to protecting and conserving our waterways, both inland and marine waterways. In the future, direct management of marine sources using SWM is a possibility, and one that could assist in protecting life below water even more.

SDG 15. Life on land

To protect life on land, land degradation must be reduced. To this end, both the K-HIT and FDMT projects provide flood and drought management to address land degradation (target 15.3) through operational action (see K-HIT) and planning approaches (see FDMT). By reducing land degradation to achieve neutral land degradation, terrestrial ecosystems can be protected, leading to reduced destruction of natural habitats and loss of biodiversity (target 15.5).

SDG 16. Peace, justice and strong institutions

One of the important aspects to promoting inclusive societies for sustainable development is ensuring responsive, inclusive, participatory and representative decision-making at all levels (target 16.7). As shown in through these case studies, the sharing of SWM data and engagement tools within the community opens up the opportunity for participatory decision-making. This has been shown consistently throughout the case studies (e.g. Africa, Paju, Mexico, SW4EU, Canada, FDMT). By providing real-time data, communities gain a greater awareness of the challenges faced, and are able to make decisions based on this data instead of based on the information passed on to them by other governing agencies. This has been shown to increase trust (see Mexico and Paju), develop stronger institutions (see Africa) and improve responsiveness and inclusivity (see China and SW4EU).

Another important aspect addressed by the SWM is the potential to develop effective, accountable and transparent institutions at all levels (target 16.6). With real-time data available at all levels, transparency is now increasingly possible, making each actor accountable for their actions and opening opportunities for more effective collaboration for SWM.

SUSTAINABLE DEVELOPMENT: HOW SWM CAN ASSIST IN ADDRESSING THE SDGS

SDG 17. Partnership for the Goals

In order to reach global sustainable development, strong partnerships, cooperation, knowledge sharing and capacity building are essential. Each of these projects have shown the potential for SWM to support collaboration and skill and knowledge transfer. This has been shown through collaborations between local and international agencies (see FDMT, Africa, China), capacity building for local workers (see Paju, Africa, FDMT) and enhancing knowledge sharing through partnerships (see K-HIT, Mexico, France, China). By sharing the lessons each of these projects has learned during their SWM implementation, upcoming projects in other countries gain experience and knowledge in what has worked in the past, what technologies can be used and what could work in the future in their region. By providing this support, these projects are supporting future projects to leapfrog any past challenges, and to implement successful SWM in the aim of reaching global sustainable development together.

CHAPTER 4. Conclusions and next steps

The SWM projects included within this report have shown the considerable potential for SWM to assist with numerous water challenges, across various scales, geographic locations and developing and developed regions while also creating social, economic, environmental and governance benefits. These projects have also demonstrated the enormous potential for SWM to assist with reaching the SDGs, across a number of goals and targets.

While it is important to recognise that each project is set within its own context, and therefore the results seen within these projects are also contextual, the overarching lessons that have emerged as part of this report highlight the similarities across contexts to show how SWM can be successfully implemented around the world, and what challenges there are still to face.

As SWM is still an emerging field these projects show the very beginning of what can be achieved using SWM technology and solutions. As the field progresses and technologies evolve, the potential for SWM adoption across all contexts will continue to grow, leading to increased opportunities for both developed and developing regions, and innovative solutions for our current water challenges.

In order to continue learning from these case studies, it is important to follow them on their journey to see how challenges are addressed as the technology evolves, and what impact introducing SWM continues to have in their region. To follow how the scaling up or down of a SWM project can affect its impact, and whether replication in various contexts results in new challenges to be addressed. It will also be interesting to see how SWM can move from the development and pilot stage to market - in other words, how SWM can become self-sustaining without reliance on initial government support in the early phases.

At this stage, many of these projects have shown the potential for SWM technology to successfully resolve water challenges. To build a business case for scaling and transferring these solutions, monitoring and measuring the benefits of SWM solutions must continue. In this way, capital investors will see the benefits and potential of SWM, potentially leading to future investment.

Now that a wider number of smart tools are on the market, integrated smart technologies to form smart networks will start to emerge, and with it increasing opportunities for sustainable cities and regions to integrate their smart systems.

This report demonstrates how far SWM has already come in a short time and the considerable benefits it can provide in both developed and developing regions. It also explores some of the constraints and barriers encountered to date. In the end, however, it is certain that SWM has nearly unlimited potential to contribute to the realization of the goals of integrated water resource management and sustainable development through smarter management of water.

CHAPTER 5. Glossary of Acronyms and Abbreviations

4MRRP	Four Major River Restoration Project
ACIAR	Australian Centre for International Agricultural Research
ADB	Asian Development Bank
AESN	Seine-Normandy Water Agency
AfDB	African Development Bank
AI	Artificial Intelligence
AIP	Agricultural Innovation Platform
AMI	Automated Metering Infrastructure
AMR	Automated Meter Reading
AMZ	Automatic Meter Readings
ANN	Artificial Neural Network
ANU	Australian National University
BBN	Bayesian Belief Nets
BCP3	Community Based Public Private Partnerships
BED	Binomial Event Discrimination
BOD	Biochemical Oxygen Demand
BRAIN	Bio-reactor Plants
CAADP	Comprehensive African Agricultural Development Plan
CCA	Causal Chain Analysis
CCTV	Closed Circuit Television
CDMA	Code Division Multiple Access
CFPD	Comparison of Flow Pattern Data
CGS	Chinese Geological Survey
CIGEM	Centre for Migration Management and Information
COD	Chemical Oxygen Demand
CONAGUA	National Water Commission, Mexico
CPA	Consumption Prediction Algorithm
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSL-CDA	Customer-side-leakage Discrimination Algorithm
CSO	Combined Sewer Overflows
DBM	Dynamic Bandwidth Monitor
DMA	District Metered Area
DMZ	Dematerialised Zone
DSS	Decision Support Systems
EA	Electrically actuated
EDEN	Environmental Data Exchange
EIP	European Innovation Platform
EMF	Electro Magnetic Flow
EPA	Environmental Protection Agency

ETH	Swiss Federal Institute of Technology Zurich
EVT	Energy Visualisation Tool
FAO	Food and Agriculture Organisation
FAS	Flood Analysis System
FDMT	Flood and Drought Management Tool
FMZ	Flow Monitoring Zones
FRC	Free Residual Chlorine
GDP	Gross Domestic Product
GEF	Global Environment Facility
GHG	Greenhouse gases
GI	Green Infrastructure
GIOS	Generation Integrated Operation System
GIS	Geographic Information Systems
GIWP	General Institute of Water Resources and Hydropower Planning and Design
GPRS	General Packet Radio Service
GPS	Global Positioning System
GRDP	Gross Regional Domestic Product
GUI	Graphical User Interface
GWP	Global Water Partnership
ha	Hectare
HB	Hydraulic Balance Algorithm
HPC	High Performance Computer
HWL	High Water Level
IC	Integrated Circuit
ICT	Information and Communication Technology
IDB	Inter-American Development Bank
IoT	Internet of Things
IPCC	Intergovernmental Panel on Climate Change
IW	International Waters
IWA	International Water Association
IWA	International Water Association
IWRA	International Water Resources Association
IWRM	Integrated Water Resource Management
IWRMS	Integrated Water Resource Management System
K-HIT	K-water Hydro Intelligent Toolkit
K-water	Korea Water Resources Corporation
KMA	Korea Meteorological Administration
KRW	South Korean won
LAN	Local Area Network
LCD	Liquid Display Crystal
LEC	Local Electrification Company
LID	Low Impact Development
LIFT	Leaders Innovation Forum for Technology
LPWAN	Lower Power Wide Area Network

LRV	Log Reduction Values
MAGES	Model Assistance for the Management of SIAAP Effluents
MCA	Multi Criteria Analysis
MNCM	Minimum Night Consumption Monitoring
MNF	Minimum Night Flow
MODFLOW	Modular Hydrologic Model
MOLIT	Ministry of Land, Infrastructure and Transport
NASA	National Aeronautics and Space Administration
NB-IoT	Narrowband Internet of Things
NEMA	National Environment Management Authority
NGO	Non-governmental Organisation
NOAA	National Oceanic and Atmospheric Administration
NRW	Non-revenue Water
O&M	Operation and Maintenance
OECD	Organisation for Economic Co-operation and Development
OFID	OPEC Fund for International Development
OPEC	Organisation of the Petroleum Exporting Countries
P3	Private Public Partnership
PFS	Precipitation Forecasting System
pH	Logarithmic scale used to specify the acidity or alkalinity of an aqueous solution
PIR	Project Implementation Reviews
PMA	Pressure Management Area
PMF	Probable Maximum Flood
PMU	Project Management Unit
PoE	Power over Ethernet
PRV	Pressure Reducing Valve
PUMAGUA	Program for Management, Use, and Reuse of Water
QPF	Quantative Precipitation Forecast
R&BD	Research and Business Development
R&D	Research and Development
RCP	Representative Concentration Pathways
RHDAPS	Real-time Hydrological Data Acquisition and Processing System
RSSUT	Residential Stormwater Smartgrid Utility Technology
RTC	Real-time Control System
RTMMS	Real-time Reservoir Turbidity Monitoring and Modelling System
RwH	Rainwater Harvesting
RWSS	Reservoir Water Supply System
SAMS	Stochastic Analysis Modelling Simulation
SAP	Strategic Action Programme
SCADA	Supervisory Control and Data Acquisition
SDG	Sustainable Development Goal
SDMA	Sub District Metering Area
SHP	Small Hydropower

SIAAP	Interdepartmental Syndicate for the Sanitation of Greater Paris
SICT	Sensing, Information and Communication Technology
SMART	Specific, Measureable, Actionable, Relevant and Time-based
Smart T-M	Smart Tele-metering
SMS	Short Messaging Service
SPI	Standardisation Precipitation Index
SSA	Sub-Saharan Africa
SVM	Support Vector Machines
SW4EU	Smart Water For Europe
SWC	Smart Water City
SWG	Smart Water Grid
SWING	Smart Water Innovation Network in the city of BurGos
SWM	Smart Water Management
TDA	Transboundary Diagnostic Analysis
TP	Total Phosphorus
TRMM	Tropical Rainfall Measuring Mission
TWIST	Thames Water Innovation and Smart Technology
UFW	Unaccounted for Water
UN	United Nations
UNAM	National Autonomous University of Mexico
UNEP	UN Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organisation
USD	United States Dollar
UV	Ultra violet
VIA	Virtual Water Academy
VIP	Vitens Innovation Platform
WAN	Wide Area Network
WB	World Bank
WDS	Water Distributed System
WFD	European Water Framework Directive
WHO	World Health Organisation
WRF	Water Research Foundation
WRIAM	Water Resource Issue Assessment Method
WSP	Water Safety Planning
WWTP	Wastewater Treatment Plant

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