

Flood resilience and smart water management: implementation strategies for smart cities

Lian Guey Ler

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ÉCOLE DOCTORALE

SCIENCES ET TECHNOLOGIES DE L'INFORMATION ET DE LA COMMUNICATION



THÈSE DE DOCTORAT

FLOOD RESILIENCE AND SMART WATER MANAGEMENT:

Implementation Strategies for Smart Cities

Lian Guey LER

Polytech Lab

Présentée en vue de l'obtention du grade de docteur en discipline d'Université Côte d'Azur et de Université Nationale d'Incheon Dirigée par : Philippe Gourbesville Co-encadrée par : Gyewoon Choi Soutenue le : 11 Juin 2018

Devant le jury, composé de :

Dongwoo Kim, Pr, Université Nationale d'Incheon Jung-Kyu Ahn, Pr, Université Nationale d'Incheon Manuel Valentin Gomez, Pr, Université Polytechnique de Catalogne Philippe Audra, Pr, Université de Nice Shie Yui Liong, Pr, Université Nationale de Singapour



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"Ever tried. Ever failed. No matter. Try Again. Fail again. Fail better." ~ Samuel Beckett (Worstward Ho, 1983)

ABSTRACT

The key aims of this thesis are to identify the challenges and strategies for implementing Flood Resilience and Smart Water Management (SWM) solutions at both the policy and field level to for efficient water management.

In the next decade, more than 4 billion people worldwide will be living in areas of water scarcity and more than two thirds of the world's population will face water-stressed conditions. This future water shortage requires immediate action on development of resources, reduction of demand and higher efficiency in treatment and transmission. In addition, future flood risk management requires immediate action in risk assessment, defence and alleviation systems, forecasting and warning systems and institutional and governance measures.

And with the climate change impacts, extreme events will be more frequent and severe. As a result, there is a necessity to adopt alternative strategies rather than the traditional predict-and-prevent approach which mainly focuses on reducing the probability of occurrence of disturbances; where this type of approach often led to an extensive construction of protection dykes, flood defences and other structural solutions along river channels and floodplains, creating a false sense of safety, which increases the vulnerability to the consequences of possible floods.

The first half of the thesis explores the various applications of flood resilience strategies and the available solutions that are and can be implemented to mitigate flood impacts. It also examines the effectiveness of flood resilience solutions through hydrological hydraulic simulations of a real case study in South Korea. From the analysis, recommendations and strategies are developed where it is found that Smart Water Management is an enabler for the implementation for Flood Resilience solutions and has great synergy with Flood Resilience concepts.

The second half of the thesis explores the concept of Smart Water Management and discusses the technologies required for the implementation and their challenges and limitations. Successful case studies of smart water solution implementations are investigated and used to validate the direction and action plans for the implementation of smart water solutions. In addition, a framework for the implementation of Smart Water System for an urban city, which includes the water demand system and water supply system, as well as a leakage detection indicator for water supply system are proposed. Finally, it discusses the importance of smart city connections between the different domains of a smart city with the smart water system and how these connections occur within the smart water system.

RÉSUMÉ

Les objectifs principaux de cette thèse sont d'identifier les défis et stratégies afin de mettre en œuvre des solutions de Résilience et de Smart Water Management au niveau des politiques et sur le terrain pour une gestion efficace de l'eau.

Au cours de la prochaine décennie, plus de 4 milliard de personnes dans le monde vivront dans des zones de pénurie d'eau, et plus des deux tiers de la population mondiale seront confrontés à des conditions de stress hydrique. Cette pénurie d'eau future nécessite une action immédiate sur le développement des ressources, la réduction de la demande et une plus grande efficacité dans le traitement et la transmission. En outre, la gestion future des risques d'inondation nécessite des mesures immédiates dans les domaines de l'évaluation des risques, des systèmes de défense et d'atténuation, des systèmes de prévision et d'alerte, et des mesures institutionnelles et de gouvernance.

Avec les impacts du changement climatique, les événements extrêmes seront plus fréquents et sévères. En conséquence, il est nécessaire d'adopter des stratégies alternatives plutôt qu'une approche traditionnelle « prédire et prévenir », qui se concentre principalement sur la réduction de la probabilité d'apparition de perturbations; ce type d'approche a souvent conduit à une construction extensive de digues de protection, à des des protections contre les inondations et à d'autres solutions structurelles le long des rivières et des plaines inondables, créant un faux sentiment de sécurité qui augmente la vulnérabilité aux conséquences d'éventuelles inondations.

La première moitié de la thèse explore diverses applications des stratégies de résilience aux inondations et les solutions disponibles qui sont et qui peuvent être mises en œuvre pour atténuer les impacts des inondations. L'efficacité des solutions de résilience aux inondations est également examinée, grâce à des simulations hydrologiques hydrauliques d'une étude de cas réelle en Corée du Sud. À partir de cette analyse, des conseils et des stratégies sont développées : la gestion intelligente de l'eau s'avère être un outil permettant la mise en œuvre de solutions de résilience aux inondations, et offrant d'importantes synergies avec les concepts de résilience aux inondations.

La seconde moitié de la thèse explore le concept de Smart Water Management et examine les technologies nécessaires à sa mise en œuvre, ainsi que les défis et limites de ces technologies. Des études de cas sur des projets réussis de mise en œuvre de gestion intelligente de l'eau sont étudiées et utilisées pour valider l'orientation et les plans d'action pour la mise en œuvre de gestion intelligente de l'eau sont étudiées et l'eau. De plus, un cadre de mise en œuvre du système d'eau intelligent pour une ville urbaine est proposé, comprenant le système de demande en eau et le système d'approvisionnement en eau, ainsi qu'un indicateur de détection de fuites pour le système d'approvisionnement en eau. Enfin, on examine l'importance des connexions intelligentes entre les différents domaines d'une ville intelligente avec le système d'eau intelligent et comment ces connexions se produisent dans le système d'eau intelligent.

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LIST OF ABBREVIATIONS

A/M	Asset Management	WWTP
BP	Business Process	WWNM W
BU	Business Unit	
CDMA	Code Division Multiple Access	
CPS	Cyber Physical System	
DMA	District Metering Area	
DSS	Decision Support System	
DW	Drinking Water	
DWNM	Drinking Water Network Management	
DWTP	Drinking Water Treatment Plant	
ICT	Information and Communication Technologies	
IFM	Integrated Flood Management	
ΙοΤ	Internet of Things	
IS	Information System	
IS/IT	Information System / Information Technology	
IT	Information Technology	
IWRM	Integrated Water Resource Management	
MDM	Meter Data Management	
MIU	Meter Interface Unit	
NRW	Non-Revenue Water	
SDO	Standards Development Organization	
SER	Social-Ecological Resilience	
SSI	Small Scale Implementation	
SWG	Smart Water Grid	
SWM	Smart Water Management	
SWNM	Storm Water Network Management	
VHF	Very High Frequency	
VSAT	Very Small Aperture Terminal	
W/M	Work Management	
WoT	Web of Things	
WSD	Web Services for Devices	
WssTP	Water Supply and Sanitation Technology Platform	
WW	Waste Water	

WWTP	Waste Water Treatment Plant
WWNM	Waste Water Network Management

1.INTRODUCTION

1.1 Background

In the next decade, more than 4 billion people (two thirds of the world's population) worldwide will be living in areas of water scarcity where they will live under conditions of severe water scarcity at least 1 month of the year. Among these 4 billion people, half of them will be living in India and China and half a billion people in the world will face severe water scarcity all year round. (Mekonnen & Hoekstra, 2016) This future water shortage requires immediate action on development of resources, reduction of demand and higher efficiency in treatment and transmission. In addition, future flood risk management requires immediate action in risk assessment, defence and alleviation systems, forecasting and warning systems and institutional and governance measures.

And with the climate change impacts, extreme events will be more frequent and severe. As a result, there is a necessity to adopt alternative strategies rather than the traditional predict-and-prevent approach which mainly focuses on reducing the probability of occurrence of disturbances. This type of approach often led to an extensive construction of protection dykes, flood defences and other structural solutions along river channels and floodplains, creating a false sense of safety that increases the vulnerability to the consequences of possible floods. This brought forth Flood Resilience and Smart Water Management into the focus as alternative solutions for flood management and water resource management respectively.

1.2 Motivations to Consider Flood Resilience and Smart Water Management

Concepts like sustainable or ecologically sustainable flood management present strategies based on "creating room for the river" or "living with floods" which are being evaluated and considered for cases like the Rhine and Meuse in Netherlands, the Loire in France , the Morava in Slovakia, the Clyde in Scotland and the Tagliamento in Italy and the Young Brahmaputra floodplain in Bangladesh . The sustainability and effectiveness of these measures are highly dependent on the conditions of the basin, the time scale adopted and the flexibility to cope with changing conditions in the future (Hooijer, Klijn, Kwadijk, & Pedroli, 2002). This relation has led to the integration of the resilience concept into flood risk management. (De Bruijn & Klijn, 2001)

In addition, the advancement of Information Communication Technology (ICT) in recent years, in particular in the field of wireless communication, mobile communication devices and cloud technologies and computing have led to adoption of smart water management technologies. All these improvements allow real-time monitoring of water infrastructures and their environment, real-time analysis and forecasts for early warning and decision-support systems and fast reaction time to potential flood or other water-related issues.

Moving traditional flood and water management to flood resilience and smart water systems will provide new tools to tackle some of the problems that modern cities are facing and also foster innovative approaches to ensure safe and adequate water provision. Both Flood Resilience and Smart Water Management (SWM), seeks to promote a sustainable, well-coordinated development and management of water resources through the integration of ICT products, tools and solutions; thus providing the basis for a sustainable approach to water management and consumption.

By harnessing the potential of ICTs in cities, the implementation of SWM can help to overcome water related socio-economic, cultural and environmental challenges, as well as to equip cities with technology to mitigate the impacts of climate change.

1.3 CORFU, NEMA and WIDEST

The research in this thesis is conducted in conjunction with the various projects listed below:

- i. CORFU¹: Collaborative Research on Flood Resilience in Urban areas (CORFU) is a FP7 4 -year collaborative research project with the overall aim to enable European and Asian partners to learn from each other through joint investigation, development, implementation and dissemination of short to medium term strategies that will enable more scientifically sound management of the consequences of urban flooding in the future. The research includes flood impact assessment and flood mitigations strategies related to planning and prevention for flood risk reduction and management during and after flood events.
- ii. NEMA: Natural Disaster Reduction Technology Development Project is a four year project support by the National Emergency Management Agency of South Korea. The research objectives include reviewing existing flood measures and developing solutions to overcome the limitations of the existing solutions against extreme floods events.
- iii. WIDEST²: Water Innovation through Dissemination Exploitation of Smart Technologies) is a European Commission (H2020 Coordination and Support Action) project that aim to establish and support a thriving and interconnected Information and Communication Technology (ICT) for the Water Community by promoting the dissemination and exploitation of the results of European Union (EU) funded activities in this area.

¹ http://www.corfu7.eu/theproject/

² https://www.widest.eu/

1.4 Objectives

The objective of the research is to examine the flood resilience and smart water management concepts and implementations, to develop strategies, recommendations and action plans for the implementation of flood resilience and smart water solutions. Different concepts and approaches of flood resilience are examined and analysed. Some of the issues examined include: (1) What is the definition of resilience that is useful and applicable in the context of flood management? (2) What indicators can be used to make resilience concepts quantifiable? and (3) What are the trends and limitations of flood resilience solutions?

Similarly for Smart Water Management, the trends, limitations and challenges in the implementation of smart water solutions are examined with the help of case studies of successful implementation of smart water solutions. The outcomes of the analysis will be used to formulate recommendations and action plans to facilitate the implementation of smart water technologies. In addition, the framework of smart water management will be discussed with respect to the water business processes in urban city and integration with the other domains of a smart city.

1.5 Structure of Thesis

The thesis comprise of 2 parts: (1) Flood Resilience and (2) Smart Water Management. Each part will have its own described methodology, results and discussions.

- **Chapter 1:** introduces the background of the water and flood management, the motivation and objectives of the research.
- Chapter 2: explores the concept of Flood Resilience and discuss the different solutions that are and can be implemented to mitigate flood impacts. It also examines the effectiveness of flood resilience solutions through hydrological hydraulic simulations of a real case study in South Korea. Discussion on how and why Smart Water Management is the next logical step forward in realizing flood resilience solutions.
- Chapter 3: explores the concept of Smart Water Management in the widest scope. It also
 discusses the technologies required for the implementation and their challenges and
 limitations. Successful case studies of smart water solution implementations are investigated
 and used to validate the direction and action plans for the implementation of smart water
 solutions.
- **Chapter 4:** proposes the framework for the implementation of Smart Water System for an urban city, which includes the water demand system and water supply system In addition, a leakage detection indicator will be introduced for water supply system. Discussion regarding the importance of smart city connections between the different domains of a smart city with the smart water system will be conducted.
- Chapter 5: provide a summary and conclusion of the research conducted.

2. Flood Resilience

2.1 Concept of Resilience

The concept of resilience, which originates from ecology, has been introduced in flood risk management to describe the ability of a system to return to a normal situation after flooding of a part of the area caused by a peak discharge. (De Bruijn & Klijn, 2001)

Nowadays, two different resilience definitions are being used (Figure 1):

- i. Resilience is the ability of a system to maintain its most important processes and characteristics when subjected to disturbances (Holling, 1973) and
- ii. Resilience is the ability of a system to return to its equilibrium after a reaction to a disturbance (Pimm, 1984).



Figure 1: Two definitions of resilience (Adger, 2000)

The graph on the left in Figure 1 represents the focus on the magnitude of disturbance that a system can absorb. The right graph represents the focus on recovery speed/time. Table 1 summarized the concept to the broader social-ecological context. The social-ecological resilience (SER) shows a research trend in which the understanding of resilience in natural systems is applied to the interplay between social and ecological systems. In this area of research, resilience is perceived as —the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks (Walker, Holling, Carpenter, & Kinzig, 2004)

Resilience concept	Characteristics	Focus on	Context
Engineering resilience	Return time, efficiency	Recovery, constancy	Vicinity of a stable equilibrium
Ecological/ecosystem resilience social resilience	Buffer capacity, Withstand shock, maintain function	Persistence, robustness	Multiple equilibrium, Stability landscapes
Social-ecological Resilience	Interplay disturbance and reorganization, sustaining and developing	Adaptive capacity transformability, learning, innovation	Integrated system feedback, cross-scale interactions

Table 1: The sequence of resilience concepts (Folke, 2006)

2.2 Risk, Vulnerability & Hazards

United Nations International Strategy for Disaster Reduction (UNISDR)³ defines Resilience as the ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management. In addition, it has defined 'Disaster Risk Management' and 'Disaster Reduction' as one of the contributions in strengthening the resilience of the cities.

Risk (or more specifically, disaster risk) is the potential disaster losses (in terms of lives, health status, livelihoods, assets and services) which could occur to a particular community or a society over some specified future time period. It considers the probability of harmful consequences, or expected losses (deaths, injuries, property, livelihoods, economic activity disrupted or environmentally damaged) resulting from interactions between natural or human induced hazards and vulnerable conditions.

Risk can be calculated using the following equation:

Risk = (Probability of Hazard x Degree of Vulnerability) - Capacity

Vulnerability refers to the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard. There are many aspects of vulnerability which arise from various physical, social, economic, and environmental factors. They include:

- poor design and construction of buildings
- inadequate protection of assets
- lack of public information and awareness
- limited official recognition of risks and preparedness measures

³ https://www.unisdr.org/we/inform/terminology

Capacity refers to the strengths, attributes and resources available within an organization, community or society to manage and reduce disaster risks and strengthen resilience. These resources include infrastructure, institutions and human knowledge and skills.



Figure 2: Definition of Risk

There are different ways of dealing with risk, such as⁴:

- **Risk Acceptance:** An informed decision to accept the possible consequences and likelihood of a particular risk.
- **Risk Avoidance:** An informed decision to avoid involvement in activities leading to risk realization.
- **Risk Reduction:** An application of appropriate techniques to reduce the likelihood of risk occurrence and its consequences.
- **Risk Transfer:** Shifting of the burden of risk to another party. One of the most common forms of risk transfer is Insurance.

2.3 Framework for Flood Risk Management

Flood risk management aims to reduce the likelihood and/or the impact of floods. Experience has shown that the most effective approach is through the development of flood risk management programs incorporating the following elements⁵:

• Prevention: preventing damage caused by floods by avoiding construction of houses

⁴ http://www.odpm.gov.tt/node/162

⁵ http://ec.europa.eu/environment/water/flood_risk/flood_risk.htm

and industries in present and future flood-prone areas; by adapting future developments to the risk of flooding; and by promoting appropriate land-use, agricultural and forestry practices;

- **Protection:** taking measures, both structural and non-structural, to reduce the likelihood of floods and/or the impact of floods in a specific location;
- **Preparedness:** informing the population about flood risks and what to do in the event of a flood;
- Emergency response: developing emergency response plans in the case of a flood;
- **Recovery and lessons learned:** returning to normal conditions as soon as possible and mitigating both the social and economic impacts on the affected population.



Figure 3: Flood Risk Management Cycle (FOCP, 2014)

Based on the 5 elements defined by UNISDR, the flood risk management cycle in Figure 3 shows how the elements interact with each other before, during and after the occurrence of a flood.

In the event of a flood occurrence, response plans and activities are carried out to reduce

flood damage. Once flood damage is under control, recovery plans are conducted to return the city to the normal state as soon as possible.

When the flood event is over, analysis will be done to investigate the impacts of the flood, in order to come up with mitigation action plans and solutions to protect and prevent similar floods to occur in the future. This also includes warning system to provide the city sufficient time to react before the occurrence of future flood.

2.4 Flood Resilience Strategies

Based on these concepts and strategies like 'Integrated Water Basin Management' and 'Green Rivers' have been presented and evaluated as solutions for an alternative flood management schemes that are able to cope better with the uncertainties of the future.

In order to have a sustainable flood management, one should need to look at (Hooijer, Klijn, Kwadijk, & Pedroli, 2002):

- i. **Reducing Damage.** When the lowering of flood levels cannot be achieved to a great extent and even when it can, there is a need to reduce the damage potential in the frequently, occasionally and even rarely flooded areas. Therefore, the most effective and sustainable reduction of flood risks could be achieved by reducing the potential damage in flood-prone areas through adapted land use and spatial planning. It also agreed on the fact that the efficiency over time depends on the minimization of potential damage.
- ii. Room. 'Flood risk management strategies and measures should be developed in anticipation of higher peak discharges in the future. As uncertainties about future developments will remain, room should be reserved in view of possible future measures. It must be noted that this room needed is not lost permanently for human uses but rather modified to hold different functions that will include water storage or discharge during temporal periods only.
- iii. Diversification. In order to reduce damage caused by different types of floods, in different areas, different strategies are required. For the Rhine and Meuse basins in the light of the extreme high-water events, technical measures near the source—i.e. land use change in the upstream basin, and retention measures along the upstream channels, are not very effective in preventing extreme flood events along the lower Rhine and Meuse rivers and would require localized measures. However, these measures will be very effective in flood risk management for larger river basins than the Rhine and Mesue basins where greater areas remain in (or can be returned to) their natural state. Thus it is recommend that the targets and measures to be diversified and regionalized.
- iv. **Integration.** A long term, interdisciplinary strategy, flexible enough to cope with different levels of risk, based on the combination of structural and non-structural measures should be applied

at the basin level, and across boundaries where necessary. (WWF, 2004).

To bring the concept of resilience into flood management is still what it appears to be a combination of adaptation and flood management strategies, having still an extensive open space for new ideas and innovation. Two means of finding new resilience measures are presented: Operationalizing a resilience approach for adaption to climate change by (Wardekker, Jong, Knoop, & van der Sluijs, 2010) and a way of looking to work with nature. (WWF, 2004).

2.4.1 Operationalizing a Resilience Approach

The principles are described in Table 2 with some examples of the options found during the study.

Principle	Description	Examples
Homeostasis	Multiple feedback loops counteract disturbances and stabilize the system	Enhance ventilation and cooling of the area through house design and spatial planning.
Omnivory	Vulnerability is reduced by diversification of resources and means	Multi-functional buildings. Diversified energy supply options.
High Flux	A fast rate of movement of resources through the system ensures fast mobilization of these resources to cope with perturbations	Elevated ground level. Re- buildable city with reusable and easy to deconstruct materials.
Flatness	The hierarchical levels relative to the base should not be top-heavy in order to rapidly implement non- standard highly local responses	Allocation of competence and power for a self-reliant, self- sufficient, self-regulating, and self-organizing society.
Buffering	Over-dimensioning of essential capacities such that critical thresholds are less likely to be crossed	Elevated areas for essential functions. Parks and underground storage areas.
Redundancy	Overlapping functions. If one fails, others can take over.	Multiple routes, multiple crisis- centers, multiple access levels in buildings.

Table 2: Resilience principles for operationalizing a resilience approach for adaption to climatechange (Wardekker, Jong, Knoop, & van der Sluijs, 2010)

2.4.2 Working with Nature

There are two processes in unaltered river systems that deal with floodwaters are transfer and storage. (WWF, 2004) In natural unaltered river systems, both these processes take place. Wetlands provided areas of flood storage while water moves quickly through steep-sided valleys and gorges.



Figure 4: Principles to attain resilience strategies

These are the two available options that flood management has to cope with floods. Based on this and on the fact that natural ecosystems and non-built environments are more resilient than common built environments some ideas to build resilience can be drawn by aiming at one or more of the following principles:

- (a) Imitation of non-built environment,
- (b) Conservation of non-built environment,
- (c) Adaptation to nature
- (d) Integration or combination of strategies.

Based on these principles and on the conditions of the area of study, a strategic plan can start to be framed to deal with risks like flooding. Further analysis and evaluation of the effectiveness of the strategies would be needed before a final plan can be proposed. An effective combination of strategies will give a higher level of resilience for the system.

2.5 Structural and Non-Structural Flood Measures

It is essential to have a combination of structural and non-structural measures in order for the system to be flexible enough to cope with different levels of flood risk. It is also noteworthy to reiterate that the management of flood has evolved through the years: In the mid-20th century, it was focus on the engineered defences for the management of floods, where now in the present there is an emerging trend of using natural resource management for the coping of flood management.

UNISDR defined structural measures as any physical construction to reduce or avoid possible impacts of hazards, or the application of engineering techniques or technology to achieve hazard resistance and resilience in structures or systems. Non-structural measures are defined as not involving physical construction which use knowledge, practice or agreement to reduce disaster risks and impacts, in particular through policies and laws, public awareness raising, training and education.

Common structural measures for disaster risk reduction include dams, flood levies, ocean wave barriers, earthquake-resistant construction and evacuation shelters. Common non-structural measures include building codes, land-use planning laws and their enforcement, research and assessment, information resources and public awareness programmes. Note that in civil and structural engineering, the term "structural" is used in a more restricted sense to mean just the load-bearing structure, and other parts such as wall cladding and interior fittings are termed "non-structural".

2.5.1 Structural Flood Measures

Construction of embankments has been the most popular structural method of flood control/mitigation in many parts of the world like Netherlands, Bangladesh, China, the United States, Canada and New Zealand. Such measures are provided to protect agricultural lands, rural settlements, and urban areas where they aim to: (1) reduce flood flows and (2) better accommodate flood flows like through the following solutions:

- Construction of flood management reservoirs and detention ponds
- Heightening and strengthening existing dykes
- Setting dykes further away from the low flow channel.
- Dividing of existing flood basins into smaller compartments (compartmentalization) using additional dykes.
- Removal of hydraulic obstacles from the river bed between the dykes.

2.5.1.1 Room for River

One example is the 'Room for River' program, which was developed in many European countries, including Belgium (Hoffmann, Graré, & Meire, 1997), the UK (DEFRA, 2004), Germany (Hartmann, 2010), Switzerland (Zaugg Stern, 2003) and Hungary. In Netherlands, 'Room for River' was declared as the new Dutch flood policy, representing the shift from 'resisting nature' to 'working with nature' (Wolsink, 2005)

In Netherlands, there is a $\in 2.2$ million propose package that consists of about 40 measures which cover 5 provinces of 60 municipalities containing 725 km length of dikes and will be supervised and carried out by 3 ministries where it is expected to be completed by 2015. Figure 3 shows the measures which consist of (a) Relocation of dyke, (b) Lower of floodplain level, (c) Height reduction of groynes, (d) Addition of side channels, (e) Green River and (f) Removal of obstacles. (Nijland, 2007)



Figure 5: Diagrams of the proposed measures in the 'Room for River' Program (Nijland, 2007)

A analysis suggest that overall the Netherlands' 'Room for the River' program can be considered a successful attempt to bring together the worlds of water management and spatial planning. However, it is less successful in bridging the gap between the civil engineers and planners on the one hand and the citizens and local stakeholders on the other hand. Initially it was the conflict between water safety and spatial development. Now it is between area development (a combination of both) and the interests and values of the residents and local interest groups. (Warner & van Buuren, 2011)

Nonetheless, there is a successful case for Netherlands' 'Room for River Waal' in Nijegen. This river Waal has a sharp bend near Nijmegen which forms a bottleneck. As a result, there had been high water and flood in 1993 and 1995. To solve the flood issue, the Wall dike located in Lent is moved inwards and an ancillary channel in the flood plains is constructed as shown in Figure 6. This increase of River Waal's capacity as well as slowing down the river flow, hence reducing the risk of flooding to the region. In addition, the artificial island created in the River Wall provides an urban river park with possibilities for recreation, culture, water and nature, proving an economical and socially sustainable and safe resilience solution.



Figure 6: Measures at River Waal shown in phases⁶

[1- The present situation with the existing dike; 2 –Moving of dyke to 350m inland; 3- ancillary channel dug to give the river more room, creating an elongated island; 4-bridges across the channel]

2.5.1.2 Green Roofs

Green roof technology has been used in many urban settings to improve storm water management by reducing total quantities of rooftop runoff and peak flow rates during high-intensity rains. The water quantity retention performance of green roofs has been measured and documented for a range of conditions and design parameters. Green roofs will absorb significant amount of stormwater during low to moderate rainfall and during extreme events, will delay and reduce peak flows. Research has shown that green roofs with 3" to 4" of growing medium vegetated with a mixture of sedum plants plus a commercial drainage mat, a root barrier and standard waterproofing generally retain stormwater runoff by 50-100% during most rains resulting in an average of about 50% - 75% total water retention from rainfall over a typical year. (Johnson, 2008)

In Copenhagen, Denmark, the government has make it mandatory for all new flat roofs at or

⁶ https://az819957.vo.msecnd.net/userfiles/www-ruimtevoordewaal-nl-en/635978679476652150-englishbrochure.png

under a 30 degree-pitch, both private and public, to be vegetated. If old roofs have to be retrofitted, the building owner may be able to receive public financial support for a green roof. In addition, the city of Copenhagen has set up requirements which the buildings with green roof have to meet at least 2 of them⁷:

- i. Absorb 50-80% of the precipitation that falls on the roof
- ii. Provide a cooling and insulating effect of the building and reduce reflection
- iii. Help make the city greener, reducing the urban heat island effect
- iv. Contribute to a visual and aesthetic architectural variation that has a positive effect on quality of life
- v. Double the roof life as roofing membrane is protected against UV rays reactive power buildings have made.

Also, for its adaption to Climate Change in year 2025, Denmark has also introduce a plan – 'Adaption Imitative 2', where green areas, pocket parks, green roofs and green walls are installed to slow down the rainfall runoff. In addition, the city realised that green roofs not only capture 60 % of rainfall, but also improve air quality, vegetation and wildlife.⁸

In Singapore, a 'Green Roof Incentive Scheme' has been implemented by the government to encourage owners of existing buildings to green their roofs. Under this new scheme, the government will fund up to 50% of the installation costs of the green roofs.⁹ Such incentives are much welcomed to make the green roof technology affordable and common practices in the future.

2.5.1.3 Green Spaces

Another alternative to flood defences is the installation of green spaces. Studies has shown that the runoff rate for surfaces with trees and grass is estimated to be 10-20% as compared to 60-70% for hard landscaped areas' (Solina, 2010). As such green defences may only flood occasionally (maybe once a year); this makes it a good recreational site during the dry periods for the residents. This also improves the biodiversity of the region, which in turns make it an environmental and socially sustainable solution.

A recent study done in UK (Kelly, Luke, & Lima, 2011) looks at the feasibility and potential of Urban Blue Corridors, which they define it as a strategy that uses both new and existing development within the urban environment setting, watercourses, overland flow paths and surface water ponding

⁷ http://livingroofs.org/20100522222/world-green-roof-policies/copenhagen-green-roofs.html

⁸ http://www.igra-world.com/links_and_downloads/images_dynamic/IGRA_Green_Roof_News_1_2010.pdf

⁹ http://www.skyrisegreenery.com/index.php/home/gris/about_the_scheme

areas to create a network of urban corridors designed to natural hydrological processes whilst minimising urban flooding, enhancing biodiversity, improving access to recreation and helping to adapt to climate change.

One of the main benefits of Urban Blue Corridors is in reducing flood risk as they can provide low risk flow paths and areas for sustainable drainage and water storage. Sustainable drainage may also be used for water reuse to reduce pressure on water resources. By relocating flood defences and development away from a watercourse, it can restore part or all of the natural floodplain, reducing risk elsewhere by creating extra storage for floodwaters. These storage areas can also be used for recreation, for example playing fields and golf courses, and provide ecological benefits (Donovan, Sadler, & Bryson, 2005). For example, research has shown a higher species richness within clusters of ponds than within single sites, demonstrating the importance of habitat connectivity and a holistic approach. (Gledhill & James, 2008)

In the city of Derby, UK, a blue corridor is planned for the River Derwent with the aim to make the river an integral part of the urban environment, increase flood protection through the City of Derby, protect and enhance biodiversity and reduce the impact on existing and future development. The corridor will be located through the City of Derby and include the River Derwent. When established, the corridor will be 120 metres wide and will broadly extend to the boundary defined in green in the Figure 7. The function of the corridor is to allow the area within the corridor to flood up to 1:100 year flood event. The land within the 'Blue Corridor' will effectively become part of the river's functional floodplain.



Figure 7: Location and extend of the blue corridor (Kelly, Luke, & Lima, 2011)

To maximize the benefits of the Urban Blue Corridor, it can be integrated with green infrastructures like green roof, green walls, rainfall harvesting capabilities and retention ponds. A research conducted by Imperial College in 2010 recommends a concept of a 'Blue-Green Corridor'¹⁰ for the urban setting. The purpose of this Blue-Green Corridor is to incorporate the roles of sustainable urban drainage, river restoration and flood management where the green spaces and the river corridor and its tributaries are interconnected. This will reduce the rain surface runoff as well as facilitate the overland flow, hence reducing the flood risk and mitigating the flood impacts in the region. To access the feasibility of this concept, a case study area in London Borough of Sutton, UK has been used to analyse its potential and evaluate the issues of implementation for the Blue-Green Corridors across the catchment. In order to provide a significant reduction in stormwater runoff from extreme rainfall events, there is a need to install an intensive amount of the Blue-Green Corridor components, which would require significant support from the stakeholders and city planners to implement them. And this may be difficult to implement voluntary if there is no direct risk to the individual property, any regulatory requirement or incentive.

2.5.1.4 Height-Adjusting Floating Wall

One solution to make the existing embankments resilient is to install an add-on structure which rises automatically when the tide is high, creating an additional protection. This is a relatively new technology with several different designs. One such design is shown in Figure 8.



Figure 8: Schematic diagram of the floating wall during low (left) and high (right) water level.

¹⁰ https://workspace.imperial.ac.uk/ewre/Public/MSc%20posters%202010/SkiltonPosterMAKSIMOVIC.pdf

This prototype design constructed in 2012 is a floating wall made of hollow iron cast such that during the high tide, water entered through the inlets making the wall to float. A screen is attached on the landward side to contain any water which may come from under the floating wall during full capacity. A full scale pilot model has been constructed and has shown successful results. The benefits of using such design instead of the conventional wall are that this provides easy access to the river during low tides and is non-motorised. The drawbacks of this solution are that is expensive to install and requires continuous monitoring and maintenance to maintain its function.

2.5.2 Non-Structural Flood Measures

Non-structural measures tend to focus on damage reduction and mitigation. A particular advantage of non-structural measures when compared to structural measures is the ability of non-structural measures to be sustainable over the long term with minimal costs for operation, maintenance, repair, rehabilitation, and replacement. Some of the available measures are listed in the Table 3 below.

Reduce Damage	Mitigating Flooding Impacts
 Flood plain regulation Development policies Design & location of facilities Housing and building codes Flood-proofing Flood forecasting & warning Flood insurance 	 Disaster preparedness Post-flood recovery Flood insurance Preservation of natural resources of flood plain Flood plain zoning and regulation

Table 3: Types of non-structural measures

2.5.2.1 Flood Insurance

Many countries have some form of flood insurance cover and they vary broadly across different countries in the treatment of risks and coverage. (Crichton, 2008) classified them into two main categories: 'Option' system and the 'Bundle' system. Under the "Option" system, insurers extend their policy to include flood on payment of an additional premium, like in the case of Belgium, Germany, Australia, and Italy. In "bundle" system, flood insurance is package together with other hazards' coverage like fire, storm thief and earthquake. Insurers using this system in countries like UK, Japan, Israel, Portugal, and Spain, often charge differential rates based on the risk intensity. Table 4 gives an overview of the flood insurance schemes available in France, Japan, UK and USA.

Countries	Flood insurance
France (APFM, WMO, GWP, 2009)	 There is a nationally legalized natural disaster insurance system called "Cat Nat." Insurance rates are uniform relative to original insurance rates, regardless of such factors as the objects insured and locality. Insurance rates rose from the initial rate of 5.5% to 9.0% as disasters increased. The rate is 12.0% as of 2009.

Japan (APFM, WMO, GWP, 2009)	 Insurance against natural disasters exists in the form of comprehensive insurance offered by private insurance companies and the basic contract of special fire insurance. The national government is not involved in the administration of the insurance. Insurance rates for flood damage are uniform throughout the country, regardless of flood
United Kingdom	 The flood insurance is privatized and is offered as a bundle insurance scheme by the private insurers. In 2009 the Associate of British Insurers (ABI) had make an agreement 'Statement of Principle' with the UK government to provide flood insurance to small business and domestic properties at significant risk provide the UK government announced plans and notified ABI its intention to reduce the risk for those customers to below 'significant level' within 5 years.
United States	 There is a national government-run flood insurance system call National Flood Insurance Program (NFIP). This system employs the use of land use regulation where settlement in floodplain areas is strictly restricted. In the case that a community participates in the flood insurance system, it is mandatory for flood hazard areas without levee protection to be insured, whereas it is not for areas with levee protection (either 1/100 or 1/200). Areas surrounded by levees must also be insured as it can be flooded both from landside and riverside. The insurance rates are determined by the Federal Insurance Administration (FIA). The rates depend on the size of the family living in the building, the size of the building, whether the building has a basement as well as the risk level of the area. The higher the risk level, the more premium the community/customer has to pay. This encourages them to implement flood measures as well as discourage development in the floodplain.
	Table 4: Various flood insurance systems

Flood insurance not only helps to relieve economic impacts caused by flooding, it also helps to reduce the flood risks by incorporating landuse and building codes regulations. One example is the National Flood Insurance Program (NFIP) in USA. From the NEMA evaluation report 2006, over a billion dollars in flood damage have been prevented each year, where most buildings being constructed in the floodplains now are built according to NFIP standards and have been proven to be less vulnerable to flood damage. In addition, flood maps have been prepared for over 20,000 communities as a basis for the flood insurance rates, insurance purchase requirements, and local floodplain management programs that can be used for other purposes like spatial planning, hence providing a unison database for an effective and sustainable integrated flood management plan. However, the maps should be regularly updated to reflect the changes and account of climate change, which is not the situation in USA now.

The effectiveness of the NFIP is tested during the Hurricane Katrina hit New Orleans in August 2005. By August 2006 virtually all of the claims received by the federal government have been paid and settled, providing insured victims with nearly \$16 billion in claim payments. However, due to the fact that the NFIP is already running a deficit and coupled with other hurricanes and floods occurring that same year, it had to borrow nearly \$18.6 billion from the U.S. Treasury. This causes many to

question the NFIP of charging adequate premiums and how those premiums were spent as well as if climate change has been properly taken into account when planning the program. (Weitzman, 2009)

2.5.2.1.1 USA

Hurricane Katrina hit New Orleans in August 2005, just two weeks before the 40th anniversary of Hurricane Betsy. On one level, the public flood insurance program passed the test: by May 2006, 162,000 Gulf Coast claims had been paid— over 95 percent of the claims received by the federal government and by far the most claims the program ever received. By August 2006 virtually all claims were settled, providing insured victims with nearly \$16 billion in claim payments. But because the National Flood Insurance Program was already running a deficit, and other hurricanes and floods occurred that same year, the program had to borrow nearly \$18.6 billion from the U.S. Treasury. Many blamed the government for failing to charge adequate rates to account for truly catastrophic losses. The issue of whether the program was charging adequate premiums, and how those premiums were spent, seems especially salient because of the increasing concentration of population and assets in flood-hazard areas, along with possible changes in climate patterns that could increase the number and/or severity of floods.

2.5.2.1.2 China

A study by Munich Re¹¹ showed that, although the 10 largest floods in China since 1980 have caused total economic losses of USD 135 billion, the insured loss has only been 1-2 percent of this amount. The report quotes that low insurance penetration in rural areas of China and the fact that official efforts are directed at protecting economic assets, rather than people, from flooding, as major drivers of this trend. It has been suggested that the low insurance signup rate by the poor rural people in flood-prone areas were reluctant to pay the insurance premium since they traditionally rely on relief from the government after flood disasters. In order to have a successful flood insurance plan, there should be a long term strategy to reduce flood risks and that responsibility needs to be shared between the government, insurers and consumers; such that properties at high flood risk to be insured at an affordable premium. This would require a holistic approach of reducing flood risk from all engineering, social and economic aspects that would include an effective flood warning system, good preparedness and awareness of the community and resilient flood prevention measures.

2.5.2.1.3 South Korea

Flood Waters Insurance Act was established in May 2006, where flood damage insurance scheme was first implemented in 8 regions (Yeongdong, Chungcheongbuk, Jeonbuk, Wonju, Jeonju,

¹¹ https://www.munichre.com/en/media-relations/publications/press-releases/2013/2013-11-11-press-release/index.html
Seogwipo, Gyeonggi, Icheon). On October 2006, the scheme expanded into 17 regions nationwide and by April 2008, it was implemented nationwide.

	Remarks
Type of Disasters Insured Against	 Heavy Rainstorm, Flood, Typhoon, Tsunami, Heavy Snowstorm
Types of Buildings Insured	Buildings, Residential homes, Greenhouses
Managed by	National Emergency Management Agency
Insurance Carriers	Dongbu Insurance, Samsung Fire & Marine Insurance, Hyundai M & F
Amount Insured	 50%-90% of the repair cost for each infrastructure/facility
Subscription	Optional
	Table 5: Flood damage insurance scheme in Korea

Table 5: Flood damage insurance scheme in Korea

For the case of the domestic flood insurance, the insurance scheme has to be renewed yearly, which causes inconvenience for the subscribers, especially the elderly where they tend to forget to renew their insurance plans.

According to the National Emergency Management Agency (NEMA), as of July 26, 2011, the number of households participating in flood-and-injury insurance was 291,056, accounting for only 2.2% of the 13 million registered households. Also, households located in rural regions are less likely to sign up for the insurance plans due to lack of public promotion and the lack of flood knowledge.

As of 2012, the government is subsidizing 55-62% of the monthly premium. However, due to the increase in flood damages, the government budget is insufficient even though the budget has increased by 2.4 billion in the previous year.

2.5.2.2 Flood Warning System

A flood warning system, when properly installed and calibrated, is able to identify the amount of time available for residents to implement emergency measures to protect valuables or to evacuate the area during serious flood events. It uses information from stream gage, rain gages, and hydrologic computer modelling to determine the impacts of flooding for areas of potential flood risk.

Using Besòs catchment, near Barcelona (Spain) and Traisen catchment, north east Austria as case study areas, it determined the flood warning reliability as a function of lead time as shown in Figure 9, where a statistical analysis of flood forecast errors is transformed into a measure of warning reliability (EWASE Approach) (CRUE, 2008). From the analysis there is a significant drop of warning reliability of 40% between 3hours and 4 hours lead time. This has implications to the preparedness and reactive attitude of the citizens. Citizens will be more likely to wait for more accurate warning before reacting, thus reducing the amount of reactive time the city has to prepare for the forecast flood.



Figure 9: Warning Reliability as a function of lead time (CRUE, 2008)



Figure 10: Damage reduction as a function of lead time (CRUE, 2008)

Assessments are also conducted on the benefit of receiving an alert before a flash flood in reducing flood damage through surveys. And the results show that there is a correlation between preparedness and effectiveness of mitigation measures. In Figure 10, the size of the triangles represents the frequency of a certain answer to the survey; the bigger the triangle, the higher the frequency. While the sample size surveyed is relative small, it nonetheless demonstrates that there is a correlation between preparedness and effectiveness of mitigation. There is an increase of 30% in damage reduction if the warning lead time is increased from 6hours to 12 hours.

An accurate forecast system alone is not sufficient to have an effective flood warning system. It also requires an efficient communication system so that the alert warnings can be transmit to the involved parties as soon as possible. The communication system should encompass a range of communication channels that cater to the need of the intended receiver shown in Table 6.

Channel	Benefits	Challenges
Radio and Television	Widespread	 Takes time to get the warnings Limited use at night
Telephone (fixed and mobile)	 Messages delivered quickly 	 Problems of authenticity Does not reach non-users Congestion
SMS	 Quick messages can be sent to groups 	 Congestion Does not reach non-users Local language problems
Cell broadcasting	 No congestion Can address a group simultaneously 	Does not reach non-usersLocal language problems
Satellite radio	High reachability	 Cannot be used to educate masses Only good for specific points
Internet/Email	 Interactive Multiple sources can be checked for accuracy of information 	Not widespread
Amateur/Community radio	 Excellent for rural, poor and remote communities 	 Not widespread People lose interest if used only in case of disaster
Sirens	 Can be used even at night Good in rural areas 	Maintenance of the system Cannot disseminate a detailed message

Table 6: Benefits and challenges of different communication channels

2.5.2.3 South Korea

On July 2011, one of the heaviest rainfall event occurred, with 440mm of rain in Seoul and 340mm in Chuncheong during 2 days, which is 15 times more that the average two day amount at that time of the year. Due to heavy rain falls in a relatively short period of time, many places were flooded, and the city government was not able to properly track them. However people took photos/videos of the local areas and shared them with others via social networking services (e.g., Twitter, Facebook). Given this, various knowledge services were instantly created to help people to make informed decisions; e.g., one service collected all the news feeds from social networking and visualized related photos/videos on the map. This demonstrates the usefulness of ubiquitous knowledge services that seamlessly integrate content (e.g., data, information, knowledge) from various sources (e.g., content providers, sensors, smart devices, humans) at large scales and derive new values for end users. (Lee, Lee, Jung, & Song, 2011)

In Korea, flood forecasting system and flood warning system are separated. The flood forecasting system is under the jurisdiction of the Han River Control Office while the flood warning system is under the jurisdiction of the Korea Water Resources Corporation and the Korea Hydro & Nuclear Power Corporation.

The flood forecasting system predicts the flood forecasting using hydrologic and hydraulic simulations

from real-time data of water levels and rainfall. A total of 388 water stations and 429 rainfall stations are located throughout the four major rivers of South Korea (Han River, Nakdong Rivfer, Geum River and Youngsan River). In addition, 13 rainfall radars are installed nationwide, with the sensing range of the radars covering all of South Korea. (Kim H., 2010)



Figure 11: Water level station, rainfall gagging station and rainfall station in South Korea

The hydrological data are transmitted real-time using VHF, CDMA, VSAT at time intervals of 10 minutes. In addition, real-time video monitoring using CCTV is implemented in 16 main stations.



Figure 12: CCTV monitoring images of Hangang Bridge and Yeoju Bridge (Kim H., 2010)



Figure 13: Flood analysis program (Kim H., 2010)

The flood forecast analysis uses the collected data of rainfall (rain gauging station and rainfall radar), water levels at rivers and flow conditions at dams to forecast the flood volume, level and occurrence time as well as the operational dam discharge for managing the flood.

There are 2 types of flood warning¹²:

- Flood Watch (Amber Alert)
 - When the water level is more than 50% of the forecasted flood volume Action is necessary to establish a safety boundary for embankment, water gate, bridge, etc
- Flood Warning (Red Alert)
 - When the water level is more than 70% of the forecasted flood volume Embankment, gates, bridges, etc are expected to fail if the water level continues to rise

¹² http://www.korealaw.go.kr/lsInfoP.do?lsiSeq=190737&efYd=#0000

In the event that the water level when the flood warning is issued is expected to drop to fall below the amber alert level or the red alert level, the warning will be lifted or change to amber alert respectively.

2.5.2.4 Flood Education

To maximize the benefits of an efficient flood warning system, there should have a good flood education program. Traditionally, the main focus of many flood education has raising flood awareness of the communities, but this approach has been put in question by several researchers where it have been shown that there is no strong correlation between hazard awareness and acting appropriately for that hazard. (Boura, 1998) (Paton, McClure, & Buergelt, 2006)

In March 2003, the Ministry of Land, Infrastructure and Transport in Japan developed a "Flood Hazard Map Manual for technology transfer". Utilizing the manual, the Asian Disaster Reduction Center (ADRC), and Fuji Tokoha University developed an exercise for "Community Based Flood Hazard Mapping". The hazard map produced shown not only the inundation areas and depth but also information such as evacuation centres, disaster management centres, dangerous spots, communication channels and systems, evacuation criteria, tips for evacuation including emergency kits and other items needed in evacuation, and mechanisms and symptoms of hazards. Those who had seen such hazard maps were 1.5 times greater in number, and they evacuated one hour earlier than their counterparts who had not seen a map. In case of an acute disaster such as a flash flood, this time difference could mean a critical determinant in evacuation. (Nishikawa, Community Based Flood Hazard Mapping: A Simple and Easy-to-Understand Tool for Public Awareness, 2003)

This demonstrates that an effective flood education program should therefore not only designed to raise awareness but also increase the flood preparedness level of the community by helping them to understand the flood impacts on their community and family and provide evacuation and mitigation information so that they will and have the knowledge of how to react before, during and after a flood event.

Another aspect of flood education that warrants change is the communication system. The traditional approach, still in widespread use, informed the community of the flood risks through the dissemination of prepared material. This one-way approach regards the target audience as a whole that has the same needs and values. Instead, it is proposed that it should be a bottom-up approach where a more participatory is promoted. Although this approach is not common in flood education, it had been well acknowledged and used in other forms of community education. (O'Neill, 2004)

One example is the 'FloodSafe Model' in New South Wales, Australia shown in Figure 14. It proposed 4 stages: (a) Community participation, (b) Face-to-face, or two-way education, (c) Social marketing, or one-way persuasion and (d) Mandatory instructions. In the model, the local community stakeholders and leaders are involved in the early stage of the planning, where they contribute local experience when preparing flood education tools as well as volunteer to be community liaison officers

between the general community and the governing bodies.

Lastly, during the planning process for flood education, it should be considered for long term. Evidence has shown that long term flood education programs of more than 1 year tends to make the community more flood prepared and has a much greater willingness to evacuate when compared to education programs of 6 months or less. (Dufty & Webber, 2008)



Figure 14: Map of Different communication approaches against desired involvement level (Robinson 2003)

2.5.2.5 Academic Education

It should be stress that flood education should also cover the area of academic education like engineering and resource management. Often in such courses, the syllabuses only cover the traditional resist and prevent approaches towards flood management. This is especially true in Asian countries where such approaches are still considered the norm and ideal solutions. Therefore there is a need to instil the importance of keeping the courses up-to-date with the new approaches.

2.5.2.6 Individual Flood Proofing

It involves everyone's responsibility to effectively reduce the flood risk. The efforts by the government and community alone will not be sufficient. On an individual level, flood prevention measures should be carried out, but this can only be achieved if the appropriate flood education has been conducted.

There are 2 types of flood proofing: (a) Wet flooding-proofing, which involves controlling the way how the water flow through the lower levels of the house and (b) Dry flooding-proofing, which is the protection of the house by preventing any water flow into the house.

UK has been active in advocating the use of flood-proofing to make the new properties more flood resilience. In May 2007, a guide 'Improving the flood performance of new buildings – Flood resilient construction', which is a joint research between Communities and Local Government and the Environment Agency, was published with the aim to provide practical and easy-to-use guidance on the design and specification of new buildings (primarily housing) in low or residual flood risk areas in order to reduce the impacts of flooding recommendations for the construction of flood resistant and resilient buildings.

A research conducted by Australian National University (Figure 15) has shown that there can be a maximum savings of about 70% - 80% for residential properties if the inundation level is less than 0.75m. This suggest that flood-proofing of properties can be very useful to realize this savings.



Figure 15 Figure of Damage-Flood level for residential properties

This has a more far-reaching effect that simply saving money for the individual. It will also provide the much needed support and motivation for both government and private insurers to offer flood insurance at reasonable price for everyone at risk of flooding.

2.6 Evaluation of Flood Resilience Solutions in Incheon

In Korea, the rainfall events have been getting more serious for the past decades. Analyses of the last 100 year (1911-2010) climatic data show that extreme rainfall events associated with urban flooding have statistically significantly increased in Seoul in the Republic of Korea. In September 2010 and July 2011, the Gwanghwamun area in Seoul was inundated for more than two hours due to the insufficient capacity of the drainage system to cope with the torrential rain. The occurrence of these floods has been deemed man-made due to the lack of drainage system, and was worsen by the low elevations of the city. Thus there is a need to take effective anti-flood measures to protect the citizens' lives and property.

To investigate the effectiveness of flood resilience solutions, a hydrologic hydraulic model (in this case DHI MOUSE is used) will be set up for a flood-prone region where various flood resilience measures are implemented to reduce the flooding.

The case study area for the hydrologic-hydraulic sewer model is located in the Incheon Gyo watershed which is a urbanized area located in Incheon city, near the Incheon Port. This area has been developed very early in the 1980s, with low and flat terrain that are almost completely covered with factories and buildings, making this area having high imperious ratio number. This makes it more vulnerable to torrential rains where the overland flow is slow due to the gentle terrain. In order to cope with the increasing flood situation, the government has made large investments in traditional flood measures in the form of pipe extension works. However, with the increasing rainfall intensity, the extended pipes are no longer able to cope during the rainy months, especially in July. This causes localised flash floods which caused incontinence and property damages to the region and its citizens.

This study was conducted in conjunction with CORFU and NEMA projects. (Ler, Choi, & Byeon, 2013)



Figure 16. Flooding in Incheon Gyo watershed during 2008

2.6.1 MOUSE

MOUSE, short for **MO**del for **U**rban **SE**wers, is a computer program that models collection system for urban wastewater and stormwater. MOUSE is the first micro-computer based software created by DHI and it was developed in 1983. It can be used for analysing CSOs and SSOs, evaluating RDII, network capacity and bottlenecks, predicting local flooding, estimating sediment build-up and transport, optimization and design of RTC solutions, analysing water quality and sediment problems, and real-time modelling embedded in RTC solutions.¹³

The MOUSE system The MOUSE system is organized in several modules (DHI, 2003):

- MOUSE Runoff: surface runoff models for urban catchment applications
- MOUSE HD: hydrodynamic network model with some limited options of flow regulation
- MOUSE RDI: advanced hydrological model for continuous simulation
- MOUSE RTC: advanced reactive RTC capabilities for MOUSE pipe models
- MOUSE LTS: long-term hydraulic simulations with statistics
- MOUSE TRAP, with sub-modules
- MOUSE SRQ: pollutants build-up and transport on catchments surfaces
- MOUSE AD: pollutants advection-dispersion in drainage networks
- MOUSE WQ: water quality processes in drainage networks
- MOUSE ST: sediment transport in drainage networks

For the simulation of the flood event and the implementation of the flood resilience solutions, two modules of the MOUSE program are used. They are:

- i. MOUSE Runoff Module
 - The MOUSE Surface Runoff Module includes five types of surface runoff computation and three hydrological levels for the description of the urban catchment surfaces.
 - This means that the surface runoff computations can be adjusted according to the amount of available information.
 - The models run with well proven default hydrological parameters, which can be adjusted for better accuracy. The computed hydrographs are used as input to the MOUSE Pipe Flow model.
- ii. MOUSE Pipe Flow Module (HD)
 - MOUSE Hydrodynamic Pipe Flow Model (HD) solves the complete St.
 Venant (dynamic flow) equations throughout the drainage network (looped

¹³ https://en.wikipedia.org/wiki/Mouse_(software)

and dendritic), which allows for modelling of backwater effects, flow reversal, surcharging in manholes, free-surface and pressure flow, tidal outfalls and storage basins.

- The program has been designed to handle any type of pipe network system with alternating free surface and pressurized flows as well as open channel network.
- The computational scheme uses an implicit, finite-difference numerical solution of the St. Venant flow equations. The numerical algorithm uses a self-adapting time-step, which provides efficient and accurate solutions in multiple connected branched and looped pipe networks.
- This computational scheme is applicable to unsteady flow conditions that occur in pipes ranging from small-profile collectors for detailed urban drainage, to low-lying, often pressurized, sewer mains affected by varying outlet water levels. Both sub-critical and supercritical flows are treated by means of the same computational scheme that adapts to the local flow conditions. In addition, flow phenomena, such as backwater effects and surcharges, are precisely simulated.

2.6.2 Time-Area Method

For the runoff simulation, the Time-Area method is used. In this method, the runoff amount is controlled by the initial loss, size of the contributing area and by a continuous hydrological loss and the shape of the runoff hydrograph is controlled by the concentration time and by the time-area (T-A) curve. These two parameters represent a conceptual description of the catchment reaction speed and the catchment shape. (DHI, 2017a)

The input data for this runoff module includes:

- Catchment Data
 - o Location: MOUSE network node identifier, defines the catchment connection point.
 - X- and Y-co-ordinate: catchment co-ordinates used for the allocation of spatially distributed rain data.
 - Catchment Area [ha]:the total horizontal surface area of the catchment
 - Inhabitants number of inhabitants associated with the catchment. Does not have any effect on runoff computation used by catchment loads.
 - Additional flow [m³/s] a constant flow to be added to the computed runoff hydrograph for the catchment. Usually used for a simplified description of a constant infiltration component in single-event simulations.
 - Impervious area: fraction of the catchment area, [%], considered to contribute to the runoff

- Hydrological Parameters
 - Initial Loss: the precipitation depth, [m], required to start the surface runoff. This is a one-off loss, comprising the wetting and filling of catchment depressions. (The default value is 6.00E10⁻⁴ m)
 - Hydrological Reduction: runoff reduction factor, accounts for water losses caused by e.g. evapo-transpiration, imperfect imperviousness, etc. on the contributing area. (The default value is 0.90)
 - Time/Area Curve: accounts for the shape of the catchment layout, determines the choice of the available T/A curve to be used in the computations. Three pre-defined types of the T/A curves are available: TACurve1 - rectangular catchment, TACurve2 - divergent catchment, TACurve3 - convergent catchment
 - Time/Area Coefficient: this formula has been introduced covering curve shapes "in between" the three standard ones (and outside). The following formulae have been suggested by Nittaya Wangwongwiroj at AIT. The curves "in between" are specified by giving the Time Area Coefficient directly in MOUSE instead of specifying a Time/Area Curve.

$$y = 1 - (1 - x)^{\frac{1}{a}}$$
 for $0 < a < 1$

$$y = x^{a}$$
 for $1 \le a$
Where $y =$ Accumulated dimensionless area
 $y =$ Dimensionless concentration time
 $y =$ Time area curve coefficient

 Concentration Time: defines the time, [min], required for the flow of water from the most distant part of the catchment to the point of outflow. (The default value is 7 min.)

2.6.2.1 Runoff Computation

The continuous runoff process is discretised in time by the computational time step Δt . The assumption of the constant runoff velocity implies the spatial discretisation of the catchment surface to a number of cells in a form of concentric circles with a centre point at the point of outflow. The number of cells equals to:

$$n = \frac{t_c}{\Delta t}$$

Where t_c = Concentration time
 Δt = simulation time step

MOUSE calculates the area of each cell on the basis of the specified time-area curve. The total area of all cells is equal to the specified impervious area. A time-area curve characterises the shape of the catchment, relating the flow time i.e. concentric distance from the outflow point and the corresponding catchment sub-area. There are three pre-defined time/area curves available in MOUSE. Irregularly shaped catchments can be more precisely described by the user-specified T/A curves.



Figure 17. Three pre-defined time/area curves available in MOUSE (DHI, 2017a)

If the Surface Runoff Model A is used for a continuous simulation of multiple rainfall events (without RDI component activated), a special solution is applied for the simulation of dry periods between the consecutive events. The solution accounts for the loss of water caused by drying out of the initial loss (representing wetting and surface storage), i.e. allowing the occurrence of the initial loss at the beginning of each simulated event, in accordance with reality.

In this context, start of a dry period is defined if two conditions are fulfilled simultaneously:

- All connected rain gauges show no rain, i.e. intensity = 0.00
- The runoff has fallen to zero from all catchments included in the simulation.

At the start of a dry period, the initial loss storage would be fully or partially filled up, the latter being the only case for small events of the total depth smaller than the initial loss storage depth. Recovery of the initial loss capacity, i.e. the process of surface drying is simulated as a constant "decay" rate, which replaces the actual evaporation. As a consequence of the recovery process, the initial loss storage would be fully or partially emptied, which depends on the actually applied loss recovery rate and the duration of the dry period. Default value for the "loss recovery rate" is 0.0005 m/h, and can be controlled through DHIAPP.INI file (see relevant documentation). The recovery process is only activated during dry periods, i.e. the evaporative action during rain events is neglected. In order to rationalise the size of the result file, entire dry period between two events is saved as a single time step in the result file.

2.6.3 Pipe Flow Module (HD)

Links in MOUSE Pipe Flow Model are defined as one-dimensional water conduits, connecting two nodes in the model. The link definition allows that the dependent flow variables (e.g. water levels and discharges) can be uniquely described as functions of time and space. (DHI, 2017b)

A link is featured by constant cross-section geometry, constant bottom slope and constant friction properties along the entire length. A straight layout is assumed. MOUSE supports two classes of links: closed conduit links (pipes) and open channel links.

2.6.3.1 Flow Computation

Saint Venant Equations are used for the computation of unsteady flows in the links for MOUSE Pipe Flow Module with the following assumptions:

- water is incompressible and homogeneous, i.e. negligible variation in density
- bottom-slope is small, thus the cosine of the angle it makes with the horizontal may be taken as 1
- wavelengths are large compared to the water depth. This ensures that the flow everywhere can be regarded as having a direction parallel to the bottom, i.e. vertical acceleration can be neglected and a hydrostatic pressure variation along the vertical can be assumed
- flow is sub-critical (Super-critical flow is also modelled in MOUSE, but using more restrictive conditions)

The Saint Venant equations are as follows:

Conservation of Mass:			$\frac{\partial A}{\partial t} = 0$		
Conservation of Momentum:			$\frac{\partial(\alpha \frac{Q^2}{A})}{\partial x} + gA\frac{\partial y}{\partial x} = gA(l_0 - l_f)$		
where:	Q = discharge, [m³/s]				
	$A = flow area, [m^2]$				
	y = flow depth, [m]				
	g = acceleration of gravity, [m/s]	²]			
	x = distance in the flow direction	n, [m]			
	t = time, [s]				
α = velocity distribution coefficient					
	<i>I0 = bottom slope</i>				
	If = friction slope				

The equations above are valid for free surface flow only. However, pressurized flows can also be modelled with those equations by introducing a thin fictive slot at the top of the pipe, called the Preissmann slot. The idea of introducing a fictitious slot was first presented in 1961 (Preissmann & Cunge, 1961) and has since been used by (Cunge & Wegner, 1964).



Figure 18. Preissmann slot (Preissmann & Cunge, 1961)

The MOUSE Pipe Flow Model provides a choice between 3 different levels of flow description approximations:

- 1. **Dynamic wave approach:** which uses the full momentum equation, including acceleration forces, thus allowing correct simulation of fast transients and backwater profiles. The dynamic flow description should be used where the change in inertia of the water body over time and space is of importance. This is the case when the bed slope is small and bed resistance forces are relatively small.
- 2. Diffusive wave approach: which only models the bed friction, gravity force, and the hydrostatic gradient terms in the momentum equation. This allows the user to take downstream boundary conditions into account, and thus simulate backwater effects. The diffusive wave description ignores the inertia terms and is therefore suitable for backwater analyses in cases where the link bed and wall resistance forces dominate, and for slowly propagating waves where the change in inertia is negligible
- 3. **Kinematic wave approach:** where the flow is calculated on the assumption of a balance between the friction and gravity forces. This means that the kinematic wave approach cannot simulate backwater effects. Thus this description is appropriate for steep pipes without backwater effects.

All three approaches simulate branched as well as looped networks. The dynamic wave description is recommended to be used in all cases except where it can be shown that either the diffusive or kinematic descriptions are adequate.

The diffusive and kinematic wave approximations are simplifications of the full dynamic descriptions which offer improved computational efficiency. However they should only be used when the omitted terms have insignificant influence.

2.6.3.2 Numerical Solution of Flow Equations

The DoubleSweep algorithm is used to solve the flow equations by an implicit finite difference method. Setting the numerical scheme into the frame of the DoubleSweep algorithm ensures preservation of the mass continuity and compatibility of energy levels in the network nodes. The solution method is the same for each model level (kinematic, diffusive, and dynamic).

The implemented numerical scheme is a 6-point Abbott-scheme where the equations are approximated by finite differences. The scheme for the method is shown in Figure 19.



Figure 19. Centred 6-point Abbott scheme (centring of continuity equation)

The computational efficiency of any discrete-time numerical simulation algorithm is highly dependent on the time step applied in the simulations. MOUSE optimises the simulation time step though an automated self-adaptive time step variation. This is controlled by the actual hydraulic and operational conditions within the entire model area throughout the numerical simulation. This concept can be applied in connection with the Dynamic and Diffusive flow descriptions while it cannot be used with the Kinematic flow description.

In addition, MOUSE also implements steps to maintain mass continuity balance. In order to reduce the amount of water generated in conduits due to the changes of surface width as function of water depth, i.e. to improve the continuity balance, the Taylor expansion of the general continuity equation is applied. However, as the width for arbitrary pipes and pipes from the cross-section database may vary in a very unpredictable way, the Taylor expanded equation is only applied to standard pipes.

For additional means of controlling the volume continuity balance for links with no or little water are provided as user-controlled minimum water depth for links running dry or with very little flow. The two user-controlled parameters are:

- **BRANCH_MIN_H_REL:** This is the relative minimum water depth (in promille of the characteristic dimension) in a link
- BRANCH_MIN_H_ABS: This is the absolute minimum water depth (mm) in a link

The minimum water depth in a link will be set to BRANCH_MIN_H_REL, calculated as promille of the link size (e.g. pipe diameter or height of the open channel), but never larger than BRANCH_MIN_H_ABS mm.

2.6.4 Characteristics of Incheon Gyo

The Incheon Gyo watershed has an area of 34km² and length of 8 km. The elevation of the Incheon Gyo watershed which is linked with Yellow Sea through two retention pond is within 5.4m to 6m. The slope of Incheon Gyo watershed is very mild (S=0.01%) and has an 81.4% of impermeability layer with a complicated drainage network system. It should be noted that the large tidal range of Yellow sea (9m) which is linked with Incheon Gyo watershed has a additional impact on the drainage of the Incheon Gyo watershed as the rainfall runoff are not able to be release downstream when the tides in the Yellow Sea is high.

Located in the northwest part of Incheon, South Korea, it is divided into seven subcatchments: the Songhyun, Seknam, Gajwa, Dohwa, Juan, Ganseok (1) and Ganseok (2) subcatchment areas.



Figure 20. Arial map of Incheon Gyo watershed

Characte Ba	ristics of sin	Drainage Zones	Total	Dwelling	Business	Industry	Farmland
		Ganseong (1)	312.1	255.7	33.2	-	23.2
	Left	Juan	533.7	333.5	75.3	71.0	53.9
Incheon	SIDE Bank	Dohwa	337.8	145.1	37.4	155.3	-
Gyo	Dalik	Subtotal	1,183.6	734.3	145.9	226.3	77.1
Covered	Right	Ganseong (2)	346.4	249.5	47.8	-	49.1
Channel	side	Gajwa	650.8	115.3	_	353.3	182.2
_	Bank	Subtotal	997.2	364.8	47.8	353.3	231.3
	S	ubtotal	2,180.8	1,099.1	193.7	579.6	308.4
Seokna	m Canal		910.9	204.4	38.4	357.9	310.2
Hwasu		302.8	161.6	67.4	61.7	12.1	
Total		3,394.5	1,465.1	299.5	999.2	630.7	
		(100%)	(43.2%)	(8.8%)	(29.4%)	(18.6%)	

The landuse allocation of the Incheon Gyo Watershed is shown in Table 7.

Table 7. Landuse allocation in Incheon Gyo watershed (Unit: ha)

2.6.5 Input Data

The pipe network system in Incheon Gyo Catchment is designed with for 20 years return period. There are a total of 2674 pipes in the model.



Figure 21. Sewer Network of Incheon Gyo watershed

Landuse	Roughness coefficient (Manning, n)
Highly Developed Downtown	0.015~0.030
Developed Downtown	0.020~0.035
High Density Residential	0.025~0.040
Low Density Residential	0.030~0.055
Park	0.040~0.080
Asphalt area	0.012
Concrete area	0.014
Forest	0.02
Grass	0.03
Pasture	0.04
Dense grass	0.06
Shrub and Grass	0.08

The roughness coefficients for the different landuse areas are shown in Table 8 below:

Table 8 Roughness coefficients for different landuse areas in Incheon Gyo

The runoff coefficients for the different landuse areas are shown in Table 9 below.

Landuse Type		Coefficient
Pusiness	Downtown	0.7~0.95
DUSINESS	Green Areas	0.5~0.7
Decidential	Houses	0.6~0.75
Residential	Apartment Flats	0.5~0.7
Industrial		0.6~0.9
Undeveloped Green	0.1~0.4	

Table 9 Runoff coefficients for different landuse areas in Incheon Gyo

Using the rainfall intensity formula in Table 10, the rainfall intensity for Incheon is calculated and tabulated in Table 11.

Return Period (Yrs)	Rainfall intensity Formula	Return Period (Yrs)	Rainfall intensity Formula
2	$\frac{660}{t^{0.627} + 3.17}$	50	$\frac{1652}{t^{0.620} + 5.26}$
3	$\frac{829}{t^{0.635} + 3.88}$	70	$\frac{1671}{t^{0.618} + 5.23}$
5	$\frac{936}{t^{0.624} + 3.92}$	100	$\frac{1792}{t^{0.624} + 5.61}$
10	$\frac{1113}{t^{0.621} + 4.247}$	200	$\frac{1981}{t^{0.622} + 5.84}$
20	$\frac{1323}{t^{0.623} + 4.77}$	300	$\frac{2084}{t^{0.620} + 5.94}$
30	$\frac{1428}{t^{0.622} + 4.29}$	500	$\frac{2241}{t^{0.620} + 6.15}$

Table 10 Rainfall intensity formula for Incheon (Park, Choi, Han, Hong, & Choi, 2011)

Return	Flood Duration [hrs]								
[Yrs)	1	2	3	4	6	8	12	18	24
3	47.8	66.9	80.43	91.24	108.42	122.16	144	169.02	189.12
5	55.75	78.80	95.31	108.56	129.72	146.72	173.88	205.38	230.64
10	65.65	93.56	113.61	129.76	155.58	176.40	209.64	248.04	279.12
20	75.23	107.96	131.49	150.48	180.78	205.20	244.08	289.08	325.44
30	80.75	116.26	141.84	162.48	195.48	222.08	264.48	313.56	353.04
50	92.18	133.66	163.68	187.92	226.74	258.00	308.04	365.94	412.56
70	93.94	136.40	167.16	192.04	231.90	264.08	315.48	375.30	423.36
100	96.97	140.86	172.56	198.12	239.04	271.92	324.48	385.20	433.92
200	106.48	155.46	190.98	219.68	265.62	302.64	361.68	430.20	485.28
300	112.04	164.10	201.93	232.56	281.70	321.20	384.48	457.92	516.96

Table 11 Rainfall for Incheon [mm/hr]

2.6.1 Flooding Situation Before Implementing Flood Resilience Solutions

For the simulation of the current situation, the 20 year return period rainfall intensity is used to generate the runoff with critical time of 50 minutes which gives the highest peak discharge hydrograph.

The results are shown in Figure 22 below. The bigger the coloured circles, the higher the flood level. The highest flood level is observed in the Seoknam District, north of Incheon Gyo catchment with a flood level of 4.43m.



Figure 22. Flood map for rainfall 20 years return period of critical time of 50 minutes

For the Incheon Gyo watershed, the implemented measures will include measures like green roof, underground storage tanks, pond storage in the parks and installation of pervious materials for road cover.

2.6.2 Implementation of Green Roofs

Green roof technology has been used in many urban settings to improve storm water management by reducing total quantities of rooftop runoff and peak flow rates during high-intensity rains. The water quantity retention performance of green roofs has been measured and documented for a range of conditions and design parameters. Green roofs will absorb significant amount of stormwater during low to moderate rainfall and during extreme events, will delay and reduce peak flows. Research has shown that green roofs with 3" to 4" of growing medium vegetated with a mixture of sedum plants plus a commercial drainage mat, a root barrier and standard waterproofing generally retain stormwater runoff by 50-100% during most rains resulting in an average of about 50% - 75% total water retention from rainfall over a typical year. (Johnson, 2008)

In the South Korea however, there is no such research for the effectiveness of green roof on retaining the rainwater. Thus the finding from a case study in USA where it determines that a green roof measure can reduce 20% rainfall is used. (The Ipswich River Watershed Association, 2006)





To implement the effect of the green roof on rainfall retention, the rainfall intensity input is reduced accordingly with the amount of buildings coverage in the watershed. The buildings (both industrial and residential) cover about 3% of the watershed. Under the assumption that 2/3 of the buildings are retrofitted with green roofs, there is a 7.6% reduction of rainfall intensity (critical time of 50 minutes) from 68.01mm/h to 62.9mm/h. The reduced rainfall intensity is then applied uniformly across the whole catchment.



Figure 24. Flood map after implementing Green Roofs

After introducing the green roof implementation, there is a decreased of flood level of 0.48m in the Seoknam District. The number of overflowing pipes also decreases from 334 to 296.

2.6.3 Implementation of Green Belts (Buffer Zones)

According to a report from the Incheon Metropolitan City¹⁴, there is a reduction of green spaces from 381.23km² to 284.98km². This corresponds to an average of 5.4% yearly decrease of green spaces between 2004 and 2009.

	Total	Urban Area [km²]						
Year	Osable Area [km ²]	Total	Residential	Commercial	Industrial	Green	Others	Orban Area [km ²]
2004	1,298.20	720.88	82.21	13.10	45.91	381.23	198.44	577.32
2005	1,298.19	720.88	85.70	12.73	46.59	388.10	187.76	577.31
2006	1,298.19	720.88	88.46	13.05	46.41	385.40	187.57	577.31
2007	1,298.19	720.88	104.72	16.96	50.21	363.16	185.84	577.31
2008	1,110.87	560.44	100.69	17.19	43.36	294.71	104.49	550.43
2009	1,147.58	570.43	105.40	17.39	41.04	284.98	106.81	550.37

Table 12. Incheon city urban planning for landuse

Using the average yearly decrease of 5.4% to project into 2013, there is an overall decrease of 20% by year 2013 when compared to 2009. As there is no announcement made by the government

¹⁴ http://www.incheon.go.kr/ebook/pdf/fb_2010121402465136a

to reduce the amount of green spaces in the city, it is assume that this decreased amount of green spaces in the planning is converted into green belts. To reflect the conversion of green spaces to green buffer zones, the landuse runoff coefficient will updated using the following equation:

$$C_{new} = C_{old} - \left(20\% * \left(C_{old} - C_{buffer}\right)\right)$$
equ (1)

Where C_{new} = new runoff coefficient of the catchment

 C_{old} = original runoff coefficient of the catchment

 C_{buffer} = runoff coefficient of the green belt buffer zone

Using the value of 0.4 for the runoff coefficient of the green belt buffer zone, the results from the MOUSE simulation showed a further decreased of 0.16m of the maximum flood level (from 3.95m to 9.79m) located in the Seoknam District with the number of overflowing pipes decreasing from 296 to 286.



Figure 25. Flood map after implementing Green Belts (Buffer Zones)

2.6.4 Implementation of Retention Storages

To further reduce to amount of flooding in the network, underground storage tanks and retention reservoirs are implemented in the catchment. Table 13 shows the implemented dimensions of the storage tanks and retention ponds for all the selected locations.

Location	Туре	Dimension [m]
Sinseok Elementary		70 x 50 x 2
Seoknam Elementary		70 x 45 x 2
Incheon Chunma Elementary		50 x 50 x 2
Gyeongin Girls High School		90 x 60 x 2
Incheon Bonghwa Elementary		60 x 40 x 2
Incheon Nam Middle School		120 x 70 x 3
Incheon Soongwi Elementary		70 x 50 x 3
Seoknam Greenery Park (1)	Underground storage tanks	260 x 90 x 1.5
Seoknam Greenery Park (2)		240 x 100 x 1.5
Gajwawanchungnokji Park (1)		100 x 100 x 3
Gajwawanchungnokji Park (2)		100 x 100 x 3
Gajwawanchungnokji Park (3)		180 x 100 x 3
Dong-gu Children's Park		300 x 100 x 3
KajudongGreen Space		300 x 200 x 5
281 Juan-dong, Nam-gu		90 x 50 x 3
72-0, Ujil-dong, Seo-gu		200 x 100 x 5
139-14, Seoknam-dong, Seo-gu	Retention Reservoirs	180 x 100 x 5
83-2, Ujil-dong, Seo-gu		150 x 70 x 5
Juan Greenery Park	Retention Pond	60 x 30 x 5

Table 13. Dimension size of storage tanks, reservoirs and retention ponds

After the implementation of the retention storages in the network system, no flood occurrences are observed as shown in Figure 26.



Figure 26. MOUSE results after implementation of all proposed solutions

2.6.5 Results and Discussions

In the existing conditions, flood is observed at many locations with flood level of up to 4.43m occurring at some manholes shown in Figure 22. With the implementation of the above-mentioned solutions, no flood occurrences are observed.

Solution Implemented	Maximum Flood Level [m]	No. Of Overflowing Pipes
Existing State	4.43	334
Green Roof	3.95	296
Green Roof + Green Belts	3.79	286
Green Roof + Green Belts + Retention Storage	0.0	0

Table 14 Flood situation after implementation of flood resilience solutions

This shows that a combination of resilience measures like green roof, permeable pavements and underground storage tanks are able to curb flooding without the need to enlarge or extend the existing pipe networks.

It is noteworthy that just by implementing green roof and green belts, the maximum flood level can be decreased by 12% (0.54m). In the model, only 2/3 of the buildings are fitted with green roof with a 20% rainfall removal rate. This shows that with the improvements on green roof technology where the rainfall removal rate increase and coupled with the addition of the remaining 1/3 of the buildings coverage, more rainfall runoff will be captured by the green roof installation.

Similarly, the installations of green belts also help to reduce the maximum flood level. Although it is seen here in the results as not as effective as green roofs, it is as important, or even more important than the green roof when it comes to coping with flood.

The main mitigation impact of the green belt is not only to reduce the runoff volume, but also to reduce the flood flow velocity. This reduction of overland flow velocity will greatly reduce the extend of flood damage as well as provide more time for the city to react. In this simulation, MOUSE itself is not able the effect of the overland flow velocity reduction as it does not have the capability to simulate the overland flow condition. For future analysis, the MOUSE can be coupled with a 2D overflow model like MIKE21¹⁵ to simulate the urban flooding with full two-way interaction between the water in the sewers and the water on the surface. This will give a much more accurate representative of the flooding situation with the flood resilience solutions installed.

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http://manuals.mikepoweredbydhi.help/2017/Water_Resources/MIKE_FLOOD_Urban_Flood_Modelling_Step_by_ Step.pdf

There are also other flood resilience solutions available that is not applied in this simulation. One of them is the installation of permeable materials for pavements and roads. Having permeable pavement and roads help to reduce the runoff volume by increasing the amount of rainfall that is infiltrated into the pavements and roads. To implement the effect of the permeable pavement on runoff infiltration in the simulation, the runoff coefficient of the watershed catchments can be reduced accordingly to reflect the impact. A research conducted in South Korea (Beum & Jong, 2007) shows that a permeable pavement can reduce up to 30% of the rainfall runoff when compared to a normal asphalt road. By apply this information to the case study in Incheon Gyo, a reduction of the runoff coefficient by 3.3% when all the roads (about 11% coverage of the watershed) are retrofitted can be achieved.



Figure 27. Map of roads in the Incheon Gyo watershed

The implementation of retention storages proved to be effective in reducing flood levels in the system. Geocellular water storage can be an ideal solution for the implementation of retention storages.

Their advantages and disadvantages are listed in Table 15¹⁶ below.

Advantages	Disadvantages
 Modular and flexible Dual usage (infiltration and/or storage) High void ratios providing high storage volume capacity Lightweight, robust and easy to install Capable of managing high flow events Can be installed beneath trafficked or non-trafficked areas (providing structural performance is proven to be sufficient) Long-term physical and chemical stability Can be installed beneath public open spaces, e.g. play areas. 	 No water quality treatment or amenity provision Performance can be difficult to monitor Can be difficult to maintain

Table 15 Advantages and disadvantages of geocelluar water storage



Figure 28. Diagram of Stormcell® stormwater storage solution¹⁷



Figure 29. Photo of a geocellular water storage installation¹⁸

¹⁶ http://www.susdrain.org/delivering-suds/using-suds/suds-components/retention_and_detention/geocellular-storage-systems.html

¹⁷ https://www.externalworksindex.co.uk/entry/33339/Hydro-International/Stormcell-stormwater-storage/

¹⁸ http://www.polypipe.com/civils-and-infrastructure/water-management-solutions/permavoid-geocellular-system/choice-shallow-or-deep-geocellular-system



Figure 30. Location of retention storages in the simulation

It should be noted that retention storages require middle to high level of maintenance, especially in terms of water quality. To facilitate the maintenance of retention storages, monitoring of the water conditions in the storages using sensors will be useful in ensuring that the retention storages especially the underground ones, are at optimal capacity to receive the infiltration runoff during a flood event.

2.7 Discussions and Recommendations

Over the years, urban flooding has become more frequently and with the fast urbanization of the cities, the impact of urban flooding will only become more and more acute. Factor in climate change, where wet seasons will be more pronounced and wetter, there will be a significant increase in flood risks in urban cities which will poses serious challenges to urban flood risk management. (Nie, Lindholm, Lindholm, & Syversen, 2009). Therefore it is of great interest to discover alternative solutions that are effective and resilience not only to the current situations but also for the future.

The traditional approach to control floods is to focus on reactive solutions by reducing the exposure to floods and vulnerabilities to flood damage mainly through structural measures like dykes where a wall is created between the rivers and the floodplains. However, this type of approach proved to be partially effective as the flood risks are shifted rather than mitigating the flood risks all together. As a result, there is an acknowledgment of the necessity of a wider multi-disciplinary approach which led to a paradigm shift from flood control to flood management. This indicates a proactive mentality recognizing that floods can never be fully constrained, but, at the same time, present positive (besides negative) aspects. (Aid & International Development Forum, 2014)



Figure 31. Integrated flood management (Aid & International Development Forum, 2014)

Integrated Flood Management (IFM) is a process promoting an integrated – rather than fragmented – approach to flood management. It integrates land and water resources development in a river basin, within the context of Integrated Water Resource Management (IWRM), and aims at maximizing the net benefits from the use of floodplains and minimizing loss of life from flooding. A good IFM plan addresses the following when managing floods (WMO, 2009):

- Manage the water cycle as a whole
- Integrate land and water management
- Manage risk and uncertainty
- Adopt a best mix of strategies
- Ensure a participatory approach
- Adopt integrated hazard management approaches.

Flood resilience builds onto the IFM approach by introducing the concept of the system's flexibility and recovery where it recognizes the ability of the city to withstand a certain degree of flooding and flood damage and recover back to the existing state without any heavy permanent flood damage done to the city.

In order to maximized the city's flexibility to resist flooding damage, a good forecast and warning system and flood education of the public is essential. It has been shown in research that when warning time is sufficiently long, like 12 hours there is a significant decrease in flood damage in property. For commercial sector, indications are that, proportionately, savings to content can often exceed those in the residential sector. (Smith, 1994).

In addition, the actual to potential damage ratio can be used as an indicator in accessing the benefits of the flood warning system. The increase in the length of the warning time will results in a greater reduction in flood damage. It is worthwhile to note that more reduction of flood damage can be achieved if the level of preparedness of the city is high. In Figure 32, a city that is well prepared can achieve up to an additional 50% of flood damage reduction compared to a city that is not prepared for flooding.

The preparedness of the city can be increased through flood awareness campaigns and flood education. According to a report in Japan, among the residents who evacuated during a flood evacuation practice drill, those who had been shown hazard maps evacuated one hour earlier than their counterparts who had not seen such maps. These hazard maps include not only inundation areas and depth but also information such as evacuation centres & routes, disaster management centres, dangerous spots, communication channels and systems, evacuation criteria, tips for evacuation including emergency kits and other items needed in evacuation, and mechanisms and symptoms of hazards. In case of an acute disaster such as a flash flood, this time difference could mean a critical determinant in evacuation and can help prevent significant flood damages. (Nishikawa, 2003)



Figure 32. Relationship of actual/potential damage ratio to preparedness and warning time for damage (Smith & Handmer, Flood warning in Australia : policies, institutions and technology, 1986)

The case study of the Incheon Gyo catchment has shown that the by using a combination of flood resilience solutions is able to effectively reduce the flood water level. (Nishikawa, 2003) (Nishikawa, 2003).

2.8 Threat & Vulnerability Assessments

In order to determine where and when resilience solutions are required, there is a need to perform threat and vulnerability assessments on the facilities of interest. Based on the methodology by Applied Research Associates¹⁹, the first step is to define the different level of threats, flood damage and vulnerabilities.

For the discussion in this research, threats are defined in three levels:

- Real Threat: Events of this nature occur in the immediate vicinity on a frequent basis.
- Potential Threat: Natural: Events of this nature occur in the immediate vicinity periodically (i.e. once every 10 years).
- Minimal Threat: There is no history of this type of event in the area.

¹⁹ http://www.wbdg.org/resources/threat-vulnerability-assessments-and-risk-analysis

Flood damages are defined in these four levels:

- **Devastating:** The facility or infrastructure is damaged/contaminated beyond operation. Most items/assets are lost, destroyed, or damaged beyond repair/restoration.
- Severe: The facility or infrastructure is partially damaged/contaminated. Examples include partial structure breach resulting in weather/water, smoke, impact, or fire damage to some areas. Some items/assets in the facility are damaged beyond repair, but the facility remains mostly intact. The entire facility may be closed for a period of up to two weeks and a portion of the facility may be closed for an extended period of time (more than one month). Some assets may need to be moved to remote locations to protect them from environmental damage.
- **Noticeable:** The facility or infrastructure is temporarily closed or unable to operate, but can continue without an interruption of more than one day. A limited number of assets may be damaged, but the majority of the facility is not affected.
- Minor: The facility experiences no significant impact on operations and there is no loss of major assets.

Using the definitions of the flood damages and threats, the vulnerability can be determined using a rating matrix shown.

	Flood Damage	Vulnerability		
		Low	Medium	High
Minimal Threat	Minor			
	Noticeable			
	Severe			
	Devastating			

Potential Threat	Flood Damage	Vulnerability		
		Low	Medium	High
	Minor			
	Noticeable			
	Severe			
	Devastating			

	Flood Damage	Vulnerability		
		Low	Medium	High
Real Threat	Minor			
	Noticeable			
	Severe			
	Devastating			

Figure 33. Vulnerability rating matrix (adapted from Applied Research Associates)

Rating Category	Description & Recommended Actions	
High	The risk is unacceptable. Immediate measures must be taken to reduce these risks and mitigate hazards.	
Medium	The risk may be acceptable over the short term. Measures to reduce risk and mitigation hazards should be implemented as soon as possible.	
Low	The risks are acceptable. Plans to reduce risk and mitigate hazards should be included in future plans and budgets.	

Figure 34. Rating category description

When the vulnerability of the facility or infrastructure has been determined, appropriate actions can be taken as shown in Figure 34. To improve the performance of the threat and vulnerability assessments, simulations can be performed to determine the flooding damages for the different threat levels or surveys and inspections of the facility or infrastructure can be conducted after the occurrence of the threats for the refinement the definitions of the flood damages.

2.8.1 Future of Flood Resilience: Smart Water Management

In order for the forecast system to produce accurate forecasts, there is a need to have up-todate hydrological and hydraulic data of the city and its water infrastructure. Similarly, to have an efficient warning system, there is a need to have the warning communication system well-integrated with the forecast system and the decision support system.



Figure 35. Framework of Flood Resilience Management

This can be achieve with the help of Smart Water Management, which utilizes information communication technologies (ICT) to provide integration of the different systems as well as real-time sensing. The integration of the different systems will require an information system that will store all the relevant data. The data includes hydrological and hydraulic data, landuse management data and characteristics of water infrastructures and their operations. In the example shown in Figure 36, the

forecast system will retrieve the required data from the information system to perform the forecasts using hydrological and hydraulic models. The forecasts from the simulation models will then be transmitted to the decision support system. In the event of a flood, it will request the warning system to issue evacuation announcement as well as operation instruction for water infrastructures.



Figure 36. Workflow of a warning system

To have an efficient workflow for the warning system, it requires:

- Real-time sensors to provide up-to-date data
- Communication networks to transmit the recorded data back to the information system as well as between the different systems
- Information system that is capable to handle large volume of data

In the following chapters, the concept of Smart Water Management will be explored, analysed and discussed after which implementation solutions and strategies will be proposed and recommended.

3. Smart Water Management

Over the recent years, technology has been developing at a rapid pace and has matured to the degree of mass production that allows a wider uptake of methods and devices. After the development phase, technology is now entering an application and implementation phase that is targeting several fields including environment. A relevant example is given by the European Union who has defined a major priority for the next 20 years on "ICT for sustainable growth" with the ambition to lead innovation at the worldwide scale. In such context, ICT refers to technologies that provide access to information through telecommunications. It is similar to Information Technology (IT), but focuses primarily on communication mediums. The current situation in the water domain is characterized by a low level of maturity concerning standardization of ICT solutions and business processes. The massive and rapid spread of communicating devices within the Society and their application to the industrial sectors is not coordinated. The only relevant angle for the development of these technologies (M2M) within the water domain has to be based on the identification of the added value provided in each business process by the introduction of the new solutions.

Right now, smart technologies provide the right opportunity to address these water challenges. According to a research commissioned by (SENSUS, 2012), water utilities can save up to \$12.5 billion annually by utilizing smart water networks from a combination of the following:

- Improve leakage and pressure management (up to \$4.6 billion annually)
- Smart network operation and management (up to \$2.1 billion annually)
- Smart monitoring and sensing (up to \$600 million annually)
- Strategic prioritization and allocation of capital expenditures (up to \$5.2 billion annually)

However, there exist challenges to implementing smart technologies. Among these changes there are:

- High economic cost (low-to-average investment cost profit benefits ratio)
- Lack of funding, political and regulatory support
- Lack of standardization (product and services are too fragmented)

The following sections will present the different challenges and provide solutions and recommendations on how to bring Smart Water Technologies into the focus of the stakeholders.

3.1 Concept of Smart Water Management

Water resource management involved many different parties that include water utilities, water authorities and regulators and the end-users. Although many planning, monitoring and optimization tools have been developed and implemented, like hydrologic and hydraulic models, real-time monitoring system and controlling systems for water treatment and distribution, decision support systems for reservoir and hydraulic infrastructure operations, these systems usually does not communicate with each other and thus raises a need to have a framework that integrate all these applications together. (Anzaldi, 2014). The lack of water ICT standards prevents an effective interoperability and increases the cost and maintenance of such applications.. (Robles, et al., 2015)

ICTs provides the means to improve the productivity and efficiency in water management, with the objective to maximize the allocation of resources using advanced information technologies for observing, storing, processing and analyzing of the system monitoring data; and presenting of the analysis results. This increasing availability of more intelligent, ICT-enabled solutions for the management of water resources leads to the development of smart water management (SWM). European countries (USmartConsumer, 2016) have incorporated IT in a broad range of policies governing, ranging from Water Management to electricity, transportation, and the environment.(Kim D.-H. e., 2015)

The objective of smart water management is to achieve water security at all levels (building, city and regional) in a sustainability and self- sufficiency manner, through the use of information technology, monitoring and control technology and the implementation of holistic system of all the processes in water cycle.

Some of the primary features of water management include pressure management, smarter leakage techniques for water networks, smart network operations and maintenance of the water cycle, smart water meter technology, and smart water quality monitoring. Countries around the globe are becoming increasingly aware of the critical nature of the water situation. According to analysts at Technavio, the global smart water management market stood at approximately \$7 billion in 2015, and is expected to reach \$16.73 billion by 2020²⁰.

The implementation of SWM in urban cities can provide significant efficiency in water distribution through leakage detection and reduction, lower operation and maintenance costs through real-time monitoring and forecasting, and improve customer service through real-time feedback of water usage and availability. It also provides the water utilities economic benefits through the reduction of non-revenue water losses through the detection of illegal connections and water theft.

According to the OECD²¹ report 'Water Security for Better Lives', in order to achieve water security means to maintain acceptable levels for these four water risks:

i. Risk of shortage (including droughts): lack of sufficient water to meet demand (in both the shortand long-run) for beneficial uses by all water users (households, businesses and the

²⁰ https://www.technavio.com/blog/smart-water-management-way-forward

²¹ http://www.oecd.org/env/resources/watersecurity.htm
environment)

- ii. Risk of inadequate quality: lack of water of suitable quality for a particular purpose or use
- iii. Risk of excess (including floods): overflow of the normal confines of a water system (natural or built), or the destructive accumulation of water over areas that are not normally submerged
- iv. Risk of undermining the resilience of freshwater systems: exceeding the coping capacity of the surface and groundwater bodies and their interactions (the "system"); possibly crossing tipping points, and causing irreversible damage to the system's hydraulic and biological functions

In order to manage the above-mentioned risks, it is imperative to investigate and indentify all the processes involved.

3.1.1 The Water Cycle

The water cycle plays a crucial role in the smart water management. The water cycle can be divided in three domains that are associated to specific activities and business processes (Gourbesville, 2011):

- · Protection of natural environment and ecosystems;
- Natural hazards mitigation and disaster prevention;
- Water uses.

The first domain considers all actions needed to assess and advice on the environmental impacts of development proposals and projects related to specific water uses. Results are used by regulatory services. The domain covers also all conservation actions of water related ecosystems.

The second domain is focused on water related natural hazards mitigation actions. Floods, water-borne and vector disease outbreaks, droughts, landslide and avalanche events and famine are the processes covered by this domain. Every year, disasters related to meteorological, hydrological and climate hazards cause significant loss of life, and set back economic and social development by years. The disaster is defined as a serious disruption of the functioning of a community or a society causing widespread human, material, economic and/or environmental losses.

The last domain covers the added influence of human activity on the water cycle. Generally, the water uses refer to use of water by agriculture, industry, energy production and households, including in—stream uses such as fishing, recreation, transportation and waste disposal. All of those uses are directly linked to specific activities and processes that are potential targets for deployment of ICT solutions. In order to stick to the reality of the water management operated by entities in charge of water services, the traditional classification can be reviewed. The main water uses appear then as: agriculture, aquaculture, industry, recreation, transport/navigation, and urban.



Figure 37 Domains of water cycle

3.1.2 Description of Domains in Water Cycle

Natural environment: Encompasses all living and non-living things, including natural forces occurring naturally on Earth or some region thereof, providing conditions for development and growth as well as of danger and damage. It is an environment that includes the interaction of all living species. Referring specifically to water environment, there are different biotopes than can be distinguished in continental waters (rivers, lakes, reservoirs ...), coastal and maritime environments.

Natural Hazards: Unexpected or uncontrollable natural event of unusual intensity that will have a negative effect on the environment or people by threatening their lives or activities. Atmospheric hazards are weather-related events, whereas geologic hazards happen on or within the Earth's surface. However, it is important to underline that atmospheric hazards can trigger geologic hazards, and geologic hazards can trigger atmospheric hazards. In the water domain, natural hazards are related to floods, droughts, tsunamis, limnic eruptions, seiche.

Water Uses: Are composed of the water cycle with the added influence of human activity. Dams, reservoirs, canals, aqueducts, intakes in rivers, and groundwater wells all reveal that humans have a major impact on the water cycle. According to the defined water domains, the water uses represent the largest field where ICT solutions can be developed and implemented. All in all, the Water uses considered in this framework are:

• Agriculture: Irrigation water use is water artificially applied to farm, orchard, pasture, and horticultural crops, as well as water used to irrigate pastures, for frost and freeze

protection, chemical application, crop cooling, harvesting, and for the leaching of salts from the crop root zone. In fact, irrigation is the largest category of water use worldwide.

- Aquaculture: also known as aquafarming, is the farming of aquatic organisms such as fish, crustaceans, mollusks and aquatic plants. Aquaculture involves cultivating freshwater and saltwater populations under controlled conditions, and can be contrasted with commercial fishing, which is the harvesting of wild fish. This implies some sort of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators and so forth. It also implies individual or corporate ownership of the stock being cultivated. Similar to agriculture, aquaculture can take place in the natural environment or in a manmade environment. This activity uses part of the water bodies in order to develop activities. Aquaculture can be more environmentally damaging than exploiting wild fisheries on a local area basis but has considerably less impact on the global environment on a per kg of production basis.
- Industry: This water use is a valuable resource for such purposes as processing, cleaning, transportation, dilution, and cooling in manufacturing facilities. Major waterusing industries include steel, chemical, paper, and petroleum refining. Industries often reuse the same water over and over for more than one purpose.
- Recreation: It often involves some degree of exercise as well as visiting areas that contain bodies of water such as parks, wildlife refuges, wilderness areas, public fishing areas, and water parks. Some of the activities that imply the uses of water for this purpose are: fishing, boating, sailing, canoeing, rafting, and swimming, as well as many other recreational activities that depend on water. Recreational usage is usually non-consumptive; however recreational irrigations such as gardening or irrigation of golf courses belong to this category of water use.
- Energy: Derived from the force or energy of moving water, which may be harnessed for useful purposes, such as Energy production. There are several forms of water power currently in use or development. Some are purely mechanical but many primarily generate electricity. Broad categories include: conventional hydroelectric (hydroelectric dams), run-of-the-river hydroelectricity, pumped-storage hydroelectricity and tidal power. Cooling of thermo-electric plants is another essential use of water in the field of energy.
- Transport/navigation: It refers to the transport of goods or people using water as a means of transportation (on rivers as well as canals). This water use refers only to commercial transport, since recreational transports such as sailing is considered

above in Recreation water use.

 Urban: Urban water use is generally determined by population, its geographic location, and the percentage of water used in a community by residences, government, and commercial enterprises. It also includes water that cannot be accounted for because of distribution system losses, fire protection, or unauthorized uses. For the past two decades, urban per capita water use has levelled off, or has been increasing. The implementation of local water conservation programs and current housing development trends, have actually lowered per capita water use. However, gross urban water demands continue to grow because of significant population increases and the establishment of urban centres. Even with the implementation of aggressive water conservation programs, urban water demand is expected to grow in conjunction with increases in population.

3.1.3 Definition of Activities

Activities in each of the identified domains can be determined using the following methodology (@QUA, 2011):



Figure 38 Invariant activities taking place in the various domains and water uses

- i. Investigation/survey: Consists of the gathering of information of the previous and actual state and/or working of the domain in study. This assembly of information can be done either by a systematic collection of field data (survey) or a collection of information or data from a methodical research of available documents and/or the production of new ones in order to understand or to improve the actual state of the domain. Ex.: Investigation of the effluents into a river.
- ii. **Observation/monitoring:** From a general point of view, this activity refers to the awareness of the state of a system. It describes the processes and activities

that need to take place to characterise and monitor the quality and/or state of the domain in study. All monitoring strategies and programmes have reasons and justifications which are often designed to establish the current status of the domain or to establish trends in its parameters. In all cases the results of monitoring will be reviewed and analysed. The design of a monitoring programme must therefore have regard to the final use of the data before monitoring starts. Ex.: Systematic collection of water sample of a river to analyse its quality.

- iii. Designing (including risk assessment): Refers to the process of devising a system, components, or processes to meet desired needs. It is a decision-making process (often iterative) in which the basic sciences, risk assessment and engineering sciences are applied to convert resources optimally to meet a stated objective. Among the fundamental elements of the design process are the establishment of objectives and criteria, synthesis, analysis, construction, testing and evaluation. In order to obtain a design that achieves the desired needs for the domain in study, the two previous steps should have been accomplished and taken into account. Ex.: Design of a wastewater treatment plant of a factory in order to improve its effluents.
- iv. Bilding & decommissioning: Consists of carrying out the proposed solution (design) for the domain. In order to execute this design, construction and/or decommission activities may be executed. It is essentially a minimal environmental impact when accomplishing these activities. The tolerable environmental impact will be obtained from the risk assessment of the designing step.
- v. Operation: It refers to the action of manoeuvring a system. It may include the combination of all technical and corresponding administrative, managerial, and supervision actions. Operation may also include routine actions which keep the system in working order. This latest actions might turn out as response of problems detected during monitoring. Ex.: Operation of the wastewater treatment plant.

3.1.4 Water Business Processes

According to the defined water domains, the water uses represent the largest field where ICT solutions can be developed and implemented, where the main sub-domains in water use consists of agriculture, aquaculture, industry, recreation, transport/navigation, and urban.

The water use sub-domain "Urban Uses" will be used as the template for the identification of associated water business processes as it encompasses all the processes found in all the sub-domains

of the Water Use. Urban Uses are generally determined by population, geographic location and the percentage of water used in a community by residences, government, and commercial enterprises. It also includes water that cannot be accounted for because of distribution system losses, fire protection or unauthorized uses. For the past two decades, urban per capita water use has leveled off – even decreased in most of western European countries - or has been increasing. The implementation of local water use. However, gross urban water demands continue to grow because of significant population increases and the establishment of wider urban centres. Even with the implementation of aggressive water conservation programs, urban water demand is expected to grow in conjunction with increases in urban population.

A total of 29 water business processes for water use has been defined which is show in Table 16.

Business Processes		Business Processes		
1 -	Asset management	16 -	Water primary network management & water balance	
2 -	Crisis management	17 -	Water secondary network management	
3 -	Field intervention management	18 -	Leak detection	
4 -	Field works	19 -	Meter reading (AMR & MMR)	
5 -	Use of GIS	20 -	AMR & MMR management	
6 -	Maintenance of GIS	21 -	Public service contract management	
7 -	Management of plant maintenance	22 -	Waste water network management	
8 -	Electro mechanical maintenance	23 -	Storm water network management	
9 -	Laboratory activity and quality control	24 -	Waste water treatment plant management	
10 -	Automation & sensors	25 -	Sewer inspection and sewer cleaning	
11 -	Real time network management	26 -	Billing	
12 -	Planning and design of new assets & plants	27 -	Customer care & communication	
13 -	Water resources management	28 -	Innovation & pilots	
14 -	Environment management	29 -	Supports	
15 -	Drinking water treatment plant management			

Table 16 Business processes for urban uses.

Upon closer analysis, these 29 BPs are merged by homogeneous categories in terms of ICT, with the same (or similar) data, functionalities and potential gaps.

The categories of the merged BPs are listed in Table 17.

Business processes category	Remarks
1 - Management of Plants	This BP includes DWTP Management and WWTP Management. It concerns not only plants but also (pumping) stations, including as well automation, in the sense of a "customer" of the needed automation.
2 - Management of Networks	This BP is the merger of DWNM, WWNM, SWNM and Real Time Networks Management (RTNM)
3 - Asset Management	In this BP is the study of ICT related to a general vision of Asset Management
4 - Work Management	This BP describes 2 levels of decision/actions: the management of jobs and interventions (field & plants) and the field and plant work in general. It also includes the inspection and cleaning of sewers (which, at this level of analysis, are not so different from the other field interventions)
5 - Geographic Information (GI)	This merged BP includes the maintenance and use of geographic information. It could be said that GI is not a BP per se, but it is included as such due to the major importance of Geographic Information.
6 - Measurements	It includes Automation & Sensors (including measurement systems), AMI "Smart Metering" and Laboratory activity & Quality Control.
7 - Customers	It includes Billing, Customer care and communication (including manual meter reading). In this BP, focus will be on: Manual metering; Billing; Customer care
8 - Public Service Contract Management	-
9 - Transverse BPs	This includes Crisis management, General reporting and communication.

Table 17 Business processes categories for urban uses.

Table 18 shows the functions of business process categories as well as the type of data they required or processed.

Business processes category	Data Required / Processed	Purpose / Function
Management of Plants	 Measurements (both real-time and offline) of DW and WW quality & quantity, status and consumption of electromechanical equipment and on-line sensors, laboratory results, description of plants Assets description (including attributes and detailed drawings/charts (e.g. electrical cabinets), technical handbooks Geographic information of the plants. Rules of Operation, Daily Organization of work and Administration data 	 To provide permanent access and visualization for processing data of DW and WW PLC programming To report on technical performance and administrative Daily work organization and supporting activities
Management of Network	 Measurements (both real-time and offline) of DW and WW quality & quantity, status and consumption of electromechanical equipment, laboratory results Description of networks like assets description, condition of assets, geographic information of technological areas, Standards for geographic objects Rules of Operation, Daily Organization of work and Administration data 	 To provide access, visualization and control for processing data (quantity and quality) in real time (water balance capacity production - AMR/AMM System) For modelling hydraulic, quality and CSO scenarios. Reporting, daily work organization and supporting activities
Asset Management	 Asset description which includes Asset Register / GIS, Condition of assets, Standards for assets description, Vulnerability/exposition to external risk and Design hypothesis data & decision done. Events and measurements Interventions & Work (done, planned, on-going) Customers, contracts, finance aspects Laws and regulations 	 To provide assessment of assets' condition, performance and risk To define capital investments strategies, maintenance policy and purchase policy To provide feedback on asset management medium term efficiency and follow-up application of strategies and policies

Business processes category	Data Required / Processed	Purpose / Function
	 Requirements and rules for choosing, prioritizing and launching the jobs and interventions 	 To transform the triggers into "job requests", including linkage to customer care.
	 Resources information (availability and location) Status of jobs & interventions 	 To launch and monitor the jobs / projects, including management of the "unexpected"
Work Management	 Status of jobs & interventions Reports Technical info (cf Plant management / Network management), including actual current status of manual valves (or sluices) 	• To monitor the unitary actions / interventions: including assignment (i.e. matching of interventions and "relevant" resources, meaning by "relevant" all competent, available and adequately located resources)
		 To provide reports at 3 levels, job manager / team manager - foreman / operator
	 Geographic context: base maps, cadastre maps, aerial or satellite 	 To provide integration of "geographic" data in all BPs' functions;
	photos, etc.; administrative boundaries, shared address system with aliases.	 To provide integration of IGR "Implicit Geographic Relationship" in all BPs' functions
	• Description of the assets: above- and	To provide cartographic HMI
Geographic Information	(including condition and current status) use of topologic functions of the GIS for the description of networks AND plants geo-indexation of multimedia info.	 To provide integration in all devices & web services
	 Geo-anchorages of alphanumeric info: i.e. alphanumerical "objects" such as customer complaints, work orders, anomalies, projects, etc 	
		 To provide data for acquisition, validation, storage, aggregation and assimilation
Measurements	 Asset condition data Equipment description Administration and external data 	• To generate and provide for visualization, automated reports, and decision support /early warning (open loop), process control (closed loop), and efficient communication between the "field equipment" and the central IS
Customer	 Customer related data like customer details, technical information, 	To provide billing support, including flexible tariff handling
	communication records, and financial status and records	To provide bidirectional real time access to customer data

Business processes category	Data Required / Processed	Purpose / Function			
		 Collecting, collating data in a common standard format - to be collated from a variety of IS (incl. emails & digitized analogue sources) & carrying out complex contract data modelling; 			
		 Provision & visualization of the data & model outputs to both – service provider & regulator; 			
Public Service	 All data used across the organization, i.e. performance indicators (environmental, financial service) 	 Comprehensive auditing facilities & tracing capture; 			
Contract		 Contract maintenance & change control, charges and cost monitoring; ordering, payment & budget procedures, resource management and planning, management reporting, asset management; 			
		 Automated, integrated case management & escalation; 			
		 Reporting & data exporting; 			
		 KPI real time system. 			
Transverse BPs • In the regards of all ICT needs for the rest of BPs, it was concluded that the specific needs in this BPs are rather low, as the depend on the data collected and managed by all the other BPs.					
Table 18 Data, functionalities of business processes categories for urban uses.					

3.2 Extension to Other Domains

The indentified BPs for urban uses can be extended to rest of domains of the water cycle. The following table describes which BP applies for each domain (Natural Environment Protection, Natural Hazards Mitigation and Water Uses).

Business Processes		Natural Nat		Water Uses					
		Environment	Hazards	Agriculture	Aquaculture	Industry	Recreation	Energy	Transport/ Navigation
1.1	WTP Management								
1.2	WWTP Management								
2.1	DWN Management								
2.2	WWN Management								
2.3	SW Management								
2.4	Real Time Network Monitoring	Х	Х	Х		Х	Х	Х	Х
3	Asset Management		Х	Х	Х	Х	Х	Х	Х
4.1	Management of field interventions & plant maintenance	X	X	x	X	х	x	x	X
4.2	Field/ Plant work	Х	Х	Х		Х	Х	Х	Х
4.3	Electromagnetic maintenance in WTP, WWTP & PS	x	X	x		x	x	x	
4.4	Sewer Inspection								
4.5	Sewer Cleaning								
5	GI	Х	Х	Х	Х	Х	Х	Х	Х
6.1	Automation & Sensors	Х	Х	Х	Х	Х	Х	х	Х
6.2	Advance Metering Infrastructure	Х		Х	Х	х	Х	Х	
6.3	Lab & Quality Control	Х		Х	Х	х	Х	Х	
7	Costumers			Х		х		Х	
8	Public Service Contract Management							x	
9	Crisis Management	Х	Х	Х	Х	Х	Х	Х	Х

Table 19 Business Processes for All Domains in Water Cycle

These indentified water business processes will be used to create the framework for the smart water management.

3.3 Smart Water Management (SWM) Framework

According to the characteristics of smart water, the following overall framework for a smart water city is proposed in Figure 39. There are seven main components which can be categorized into three main compartments. They are as follows:

- i. Hardware (Sensors and Sensors Adapters)
 - a. Data acquisition and monitoring
 - b. Data conversion and transmission
- ii. Water Information System (Big Water Data Management and Analysis)
 - a. Data processing and Storage
- iii. Software (Support Services and Applications)
 - a. Modelling and analytics
 - b. Real-Time Monitoring and Control System
 - c. Decision Support System and Visualization
 - d. Dissemination of information to stakeholders





3.4 Hardware: Sensing Technologies

This layer of the architecture is the "eyes" for the SWM, responsible for collecting and transmitting data regarding the water system and water cycle. There are two main components:

- Sensors: They are responsible for capturing the data for the water information system.
- **Sensor Adapters:** They are responsible for collecting and converting the sensor data into a standardized-readable format for water information system.

It should be noted in this layer that the sensors are monitoring the areas indentified in the water cycle and the business processes in sections 3.1.1 and 3.1.4. The areas to be monitored are:

- Water resources
- Water environment (including marine monitoring)
- Water-related hazards

3.4.1 Sensors

In this section, the focus will be on water metering. Mechanical flow and volume restrictors has been widely adopted and implemented worldwide as a means to reduce water usage. These low-flow fixtures include sink faucets, showerheads and toilets that use less water per minute than the older, traditional models. They conserve water by using a high-pressure technique to produce a strong or equal flow of water with less water than other less-efficient fixtures. However, their potential to provide more conservation of water is limited as the flow-rates of the current existing fixtures has already reached the minimum level that is accepted by the users. This leads to the motivation to further reduce water consumption through other means. Research has shown that feedback in water consumption has a profound effect on water conservation. With real-time feedback, there is up to 22% reduction in resource consumption for the target behaviour. (Tiefenbeck, et al., 2016). Similarly in a research conducted in Tokyo, Japan showed that water use in high consumption consumers decreased when they received feedback using emoticons, while water use in low consumption consumers decreased when they saw that their use had decreased by feedback on ranking. (Otaki, Ueda, & Sakura, 2017). Data-driven approaches have also shown effective in the reduction of water usage. Research has shown that data-driven approaches are promising in real life burst detection in water distribution systems (Wu & Liu, 2017). In addition, findings has shown that that data-driven urban water management help in the development and application of novel methods, the optimisation of the efficiency for the current network-based approach, and the extension of functionality for today's systems. (Eggimann, et al., 2017)

This brings the sensors into the focus for water management as the above-mentioned solutions required high frequency, accurate and real-time measurements. Sensors can be implemented on three different scales: single fixture (e.g., on faucet-level), block level (e.g., household, building, hydraulic

infrastructure like dam) and district level (e.g., water distribution network). At the one side of the spectrum, approaches are focused on extracting information from a single sensing point through data disaggregation (centralized systems). On the other side, a (possible large) number of additional sensors at individual fixtures are used (distributed sensing), with the solution resembling a networked system of sensors that are able to communicate.

3.4.1.1 Mechanical water meters

Mechanical meters are primarily deploys in the domestic domain, which includes displacement meters, velocity water meters, turbine meters and compound meters.

3.4.1.1.1 Displacement Meters

There are two common types of displacement meters: oscillating piston meters and nutating disk meters. Both use the displacement of the moving measure element by the water to measure the amount of water that passes through the meter. Because displacement meters require that all water flows through the meter to "push" the measuring element, they generally are not practical in large commercial applications that require high flow rates or low pressure loss. This type of meter is mainly used for residential and small commercial users. (Water metering, 2017)

3.4.1.1.2 Velocity Water Meters

Velocity water meters measure the velocity of flow through a meter of a known internal capacity (impeller). The speed of the flow can then be converted into volume of flow to determine the usage. There are several types of meters that measure water flow velocity, including jet meters (single-jet and multi-jet), turbine meters and propeller meters. Most velocity-based meters have an adjustment vane for calibrating the meter to the required accuracy (Water metering, 2017).

Multi-jet meters are more efficient compared to single-jet meters, where the impeller in the former is driven in a more balanced way, avoiding one-sided wear. Multi-jet meters are also more tolerant to the pipe's velocity profile and to low flow rates compared to single-jets. Multi-jet meters generally have an internal strainer element that can protect the jet ports from getting clogged. However, once the jet ports are clogged, the accuracy of the meters decrease significantly.

Turbines meters are less accurate than displacement and jet meters at low flow rates, but are better at high flow rates (Woltmann Turbine, 2017). They are used for large commercial users, fire protection and as master meters for the water distribution system. They are accurate in normal working conditions but are greatly affected by the flow profile and fluid conditions.

3.4.1.1.3 Compound Meters

Compound meters consist of a combination of displacement meter or multi-jet meter (low flow element) and a turbine meter (high flow element) (Water Meters - Combination, 2017). At high flow rates, water is diverted to the turbine meter. When the flow rate decreases to a level where the turbine is not able to measure accurately, a check valve is closed to divert the flow to the low flow element. This allows high accuracy at low flow rates with low pressure drops at high flow rates which is suitable in domains that has a wide range of water flows.

3.4.1.2 Electromagnetic water meter

Electromagnetic water meters use the physics principle of Faraday's law of induction to determine the water flow velocity and require electricity from a power line or battery to operate the electromagnets. As there is no mechanical measuring element for in the electromagnetic water meters, they can be used for measuring raw (untreated/unfiltered) water and waste-water as there is no risk of wear and tear to the measuring element. Stray electrical signals is a source of inaccuracy for the electromagnetic meters which can be reduce by installing grounding rings or electrodes to divert the stray signals from the measuring electrodes or using alternating currents to reduce the disturbance voltages. Electromagnetic meters are ideal for applications where low-pressure drop and low maintenance are required. They are also ideal for wastewater applications or any dirty liquid which is conductive or water based. Magnetic flow meters will generally not work with hydrocarbons, distilled water, and many non-aqueous solutions.

3.4.1.3 Ultrasonic water meter

There are two types of ultrasonic water meters, Doppler Effect Meters which utilize the Doppler Effect to determine the velocity of water passing through the meter, and Transit Time Meters which measure the amount of time required for the ultrasonic signal to pass between two or more fixed points inside the meter. Ultrasonic water meters are typically very accurate, with residential meters capable of measuring down to 3.8e-5 m3.(Water metering, 2017) Although both ultrasonic water meters are sensitive to flow turbulences and turbidity, they work best in opposite applications.

Doppler ultrasonic flow meters rely on particles flowing in the liquid to operate, care must be given to the lower limits for concentrations and sizes of solids or bubbles. In addition, the liquid must flow at a rate high enough to keep the solids suspended. Doppler meters are usually used in situations where only flow monitoring is important and billing is not considered. (OMEGA, 2017)

Time transit meters typically operate in the 1-2 MHz frequencies. Higher frequency designs are normally used in smaller pipes and lower frequencies for large pipes up to several meters in diameter.. Because the ultrasonic signal must cross the pipe to a receiving transducer, the fluid must not contain a significant concentration of bubbles or solids. Otherwise the high frequency sound will be attenuated and too weak to traverse the pipe. (Greyline, 2017) Doppler flow meters work best in dirty or aerated liquids like wastewater and slurries. Transit Time flow meters work with clean liquids like water, oils and chemicals.



Figure 40 Types of Ultrasonic Water Meters

Type of Sensor		Flow Rate High	Flow Turbidity High	Applications
	Displacement Metes	Low	Low	Water Supply
Conventional	Velocity Meters	Low	Low	Water Supply
Meters	Turbine Meters	High	Low	Water Supply
	Compound Meters	Low / High	Low	Water Supply
Electromagnetic Meters		Low / High	High	Wastewater, Sewer
Ultrasonic	Doppler Meters	Low / High	High	Wastewater, Sewer
Meters	Time Transit Meters	Low / High	Low	Water Supply

Table 20 Characteristics of Water Meters Sensors

Table 20 shows the capability of the water meters of measuring the water flow for flow rate and flow turbidity. Meters that are only able to measure low flow rate are suitable for residential while meters that are capable of handling both high and low are suitable to industrial (eg. water treatment plants and waste water treatment plants). In addition, meters that can handle low flow turbidity require attention to the flow quality. For conventional meters, attention should be given for the maintenance of physical measuring elements to ensure there is no clogging. For time transit meters, it is not suitable for measuring high turbidity flow like wastewater or sewer water, which Doppler meters are suitable for. Electromagnetic meters are also ideal for wastewater and sewer applications.

3.4.1.4 Noise Water Meter

Using the accelerometers, researches conducted in a laboratory environment where the accelerometers are mounted on the exterior of water pipes have a strong deterministic relationship to water flow rate. They are able to sense the pipe vibrations induced by the translation of pressure fluctuations in the fluid. (Evans, Blotter, & Stephens, 2004). In recent years, Visenti²² has developed LeakViewTM system which is able to detect water main breaks on pipes with diameter less than 600mm with an average accuracy of +/-5m by indentifying acoustic noise related to such breaks.

3.4.1.5 Pressure water meter

HydroSense is a low-cost pressure-based sensor that automatically determines water usage activity and flow from a single non-intrusive installation point, by continuously analyzing pressure in a residential water infrastructure.(Froehlich, et al., 2012) Identification of water fixtures is based on the unique pressure waves that propagate to the sensor when valves are opened or closed. The amount of water being used at a fixture is estimated from the magnitude of the resulting pressure drop within the water infrastructure. An experimental evaluation indicated that the proposed algorithms identified fixture events with 98% accuracy and estimated water usage with error rates comparable to empirical studies of traditional utility-supplied water meters. However, the proposed approach requires an external power source to operate. Moreover, the technique requires a time consuming and sophisticated learning phase to train the system in order to determine which pressure pattern belongs to which outlet. Changes in pressure drop are likely to lead to different pressure signatures, which dramatically reduces accuracy. Moreover, even smaller changes of the infrastructure (e.g. new shower head in the shower, new washing machine) would require a new training phase. While the approach itself is interesting from an academic perspective, it cannot be foreseen when and how the challenges of applying the results at a commercial scale can be overcome.

3.4.2 Sensors Adapters

The measurements from the sensors have to be collected in real-time filtered and converted into a standardized form before it can be send to the Water Information System. The process is as follow:

- Collection of Raw Data: The measurements captured by the sensors installed in the system are collected by these data loggers in their original raw format of the sensors' format.
- ii. **Filtering of Raw Data:** The collected raw data will undergo a filtering process where missing data values, repeated measurement data or corrupted data will be removed.
- iii. Conversion of Filtered Raw Data: The filtered raw data will then be converted into a

²² https://www.visenti.com/resources/front/template/visenti/doc/1703-Visenti-LeakView_Final-Lowres.pdf

standardized format which will be then saved in the Water Information System.

iv. Transmission of Standardized filtered Data: The uploading of the standardized filtered data to the water information system will be carried out either using wired or wireless means.

3.4.3 Data Format and Data Sources Linking

It is important to ensure that the sensor data from different sources are properly defined and integrated. Figure 41 shows the relationship of the sensors data fields from a typical sensor reading. By storing the information into four distinct tables, it is possible to have an aggregation of the data of different types of measurements in a standardized single table.



Figure 41 Tables relationship for sensor data from different sources

The 'Sensor' table contains the general information of the sensor like its manufacturer, installed date, the maintenance date and installed location of the sensor. The' Obs' table contains the measured data by the sensor. This table is link to the 'Obs_Type' table which specifies what the type of measurement data the sensor is observing as well as the unit of the measured data. This allows different types of data to be stored in the same 'Obs' table. Finally, the 'Agg' table stores the processed data where measured data from the sensors are summed up for a larger time scale.

3.4.4 Standards for Hydrological Information

For the Hydrological information, there has exists many different standards and tools available for collecting, processing and managing them. They include Archydro, WaterML2.0, Australian Water Data Transfer Format, Water Quality Exchange (WQX), XHydro, KISTERS, EA Time Series Data Exchange Format (UK-EA-TS), The French National Service for Water Data and Common Repositories Management (SANDRE), The Open Modelling Interface (OpenMI), DelftFEWS, Climate Science Modelling Language (CSML), CUAHSI Hydrologic Information System (CUAHSI-HIS).

3.4.4.1 WaterML2.0

WaterML2.0 is implemented as an application schema of the Geography Markup Language version 3.2.1, making use of the OGC Observations & Measurements standards. WaterML2.0 is designed as an extensible schema to allow encoding of data to be used in a variety of exchange scenarios. Example areas of usage are: exchange of data for operational hydrological monitoring programs; supporting operation of infrastructure (e.g. dams, supply systems); cross-border exchange of observational data; release of data for public dissemination; enhancing disaster management through data exchange; and exchange in support of national reporting. The core aspect of the model is in the correct, precise description of time series. Interpretation of time series relies on understanding the nature of the process that generated them. This standard provides the framework under which time series can be exchanged with appropriate metadata to allow correct machine interpretation and thus correct use for further analysis. Existing systems should be able to use this model as a conceptual 'bridge' between existing schema or systems, allowing consistency of the data to maintained.

3.4.4.2 Australian Water Data Transfer

Water Data Transfer Format (WDTF) is a data delivery standard implemented by the Australian Bureau of Meteorology (BoM) that was jointly developed with the CSIRO. It forms part of the Bureau of Meteorology's AWRIS software. It facilitates the transfer of Time Series data, and Metadata provides a streamlined process to deliver water data while ensuring that the data delivery solution is commercially available and supported by the current IT industry. The standard not only addressed observational data, but also descriptions of features (storages, water courses), transactional information (for synchronizing with a data warehouse), conversions (e.g. a rating table conversion) and water quality samples. Version 1.0 includes groundwater observations. This format makes use of the O&M specification, through a simple features GML profile [ISO19125-1] that restricts certain aspects such as the available geometries and complexity of types. It also uses GML for spatial types.

3.4.4.3 Water Quality Data (WQX)

The WQX standards are developed by the Environmental Data Standards Council (The Council) which is comprised of ten members from Tribes, States and US EPA. The Council's primary function is to develop and adopt Data Standards - documented agreements on terms, definitions, and formats - when there is an environmental business reason. Version 2.0 of the standard is used by the US EPA, and the USGS to deliver water quality information over web services and REST interfaces. With the use of the Water Quality Exchange (WQX) data format, data are now easily shared with 400 federal, state, tribal and other partners through a Water Quality Portal which acts as a single access point for over 300 million water quality data records.

3.4.4.4 Xhydro

XHydro is an XML format for inter-departmental and cost-efficient time-series data exchange for optimized transmission of gauging-station data in the Water and Shipping Administration (WSV). Its purpose is to standardize the transmission of time series data between sensor, data logger, central data node and long time data archives. It was developed in 2007 by Disy Informations Systeme GmbH and KISTERS AG and tested by the German Federal Institute of Hydrology. Key design criteria were neutrality in terms of fields of application, user affiliation, and nationality as well as openness for extensions by additional user-specific data contents.

3.4.4.5 EA Time Series Data Exchange Format (UK-EA-TS)

The UK Environmental Agency developed the EA Time Series Data Exchange Format (UK-EA-TS) to address the need to exchange a variety of sets of time-series data with both internal and external stakeholders. The standard addresses:

- Rainfall amounts
- River levels and flows
- Tide levels
- Lake and reservoir levels
- Groundwater levels
- Areal modelled evaporation, soil moisture deficits, etc.
- Continuously monitored water quality parameters: e.g. dissolved oxygen and ammonia quantities
- Climate station data: e.g. temperatures, wind speed and radiation

3.4.4.6 French National Service for Water Data and Common Reference Frames Management (SANDRE)

SANDRE was created in 1993 by the organisation of the French National Service for Water Data and Reference Datasets Management to simplify the exchange of data between the various stakeholders involved. Its architecture is based on the use of a common language for water information that was used to define standards for a number of areas of both spatial and observational hydrological information. It made use of ISO and OGC standards, using ISO19115 for its metadata definitions and a number of OGC service interfaces for describing data assets. The information models developed within this project are well developed and in active use.

Sandre uses a MDA approach: starting from UML to generate XML Schema for the exchange of data via web services. Sandre has been progressively switching its model to OGC standards; work has already been done on moving referential datasets (surface waters, WFD water bodies, etc) towards GML based schema.

3.4.4.7 The Open Modelling Interface (OpenMI)

The OpenMI (Open Modeling Interface) Standard was originally conceived to facilitate the simulation of interacting processes, particularly environmental processes. It did so by enabling independent models of the processes to exchange data as they ran, time step by time step. However, it was quickly realised that OpenMI could be made into a generic solution to the problem of data exchange between any models, not just environmental models, and soon after that not just models but software components. Hence, it could be applied to linking any combination of models, databases and analytical and visualisation tools. When the standard is implemented, OpenMI compliant components can be configured to exchange data during computation (at run-time) as well as running simultaneously and sharing information at each timestep making model integration feasible at the operational level.

3.4.4.8 Delft-FEWS

Delft-FEWS provides an open shell system for managing forecasting processes and/or handling time series data. It incorporates a wide range of general data handling utilities, while providing an open interface to any external (forecasting model). The modular and highly configurable nature of Delft-FEWS allows it to be used effectively for data storage and retrieval tasks, simple forecasting systems and in highly complex systems utilising a full range of modelling techniques. Delft-FEWS can either be deployed in a stand-alone, manually driven environment, or in a fully automated distributed client-server environment.

3.4.4.9 Climate Science Modelling Language (CSML)

Climate Science Modelling Language is a data model for encoding climate, atmospheric and oceanographic data in terms of geometry-based observation classes such as Points, Profiles, Trajectories and Grids. It is a specialist profile of ISO 19156 Observations and Measurements and there is an accompanying implementation as a GML 3.2.1 Application Schema. Earlier versions of CSML were developed as part of the NERC DataGrid (NDG) projects funded by the Natural Environment Research Council. CSML also leverages existing OGC standards such as GML and SWE. They also employ the MDA approach to developing information models.

3.4.4.10 CUAHSI Hydrologic Information System (CUAHSI-HIS)

The CUAHSI Hydrologic Information System (HIS) is an internet-based system for sharing hydrologic data. It is comprised of databases and servers, connected through web services, to client applications, allowing for the publication, discovery and access of data.

One of the major components of the HIS is a software stack called HydroServer that can be used for storing and publishing hydrologic data. HydroServer includes a point Observations Data Model (ODM), which is a relational database schema that was designed for storing time series data, a suite of data loaders and tools for working with ODM, the WaterOneFlow Web services that publish data stored

in an ODM database on the Internet in WaterML format, and the capability to publish geographic information systems (GIS) datasets as spatial data services. Using the HydroServer software stack, server administrators can create any number of observational data services published using the WaterOneFlow web services as well as any number of spatial data services published as Open Geospatial Consortium (OGC) Web Map Services (WMS), Web Coverage Services (WCS), and Web Feature Services (WFS).

3.4.5 Connectivity and Transmission

Once the data is collected, filtered and standardized, it has to be stored or transmitted. Data loggers are used to collect and store the data which in turn will transmit the data to the central system via direct or remote access. There are two technologies available, which are Automatic meter reading (AMR) and Advanced Metering Infrastructure (AMI).

- AMR allows in an automated procedure to collect data related with consumption, diagnostic, and status from water meter or energy metering devices (gas, electric) using sensing devices (also known as smart meters) and transfers it to a central system. Detailed water usage data can be collected continuously at regular intervals (for example, every 30 minutes) and can be read remotely via an automated process, with the usage data sent to the utility's management and billing system.
- AMI starts with smart meters and adds two-way communication between the meter and utility, and between the meter and consumer. This means that in addition to providing readings, the meter can also receive (and often act on) instructions sent from the utility or consumer

Domains	Characteristics
	Readings are automatically read, transmitted and recorded by having a
	device pinging on the meters.
	 ARM systems can be walk-by, drive-by or fixed network.
Automated Meter Reading	• It should be noted that the communication is only one-way, from the meter
(AMR)	to the pinging device.
	• AMR systems are useful if the main objective is to read the meters quickly
	and accurately.
	AMI can be considered Smart Water Grid in the "purest" form
	 This technology is a step-up from the AMR, where it allows two-way
	communication over a fixed network between the utility system and the
Automated Meter	metering endpoints.
Infrastructure (AMI)	Meter readings are recorded and sent to a meter data management
	system (MDMS), from which they may be accessed by the utility's
	customer information system (CIS) and other systems.

The characteristics of AMR and AMR can be found in Table 21 below.

Domains	Characteristics
	If the utility desires, the information can be made available to customers
	through a web portal, or mobile apps.

Table 21 Characteristics of AMR & AMI

As mentioned in 3.4.1, sensors are employed at different scales: single fixture (e.g., on faucetlevel), block level (e.g., household, building, hydraulic infrastructure like dam) and district level (e.g., water distribution network). Similarly, there are different types of connectivity solutions that will be applicable and ideal for the sensors employed at different scales.



Figure 42 Figure of Smart Grid Communication Architecture

3.4.5.1 Home Area Network (NAN)

A home area network (HAN) is a network that is deployed and operated within a small boundary, typically a house or small office/home office (SOHO). It enables the communication and sharing of resources (like the Internet) between computers, mobile and other devices over a network connection.

(Home Area Network (HAN), 2017). This network manages the on-demands requirements of the endusers and will in-turn communicates with the Building Area Network. Typically, HANs need to cover areas of up to 200 square meters and support data speed of 10-100 kilobits per seconds (kbps). (Ho, Gao, Rajalingham, & Le-Ngoc, Smart Grid Communications Network (SGCN), 2014).

3.4.5.2 Building Area Network (BAN)

Similar to HAN, a BAN is responsible for controlling and monitoring consumer smart devices and communication with the utilities. A BAN manages the network for the entire building which consists of apartments and offices. The BAN smart meter is typically set up at the building's power feeder. Due to a higher number of network elements and energy management applications, higher data rates, compared to HAN, are required. (Home Area Network (HAN), 2017)(Ho, Gao, Rajalingham, & Le-Ngoc, Smart Grid Communications Network (SGCN), 2014)

3.4.5.3 Neighborhood Area Network (NAN):

The NAN is responsible for smart metering communications between BANs and Wide Area Networks (WANs). A Nan usually covers an area of several square kilometres and contains smart meters of few hundreds to few thousands depending on the grid topology and employed communications technology and protocol. (Ho, Gao, Rajalingham, & Le-Ngoc, Smart Grid Communications Network (SGCN), 2014). As NAN handles a large volume of different types of data, special attention should be given to avoid security threats and network congestion. (Zubair Md. Fadlullah, 2011).

3.4.5.4 Wide Area Network (WAN):

A WAN acts as the commutation channel between NANs and utility company's private network. It aggregates data from the multiple NANs through the data aggregation points (DAPs) and is responsible for providing the two-way network required for substation communication, distribution automation, quality monitoring, etc. The WAN covers a large area (i.e., thousands of square kilometers) and aggregate a large number of support devices, and thus requires a high data transmission rate of hundreds of megabits per second (Mbps). (Zubair Md. Fadlullah, 2011)

It is worthwhile that the above-mentioned relates to the residential and commercial areas. In water management, a lot of the monitoring and control is required for efficient water management and distribution. Therefore, it is important to include the industrial and field monitoring into the network architecture. This brings into the consideration of Industrial Area Network (IAN) and Field Area Network (FAN).

3.4.5.5 Industrial Area Network (IAN):

An IAN as the name suggests is deployed in factories, where it incorporates connected sensors,

controllers and specialised building management software. Similar to BAN, a mircogrid is an important element of IAN. However, a microgrid of this network has a larger scale, higher capacity and complexity than that of a BAN. Also, the more sophisticated applications that are run in the industries require smart meters that are able to record these additional data. The smart meter is also used as a gateway for the communication between other network segments and the utilities control station. They are mainly deployed in indoor environments and need to support short-range communications between network elements for monitoring and control applications. (Ho, Gao, Rajalingham, & Le-Ngoc, Smart Grid Communications Network (SGCN), 2014)

3.4.5.6 Field Area Network (FAN)

A FAN provides the utilities to extend the reach of Smart Grid deep into the distribution networks to enable distribution automation, substation automation, distributed generation and advanced metering infrastructure, by providing secure, flexible and manageable communications bandwidth for the smart devices in the distribution network. (Field Area Network for Power Utilities, 2017) . They are used to quickly detect anomalies and failures and to automate responses to improve reliability and quality of services. FAN also enables mobile workers to access field devices using hand-held equipment to collect and analyze data for failure/fault detection, troubleshooting and service restoration. Similar to NAN, FAN incorporates a large number of devices and covers wide areas. NAN and FAN may also have overlapped coverage since numerous smart devices are tied to both of them for successful implementations of various emerging applications. For example, smart meters need to be accessible by both of these network segments to ensure that the distribution grid can obtain vital information from customer premises in real-time to enable efficient control. (Ho, Gao, Rajalingham, & Le-Ngoc, Smart Grid Communications Network (SGCN), 2014).

3.4.5.7 Communication Technologies

The various communication technologies and their technical Table 22 below (Gungor, et al., 2011) (Parikh, Kanabar, & Sidhu, 2010), (Ho, Gao, Rajalingham, & Le-Ngoc, Wireless Communications Networks for the Smart Grid, 2014):

Technology	Spectrum	Data Rate	Coverage	Standards Protocols
3G Cellular	1.6-2.5 GHz	Up to 2 Mbps	1-10 km	UMTS, CDMA2000, EV- DO, EDGE
4G Cellular	2.0-8.0 GHz	Up to 1 Gbps23	1-10 km	LTE
 5G Cellular	3.3-86.0 GHz	>1Gbps	1-10 km	-
Bluetooth	2.4 Ghz	721 Kbps	1 – 100m	IEEE 802.15.1

²³ https://whatsag.com/g/understanding_5g.php

Technology	Spectrum	Data Rate	Coverage	Standards Protocols	
GPRS	900 - 1800 MHz	14.4 Kpbs	1-10 km	IP, PPP, X.25	
LoRa	150Mhz -1 Ghz	0.3–50 Kb/s	<30 Km	LoRaWAN R1.0	
PLC	1.8-86.0 MHz	2-3 Mbps	1-3 km	Universal powerline bus, X10, LonTalk	
WiMAX	2.3 GHz, 2.5 GHz, 3.3 GHz, 3.5 GHz, 5.8 GHz	75 Mbps	1-50km	IEEE 802.16	
Wireless Local Area Network (WLAN)	2,4 GHz	1-54 Mbps	100 m	IEEE 802.11b/g/n	
ZigBee	868 - 915 MHz, 2.4 Ghz	250 Kbps	10-100 m	EEE 802.15.4, ZigBee Alliance	
	Table 22 Overview of communication technologies for water sensing				

Based on their technical specifications, the advantages, disadvantages and applications are listed in below.

Technology	Advantage	Disadvantage	Application
3G Cellular	 Expensive infrastructure already widely deployed, stable and mature Well standardized Equipment prices keep dropping; Readily available expertise in deployments Cellular chipset very inexpensive Large selection of vendors and service providers 	 Utility must rent the infrastructure from a cellular carrier for a monthly access fee Utility does not own infrastructure Technology is in the transition phase to LTE deployment Public cellular networks not sufficiently stable/secure for mission critical/utility applications Not well-suited for large data/high bandwidth applications 	 AMI Backhaul, Field Area Network (FAN)
4G Cellular	 Low latency, high capacity Fully integrated with 3GGP, compatible with earlier 3GPP releases Full mobility for enhanced multimedia services Carrier preferred protocol Low power consumption 	 Utility must rent the infrastructure from a cellular carrier for a monthly access fee Utility does not own infrastructure Not readily available in many markets/still in testing phases in others; Equipment cost high Vendor differentiation still unclear Lack of expertise in designing LTE networks; Utilities' access to spectrum 	 AMI Backhaul SCADA Backhaul Demand Response FANs Video Surveillance

Technology	Advantage	Disadvantage	Application
WiMAX	 Efficient backhaul of data – aggregating 100's access points QoS supports service assurance Battery-backup improves reliability and security; Simple, scalable network rollout and customer-premises equipment (CPE) attachment Faster speeds than 3G cellular; Large variety of CPE and gateway/ base station designs 	 Limited access to spectrum licenses in the US Trade off between higher bit rates over longer distances Asymmetrical up and down link speeds User shared bandwidth Competing against future 4G cellular 	 AMI Backhaul SCADA Backhaul Demand Response FANs Video Surveillance
Wireless Local Area Network (WLAN)	 Low-cost chip sets - inexpensive consumer devices Widespread use and expertise; Low-cost application development Stable and mature standards 	 Does not penetrate cement buildings or basements Small coverage and short distances limit wide spread use Security issues with multiple networks operating in same locations 	• HANs • NANs
Zigbee	 Very low cost - inexpensive consumer devices Low power consumption - years of battery life Self- organizing, secure, and reliable mesh network; Network can support a large number of users; Smart energy profile for HANs is available 	 Very short range Does not penetrate structures well; Low data rates Developers must join ZigBee Alliance 	• HANs

Table 23 Advantages, disadvantages and applications for communication technologies

3.5 Big Data and Data Analytics

In 2012, Gartner²⁴ provided a definition for Big Data that has been widely accepted through research and industry: "Big data is high volume, high velocity, and/or high variety information assets that require new forms of processing to enable enhanced decision making, insight discovery and process optimization." Gartner's definition of the 3Vs is widely used, and in agreement with a consensual definition that states that "Big Data represents the Information assets characterized by such a High Volume, Velocity and Variety to require specific Technology and Analytical Methods for its

²⁴ https://www.gartner.com/newsroom/id/1731916

transformation into Value".

Additionally, a new V "Veracity" is added by some organizations to describe it, revisionism challenged by some industry authorities. The 3Vs have been expanded to other complementary characteristics of Big Data:

- Volume: Big Data doesn't sample; it just observes and tracks what happens. This means continuous registering along the whole Water Distribution Network.
- Velocity: Big Data is often available in real-time, for example providing graphs and tables of actual usage and summaries of the data being acquired "right now".
- Variety: Big Data draws from text, images, audio, video; plus it completes missing pieces through data fusion. For example, linking water data to live videos using computer vision, or adding meteorological data to smart meters to take decisions.
- Machine Learning: Big Data often doesn't ask why and simply detects patterns, this means that incorporating data to Machine Learning models can forecast future states of the Water Distribution Network.

According to (Brown, 2012) the most attractive advances that Water Management can benefit from Big Data are:

- Better real-time operations decision-support
 - The most immediate and obvious use for Big Data Analytics is in operating the existing infrastructure. Although this requires to provide more communication and information retrieval capabilities to the asset management infrastructure and foster the advancement of the installation of metering infrastructure by water utilities. As this data becomes available, predictive maintenance (IBM, 2015b), leak detection (Fukushima, Maruta, Ito, Yoshizawa, & Tanaka, 2014), and energy optimization (IBM, 2015a) can be done using Big Data techniques.
- Improved customer relationships and communications
 - At the same time that data is retrieved from the water distribution infrastructure, smart meters and advanced customer-used devices can be retrieving information about user's water usage. This could lead to a better understanding of how and when water is used by customers and also enable the opportunity to increase the communications and interaction between utilities and government with citizens. The feedback that can be provided to customers, combined with incentives for water use efficiency, offer a more dynamic and effective means of incorporating demand management into utilities resource mix (Gleick, 2000).
- Stormwater management
 - As an example, it is known that trees, can contribute to stormwater management and urban cooling (EPA, 2013) – reducing energy costs and decreasing the amount of

urban runoff reaching receiving waters. At the same time, tree planting is often seen as a supplemental benefit rather than a replacement for the traditional stormwater infrastructure characterized by pipes and pumps. By monitoring wastewater infrastructure in a Big Data approach one can log and analyse how all the elements of the city can help to improve water treatment and benefit to urban environment. Increasing monitoring and deploying more sensors in the natural environment can provide the necessary data for managers to see that natural systems are reliably doing their part in the urban environment (Boyle, et al., 2013).

- Citizen involvement in infrastructure management
 - Through the development of apps, citizens can collaborate to keep the infrastructure in a good state and also citizens can be alerted of the inconveniences of maintenance, such as water distribution disruptions. Web and mobile apps allow government and organizations to receive immediate feedback from citizens including reports of incidents, suggestions, and general comments. For example, a person walking through a park can pull out a smartphone and provide a real-time report on problems or ideas for improvement (Pratt, 2012).
- Improvement of preparedness and response to flooding
 - As stated in (IBM, 2013): "flooding cannot be avoided". However, the human and financial costs of flood events can be mitigated if flood defenses are managed more effectively through accurate early warning systems and alerts. Smarter water management also means data can be collected in real-time from river systems, levees, sensors and weather systems, combined with historical data, and aggregated to generate a unified view of the physical infrastructure. Analytics and advanced weather simulation models can be applied to this data to monitor and predict water flows and floods, monitor emerging threats from flooding, and pinpoint with greater accuracy potential areas at risk. The city of Rio the Janeiro in collaboration with IBM, developed the intelligent operations centre²⁵. They implemented a platform to integrate all of the data derived from city's management of urban watersheds including, both the man-made and the natural infrastructure that supports the water distribution network.

3.5.1 Internet of Things (IoT) and Cyber-Physical System (CPS)

Cyber-Physical System (CPS) is a co-engineered interacting network of physical and computational components. Today, CPSs can be found in such diverse industries as aerospace, automotive, energy, healthcare, manufacturing, infrastructure, consumer electronics, and communications. Examples of CPS include robots, intelligent buildings, implantable medical devices

²⁵ http://www.fastcompany.com/1712443/building-smarter-favela-ibm-signs-rio

and self-driving cars. Everyday life has become increasingly dependent on CPS where it provides dramatic improvements for some cases. CPSs are starting to be part, not only of Smart Cities, but also of all world cities. As an example, Donosti (Spain) has incorporated a driverless vehicle in its transportation network²⁶.

Some of these CPSs interact with the world with sensing devices that are connected to the Internet. These devices have decreased its size and price thanks to the advances in electronics. They are referred as 'Internet of Things' or IoT devices as they can be embedded to almost anything to provide connectivity due to its small size.

The IoT describes a network of physical objects embedded with electronics, software, sensors, and connectivity that allows the exchange of data with multiple entities and other connected devices. The focus of IoT is often more on sensing and connectivity where CPS on the other hand puts more emphasis on reliability, security, and system control.

One critical issue of the deployment of IoT networks is the connectivity among its components. In the U.S. the recommended solution for this kind of devices (such as smart meters, data loggers, etc.) is the low power RF (LPRF) communication using a Sub-1 GHz mesh network. However, depending of the country and the nature of the grid, a wireless solution might not be the best choice, for example in Spain or France where wired narrowband Orthogonal Frequency-Division Multiplexing (OFDM) Power Line Communication (PLC) technologies are used.

IoT has a huge potential applicability in Smart Cities and Water Management Systems. At the lowest communication level, the appearance on scene of new methods and technologies enabled the use of electronical devices for monitoring and transmitting data in almost any part of the Water Distribution System. (Monnier, 2014). However, it should be noted that there is no connectivity solution that fits all deployments. In order to realize the IoT requires a larger portfolio that can go from wired to wireless and in some cases a combined of both.

An example of IoT application is in the use of smart meters in household environments where it is possible to deliver useful power consumption information through an in-home display or a gateway. This information allows consumers to adapt resources behaviour and lower utility bills. So in essence, smart meters are becoming smart sensors that communicate both ways, inside and outside homes and buildings, connected to each other in a mesh network while reporting essential resource consumption data to utilities. Regarding the connectivity issue, in the U.S. the IEEE 802.15.4 2.4 GHz ZigBee standard is being used in combination with Smart Energy application profile. Other countries such as the U.K. or Japan are evaluating Sub-1 GHz RF or PLC solutions for greater reach or a combination implementation with both hybrid RF and PLC.

²⁶ http://www.citymobil2.eu/en/

For meter vendors, the move to the smart meter has a big impact on the meter topology. On top of the metrology piece that measures energy consumption, flow rate or water pressure, several radios or PLC solutions are now integrated onto the meters. Sometimes, pre-payment and Near Field Communication (NFC) functions are also implemented. The needs of host microcontrollers (MCUs) are changing, where it require them to have greater memory size and more connectivity and security options to carry the communication protocol. Also, the MCU on a smart meter needs to support advanced functions like dynamic pricing/demand response, remote connect and disconnect, network security, over-the-air downloads and post-installation upgrades so utility providers don't have to send out technicians to each meter.

Many research communities have devoted efforts for fostering Architectures and Protocols for IoT in Water Management and Smart Cities (Zanella, Bui, Castellani, Vangelista, & Zorzi, 2014), (Jin, Gubbi, Marusic, & Palaniswami, 2014) and (Robles, et al., 2015). For example, researchers (Sheng, Yang, Yu, Vasilakos, Mccann, & Leung, 2013) provide a review of the IETF (Internet Engineering Task Force²⁷) standards for IoT.

Some of the standards which are essential and useful for Smart Cities connection are as follow:

• **IEEE 802.15.4:** IEEE 802.15.4 is a radio technology standard for low-power and low-data rate applications with a radio coverage of only a few meters. The standard has been developed within the IEEE 802.15 Personal Area Network (PAN) Working Group. Because of its designated nature as low power and low complexity, an increasing number of IoT devices have been built as IEEE 802.15.4-compliant devices. Moreover, many well-known standardization organizations are also active in developing low-power protocol stacks based on IEEE 802.15.4, such as WirelessHART²⁸ and ZigBee²⁹.

• **6LoWPAN:** Since the beginning of the IETF research on IoT related technologies, IPv6 has been selected as the only choice to enable wireless communication. Its key features, such as universality, extensibility, and stability, have attracted a lot of attention and may become the de facto solution for future Internet technology. In order to enable IP connectivity in resource constrained sensor networks, the IPv6 over Low-Power WPAN (6LowPAN) Working Group has been established and works on protocol optimization of IPv6 over networks using IEEE 802.15.4. Specifically, the 6LoWPAN protocol discusses how to apply IPv6 to the MAC

²⁷ The Internet Engineering Task Force (IETF) develops and promotes voluntary Internet standards, in particular the standards that comprise the Internet protocol suite (TCP/IP). It is an open standards organization, with no formal membership or membership requirements. All participants and managers are volunteers, though their work is usually funded by their employers or sponsors.

²⁸ http://en.hartcomm.org/main_article/wirelesshart.html

²⁹ http://www.zigbee.org/what-is-zigbee/

and PHY layers of IEEE 802.15.4

• **RPL (Routing Protocol for LLN³⁰):** RPL responds to the necessity of constructing routing protocols for LLNs. Based on this kind of networks requirements, the RFC 6551 introduces two kinds of quantitative metrics: node metrics, including node state, node energy, and hop count, and link metrics, including throughput, latency, link reliability, expected transmission count (ETC), and link colour object. In order to assist dynamic routing, nodes can select path(s) based on the quantitative metrics to achieve the defined objective. The RoLL (IETF Routing over Lossy and Low-Power Networks working group) developed this routing protocol RPL supports three kinds of traffic flow: point-to-point (between devices inside the LLN), point-to-multipoint (from a central control point to a subset of devices inside the LLN), and multipoint-to-point (from devices inside the LLN toward a central control point). RPL is a distance-vector routing protocol, in which nodes construct a destination-oriented acyclic graph (DODAG) by exchanging distance vectors and root with a controller.

• **CoAP:** The Constrained Application Protocol (CoAP) specified by the IETF CoRE Working Group, is a specialized web transfer protocol for resource constrained nodes and networks. CoAP conforms to the REST³¹ style. It abstracts all the objects in the network as resources. Each resource corresponds to a unique Universal Resource Identifier (URI) from which the resources can be operated stateless, including GET, PUT, POST, DELETE, and so on. Strictly speaking, CoAP is not an HTTP compression protocol. On one hand, CoAP realizes a subset of HTTP functions and is optimized for constrained environments. On the other hand, it offers features such as built-in resource discovery, multicast support, and asynchronous message exchange.

There exist other standards from other standardization entities such as MQTT that is part of the OSASIS³² Standard since 2014. MQTT is a machine-to-machine (M2M)/"Internet of Things" connectivity protocol. It was designed as an extremely lightweight publish/subscribe messaging transport. It is useful for connections with remote locations where a small code footprint is required and/or network bandwidth is at a premium. For example, it has been used in sensors communicating to a broker via satellite link, over occasional dial-up connections with healthcare providers, and in a range of home automation and small device scenarios. It is also ideal for mobile applications because of its small size, low power usage, minimized data packets, and efficient distribution of information to one or many receivers.

These standards facilitate the communications between IoT elements. These mentioned elements have gained a lot of attention thanks to the appearance of Open Hardware platforms such as RaspberryPi or Arduino. These platforms allow users to implement architectures using tiny, cheap and

³⁰ Lossy and Lowpower Networks (LLNs)

³¹ http://www.ics.uci.edu/~fielding/pubs/dissertation/rest_arch_style.htm

³² https://www.oasis-open.org

highly customizable pieces of hardware and build in a very easy manner. At the same time, the openness of its design make very easy to provide a final prototype without having to spend time and money worrying about the electronic part. The openness also helped in the development of operating systems that already incorporate standard protocols, this is the case of Contiki³³, TinyOS³⁴, FreeRTOS³⁵, Riot³⁶, and OpenWSN³⁷.

At the other spectrum of the IoT communication are the servers capable of reading the data provided by IoT elements and provide useful information to the user. These servers are the endpoint where the final user work and are commonly referred as "IoT platforms". Generally speaking, an IoT platform provides a comprehensive set of generic application independent functionalities which can be used to build IoT applications. Although there is a wide range of different services and functionalities existing IoT platforms offer, the most common ones are:

- **Connectivity & normalization:** harmonizes the inherent dispersion of protocols and data formats of the connected devices and services.
- Device management: ensures the connected "things" are working properly, seamlessly running patches and updates for software and applications running on the device or edge gateways.
- Database: offers a scalable storage solution.
- Processing & action management: define rule-based event-action-triggers.
- Analytics: Integrates some sort of analytic tools to extract information from the collected data.
- Visualization: includes data visualization tools.

Below are some of the most well-known IoT platforms, focusing on open implementations:

Kaa³⁸: Kaa is a production-ready, multi-purpose platform for building complete end-to-end IoT solutions, connected applications, and smart products. The Kaa platform provides an open, feature-rich toolkit for the IoT product development and thus dramatically reduces associated cost, risks, and time-to-market. For a quick start, Kaa offers a set of out-of-the-box enterprise-grade IoT features that can be easily plugged in and used to implement a large majority of the IoT use cases

³³ http://www.contiki-os.org/

³⁴ http://tinyos.stanford.edu/tinyos-wiki/index.php/TinyOS_Documentation_Wiki

³⁵ http://www.freertos.org/

³⁶ https://www.riot-os.org/

³⁷ https://openwsn.atlassian.net/wiki/pages/viewpage.action?pageId=688187

³⁸ http://www.kaaproject.org/smart-energy/

- Temboo³⁹: Temboo is an IoT platform that provides a software stack with pre-built processes that handle common aspects of IoT applications monitoring, data logging, notifications, remote control, and more. Temboo has a prebuilt system that can sense the water levels in a tank, and call the administrator when water levels are too low and allows to remotely refill from a reserve.
- Fiware⁴⁰: The FIWARE platform provides a rather simple yet powerful set of APIs (Application Programming Interfaces) that ease the development of Smart Applications in multiple vertical sectors. The specifications of these APIs are public and royalty-free. In addition, an open source reference implementation of each of the FIWARE components is publicly available so that multiple FIWARE providers can emerge faster in the market with a low-cost proposition.

There already exist IoT solutions that address water sustainability in cities. One example is the project that teamed AT&T, IBM and Mueller Water Products⁴¹. This partnership combines Echologics sensors⁴² and sound technology from Mueller Water Products with AT&T's LTE wireless network to detect water pressure, temperature and leaks in urban water systems. The IBM Water Management Center helps aggregate the water data, providing a complete view of past, present and future performance. The enhanced water management solution put forth by these companies was part of NIST's Global City Teams Challenge, an initiative to advance the deployment of IoT technologies within smart city environments. It enables cities to track information on the condition of their fire hydrants, underground pipes, and drainage systems.

3.5.2 Systems of Systems

Tools like Big Data, Data Mining, IoT, Cloud Computing and many other ICT paradigms are providing new features to managers. As a result, there is a significant increase in the adaptation of new isolated systems for managing the resources of a utility, industry or even in citizens' homes. With the standardization of communications with the Internet Protocol, these systems have the ability to share data and features to almost any device or person in the world. This growing overall complexity of systems has triggered a paradigm shift and the need to enhance the classical view of Complex System Engineering towards System of Systems (SoS) Engineering. System of Systems describes the large

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³⁹ https://temboo.com/iot-applications

⁴⁰ https://www.fiware.org/2016/03/08/iot-fiware-along-the-revolution-of-smart-digital-services/

http://www.sustainablebrands.com/news_and_views/ict_big_data/brynn_mcnally/iot_technology_helping_att_ibm_r evolutionize_city_water_ma

⁴² http://www.echologics.com/

scale integration of many independent self-contained systems to satisfy global needs or multi-system requests (European Commission, 2012).

The term SoS has arisen from the systems engineering community and reflects the interest in concepts and developments such as smart grids, integrated supply chains, collaborative enterprises, and next-generation air traffic management. As defined in (Samad & Annaswamy, 2011), a SoS is built of components that are themselves systems. But the term gains specificity with two properties that the whole must possess for it to be considered a SoS:

- **Operational independence of components:** The component systems fulfil valid purposes in their own right and continue to operate to fulfil those purposes if disassembled from the overall system
- **Managerial independence of components:** The component systems are managed (at least in part) for their own purposes rather than the purposes of the whole.

As explained in (Cheng & Sun, 2015), from the perspective of urban structure, a city is a combination of interactive elements, such as the economic structure, social structure, and spatial structure. From a technical perspective, a city is a complex system composed of multi-field, multiclass, multilevel, and multidirectional heterogeneous subsystems for collaboratively processing different types of massive data in different areas.

According to this definition, a Smart City can be considered a System of Systems. Communication between systems has gained a lot of attention, as it is a crucial issue to take into account not only for the feasibility for physical connectivity but also for the semantics and syntax of the relying data.

3.5.3 Machine to Machine (M2M)

M2M communications can be defined as a system in which individual devices capture data on events, and relay that data through a network (wired, wireless or hybrid) to an application (software program) that translates the captured data into meaningful information. This concept is closely coupled to the idea of IoT^{43 44}, as Internet has become the de facto protocol for data transmission. However M2M is also an enabler for future Intelligent Systems, where a central system orchestrator can talk to every component in the SoS architecture.

One example⁴⁵ of a M2M solution is the remote communication with a Programmable Logic Controller (PLC) without the presence of an on-site technician. The operator can monitor and control an individual device or group of devices through a panel interface. This solution can also allow a technician

⁴³ https://m2m.telefonica.com/blog/smart-water-the-smart-way-to-distribute-treat-and-supply-water

⁴⁴ http://www.koretelematics.com/blog/can-m2m/iot-safeguard-the-worlds-most-sacred-resource-water

⁴⁵ http://www.engineerlive.com/content/m2m-communications-brings-sophistication-water-industry

to do PLC programming over the air to the remote M2M device. There is no need for a technician to go out to site to do a program change. The PLC can be configured to send data on a time interval, on an alarm event, when the storage buffer limits are reached, or when it is manually polled. Event and alarm data is transmitted to the central system simultaneously. Communications can also be set to live mode which will show real time data as the site changes.

Another example is the monitoring of the temperature of three different bearings, a motor's load and its run time, the flow rate of the water and its turbidity at a remote pumping station. Retrieving this data will be a simple means of adding the appropriate data-logging hardware and one or more communications options. When the data is collected, the software can then convert this raw information into reports, each formatted appropriately for the intended user. For instance, a maintenance engineer would be interested at current temperatures and total run times; a process engineer would focus on flow rates and volume, while an environmental scientist would check the turbidity. Once the data is transferred to the central server, it is integrated with data from other pumping stations to produce management level reports and to update business systems.

There are more similar scenarios⁴⁶ for every aspect of a water industry's and Smart Cities assets and it is clear that Big Data analytics will be required to handle the large amount of data collected.

3.5.4 Cloud Computing Infrastructure

Web-based software services, more commonly called cloud computing are being implemented globally by users in virtually all types of organizations, including manufacturing, government, services, retail, and water utilities to reduce cost and improve efficiency. As new systems often require new technology resources to operate and support, cloud computing provides water utilities a viable alternative for investing in additional hardware.

According to NIST, Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction. (NIST, 2011)

The NIST definition lists five essential characteristics of cloud computing: on-demand selfservice, broad network access, resource pooling, rapid elasticity or expansion, and measured service. It also lists three "service models" (software, platform and infrastructure), and four "deployment models" (private, community, public and hybrid) that together categorize ways to deliver cloud services. The definition is intended to serve as a means for broad comparisons of cloud services and deployment strategies, and to provide a baseline for discussion from what is cloud computing to how to best use

⁴⁶ http://www.environmentalleader.com/2014/06/13/qualcomm-ch2m-hill-cincinnati-develop-m2m-watermanagement-system/
cloud computing.

3.5.4.1 Cloud Service Models

The three service models for cloud computing are as follows:

- Infrastructure as a Service (laaS): provides the computing infrastructure, physical or (quite often) virtual machines and other resources like virtual-machine disk image library, block and file-based storage, firewalls, load balancers, IP addresses, virtual local area networks etc. Examples include Amazon EC2, Windows Azure, Rackspace, Google Compute Engine.
- Platform as a Service (PaaS): provides the computing platforms which typically include operating system, programming language execution environment, database, web server etc. Examples: AWS Elastic Beanstalk, Windows Azure, Heroku, Force.com, Google App Engine, Apache Stratos.
- Software as a Service (SaaS): provides the access to application software often referred to as "on-demand software". Installation, setting up and running of the application are all handled by the service provider. Examples include Google Apps, Microsoft Office 365, Dropbox.

These cloud computing services have these several major characteristics:

- Quick to deploy
- No hardware to purchase
- Experts maintain the system so utilities can focus on their core competency
- Automatically implemented software updates
- Rapid elasticity or expansion as utility's needs change
- Subscription pricing provides a pay-as-you go option

Figure 43 shows the level of responsibilities of the user and the service providers for the three service models. IaaS provides the consumer the capability to provision processing, storage, networks, and other fundamental computing resources where the consumer is able to deploy and run arbitrary software, which can include operating systems and applications. The consumer does not manage or control the underlying cloud infrastructure but has control over operating systems, storage, and deployed applications; and possibly limited control of select networking components (e.g., host firewalls).

PaaS provides the consumer the capability to deploy onto the cloud infrastructure consumercreated or acquired applications created using programming languages, libraries, services, and tools supported by the provider. The consumer does not manage or control the underlying cloud infrastructure including network, servers, operating systems, or storage, but has control over the deployed applications and possibly configuration settings for the application-hosting environment. SaaS provides the consumer the capability to use the provider's applications running on a cloud infrastructure. These applications are accessible from various client devices through either a thin client interface, such as a web browser (e.g., web-based email), or a program interface. The consumer does not manage or control the underlying cloud infrastructure including network, servers, operating systems, storage, or even individual application capabilities, with the possible exception of limited user-specific application configuration settings.

As water data are often considered middle to highly sensitive data, water utilities will be more interested in IaaS and PaaS, depending on the required level of customization of the water information platforms.



Figure 43 Types of models for cloud computing (Alioto, 2010)

A 2014 Gartner report (Figure 44) analyzed the current state of the market in terms of cloud service providers. Based on their analysis, these vendors are considered the leaders of the pack:

- Amazon Web Services (AWS)
- Microsoft Azure
- Google Compute Engine (GCE)



Figure 44 Comparison of cloud services providers (Leong, Toombs, & Gill, 2015)

The following Table 24 shows the general information for the three above-mentioned vendors compiled from (Leong, Toombs, & Gill, 2015) and (Sullivan, 2014).

Vendor	Amazon AWS	Windows Azure	Google Compute Engine
Overview	 Offers full range of compute service offerings that include on demand instances in a range of sizes to specialized services like Amazon Elastic Map Reduce (EMR), which is a hosted version of the Hadoop platform based on EC2 and S3, and Cluster GPU Instances that bring high performance computing and specialized graphics processing unit (GPU) computing to public cloud users. The storage offerings are similarly wide ranging with S3 block storage, reduced redundancy storage, EBS, and high performance solid state drives. 	 Despite the name, Windows Azure is not a Windows-only laaS. The compute and storage services offered are typical of what you'll find in other laaS providers, and administrators used to Microsoft platforms will find working with Windows Azure much easier. The laaS offers ready access to virtual networks, service buses, message queues, and non-relational storage platforms as well. 	 Google Compute Engine is well suited for big data, data warehousing, high performance computing and other analytics-focused applications. It is well integrated with other Google services, such as Google Cloud Storage, Google BigQeury and Google Cloud SQL.
Key Features	• Rich set of services and integrated monitoring tools; competitive pricing model. AWS can also be used as a PaaS.	• Easy-to-use administration tool, especially for Windows admins. Windows Azure can also be used as a PaaS.	• With the Google infrastructure backing it up, this laaS is designed to scale.
Locations	 Groups its data centers into "regions," each of which contains at least two availability zones. It has regions on the East and West Coasts of the U.S., and in Germany, Ireland, Japan, Singapore, Australia, Brazil, and (in preview) China. It has one region dedicated to the U.S. federal government. The portal, documentation and support are provided in English, Dutch, French, German, Japanese, Korean, Mandarin, Portuguese, and Spanish 	 Groups its data centers into "regions There are multiple Azure regions in the U.S., Ireland, the Netherlands, Australia, Hong Kong, Japan, Singapore and Brazil. There are also two regions for the U.S. federal government. Azure China is a separate service operated by 21Vianet. Support is provided in English, French, German, Italian, Spanish, Japanese, Korean, Mandarin and Portuguese. The portal and documentation are available in those languages, as well as Russian 	 Groups its data centers into "regions," each of which contains at least two availability zones. There is a central U.S. region, a European region (located in Belgium), and an Asian region (located in Taiwan). Support is available in English and Japanese. The portal is available in English, French, German, Spanish, Portuguese, Korean, Japanese and Mandarin.

Vendor	Amazon AWS	Windows Azure	Google Compute Engine
Compute	• Xen-virtualized multitenant and singletenant compute, with multitenant storage, along with extensive additional IaaS and PaaS capabilities, including object storage with an integrated CDN (Amazon S3 and CloudFront) and a Docker container service (EC2 Container Service)	• Hyper-V-virtualized multitenant compute (Virtual Machines), with multitenant storage, along with many additional laaS and PaaS capabilities, including object storage (Blob Storage) and a CDN	 KVM-virtualized Compute VMs metered by the minute.
Recomme nded Uses	• All use cases that run well in a virtualized environment, although highly secure applications, strictly compliant or enterprise applications (especially complex ones such as SAP business applications) require special attention to architecture.	 General business applications and development environments for Microsoftcentric organizations; cloudnative applications; batch computing. 	 Cloud-native applications and batch computing, as well as projects leveraging Google Cloud Platform as a whole.
Limitation s	• AWS is a complex mixture of services. As workflows become more complex and can be difficult to project expenses when more services are used. However, Amazon offers a monthly calculator to help estimate your costs.	 Minimal, easy-to-use portal interface may not be so appealing to command line gurus. 	• Lacks ease of administration features. Running Hadoop on Google Compute Engine, for example, requires more from users; because it's not integrated you have to download the Hadoop package, a patch for Hadoop and a set of JDK packages along with several other steps to deploy a Hadoop cluster.
Pricing	 Instances range from \$0.113/hour to \$6.82/hour, with volume discounts available for reserved instances. Storage prices range from \$0.095/GB/month to \$0.125/GB/month. Additional charges for application services and data egress may apply. 	 Prices start at \$0.013/hour for the extra small virtual machine and increase up to \$0.64/hour for the extra large option. (Same for both Windows and Linux operating systems.) Storage starts at \$0.093/GB for locally redundant data and \$0.125/GB for up to 1 TB of data per month. The storage charge is based on the average daily amount of data stored during the course of a month. 	 Persistent disk storage is available for \$0.10 GB/month for general-purpose storage but snapshot storage is higher at \$0.125 GB/month. In addition, I/O operations are charged at a rate of \$0.10 per million. Prices for standard object storage start at \$0.085 for the first terabyte and drop to \$0.054 when storing over 500 TB.

Table 24 Comparison of Amazon AWS, Windows Azure and Google Compute Engine

3.5.1 Cloud Deployment Models

There are four types of cloud deployment models. The definitions of the four deployment cloud models are listed in Table 25 below:

Deployment Cloud Models	Definition
Private cloud	 The cloud infrastructure is provisioned for exclusive use by a single organization comprising multiple consumers (e.g., business units). It may be owned, managed, and operated by the organization, a third party, or some combination of them, and it may exist on or off premises
Community cloud	 The cloud infrastructure is provisioned for exclusive use by a specific community of consumers from organizations that have shared concerns (e.g., mission, security requirements, policy, and compliance considerations). It may be owned, managed, and operated by one or more of the organizations in the community, a third party, or some combination of them, and it may exist on or off premises.
Public cloud	 The cloud infrastructure is provisioned for open use by the general public. It may be owned, managed, and operated by a business, academic, or government organization, or some combination of them. It exists on the premises of the cloud provider.
Hybrid cloud	• The cloud infrastructure is a composition of two or more distinct cloud infrastructures (private, community, or public) that remain unique entities, but are bound together by standardized or proprietary technology that enables data and application portability (e.g., cloud bursting for load balancing between clouds).

Table 25 Definitions of cloud deployment models (NIST, 2011)

3.5.1.1 Public Clouds

A Public Cloud is a huge data centre that offers the same services to all its users. It exists on the premises of the cloud provider. The services are accessible for everyone and much used for the consumer segment. It should be noted that the data and processing environment is under the control of the cloud provider, which poses an issue for water utilities where security is required for some of its applications and data.

3.5.1.2 Private clouds

Private clouds are suitable for water utilities that already own datacenter and developed IT infrastructure and have particular needs around security or performance. A professional Cloud vendor may also offer a Private Cloud by supporting a separate hardware environment in the data centre. They are also a better choice for the company datacenter compared to Legacy servers. However they provide some challenges, mostly in that the water utilities need to migrate or re-factor applications to take advantage of the Cloud automation.

3.5.1.3 Community Clouds

A community cloud is a means to preserve the benefits of economy of scales while still enjoying the security and privacy of a private cloud. It can be considered as a closed Private Cloud for a group of users. When used for governments, this is called Government Cloud and is a type of Cloud that is more and more adapted. Due to legislative issues, a Government Cloud may be the answer to country specific judicial concerns. Community clouds can also involve multiple organizations. In this case, it is slightly different from a Public Cloud where it requires the interoperability, integration and compliance of between member organizations and their resources. A community cloud can be used for the cross-domain data sharing in a smart city.

3.5.1.4 Hybrid Clouds

A Hybrid Cloud is a combination of both Private and Public. This is a setup that is much used for large companies. Sensitive and vital data is usually preferred in a Private Cloud and supporting services in Public, for instance search, email, blogs, CRM etc. In other words strategic applications are run separately. Hybrid cloud requires the most effort to manage but is also the most economical for modern companies. It requires deeper enterprise IT/cloud modernization as well as the re-engineering and re-architecting of the workflow processes. Also, compatibility, standardization and compliance are needed to ensure the seamless integration between the Private and the Public cloud.

3.5.1.5 Emerging models: Intercloud

Research has suggested that, like the Internet, a mechanism should exist for users to be able to utilize multiple clouds from multiple providers or companies, and not have the details visible. The Intercloud started as a research project in Cisco in 2008 and was soon taken up by the Institute of Electrical and Electronics Engineers (IEEE).⁴⁷ The concept of Intercloud is to connect different cloud models (private, public and hybrid clouds) by improving interoperability and portability among cloud networks. Despite the various initiatives, there are many challenges to create a global, interoperable Intercloud, including security and trust, governance and legal issues, QoS, monitoring, arbitrage, and billing. Another blow to the development of Intercloud comes from the Cisco decision to focus on hybrid cloud.⁴⁸

⁴⁷ https://www.sdxcentral.com/sdn/network-virtualization/definitions/what-is-intercloud/

⁴⁸ https://www.networkworld.com/article/3122418/cloud-computing/cisco-moves-on-from-intercloud-will-focus-oncloud-management-instead.html

3.5.1.6 Selection Criteria for Cloud Model for Deployment

From the discussions of the different cloud models, it is evident that different cloud models offer different benefits and limitations. Some of the important factors to consider include⁴⁹:

- Flexibility: Cloud implementations provide the opportunity to use the resources in a 'pay-as-you-use' manner and different models offer different level of flexibility (in terms of costs).
- **Scalability:** It refers to the capability of a system, network or process to handle a growing amount of work, or its potential to be enlarged in order to accommodate that growth. Among the cloud models, IaaS provides the highest level of scalability.
- **Security:** The data that water utilities handle are often sensitive or classified data, hence the level of security the cloud model can offer is a critical factor to consider.

3.5.2 Water Information Platforms

One of the main components of the water information system is the water information platform software. In this section, the current solutions available in the market from different vendors for the management of water in urban, industrial and agricultural environments will be summarized here.

3.5.3 IBM – Intelligent Water



IBM Intelligent Water⁵⁰ software delivers smarter water management through insights from data to help utilities manage pressure, detect leaks, reduce water consumption, mitigate sewer overflow, and better manage their water infrastructure, assets and operations. This software uses advanced data management, visualization, correlation and collaboration technologies to transform the vast amounts of disparate data received from various devices (including metering systems), assets, systems and stakeholders into actionable information that can guide executive and operational decision-making. Intelligent Water is a water management platform that enhances infrastructure visibility to deliver an advanced level of situational awareness, event and incident management, informed decision-making and collaboration among stakeholders. Its benefits include:

⁴⁹ https://hackernoon.com/how-to-select-the-perfect-cloud-deployment-model-for-your-business-b66f1e768f8f

⁵⁰ http://www-03.ibm.com/software/products/en/intelligentwater

- Intelligent Operations for Water component, which provides extensive visibility and situational awareness spanning water and wastewater operations. This helps improve decision-making, enhance efficiency and reduce risk.
- Water Efficiency Analytic component, which helps mitigate non-revenue water through pressure optimization and pipe failure prediction.
- Using data from smart meters for opportunities to recapture revenue and detect fraud.
- Delivery of insights from big data and smart devices to help operators improve irrigation, flood management and sewer overflows.
- Takes advantage of flexible deployment options by offering multiple deployment models.

3.5.4 Siemens – Smart Water Platform

SIEMENS

Siemens Smart Water Platform⁵¹ is a proven, scalable and rapidly-deployed application platform that bridges the gap between IT and Operations, empowering water utilities to take control of rapidly-growing smart grid data volumes by quickly converting data into actionable information.

Siemens Smart Water Platform provides a proven, reliable and cost-effective solution to help utilities and cities start solving your water challenges today and across their network over the long term. The Smart Water Platform combines EnergyIP Core Platform⁵² functionality with integration and an ever-growing portfolio of customizable apps. The platform seamlessly integrates with new or existing metering system, providing actionable data to help address issues before they become problems, providing new ways to engage customers and strengthen relationships, and most importantly allowing utilities to generate a more predictable revenue stream.

3.5.5 Schneider Electrics - StruxureWare for Water



StruxureWare⁵³ for Water provides full visibility into the complete water supply, collection, and treatment system while delivering process control and energy efficiency from field to enterprise. It

⁵¹ http://w3.siemens.com/smartgrid/global/en/products-systems-solutions/smartmetering/emeter/Documents/SmartWater_iPDF.pdf

⁵² http://w3.siemens.com/smartgrid/global/en/products-systems-solutions/software-solutions/emeter/pages/energyip.aspx

⁵³ http://www2.schneider-electric.com/sites/corporate/en/solutions/struxureware/suites/water.page

permits to control, operate, and optimize the water and wastewater infrastructure from field to enterprise level. Utilities can reach operational excellence across the full water cycle while reducing energy consumption and total cost of ownership.

It is an open, scalable, and easy tool to incorporate into third-party and legacy systems, StruxureWare for Water transforms - in real-time and from shop floor to top floor - the massive amount of data into meaningful information to all stakeholders enabling the utility to make informed decision and take decisive action. It provides a solution for the following challenges:

- Supply cleaner water via aged infrastructures without increasing costs
- Balance reduced government spending on infrastructure investment with increased regulation
- Control energy impact on environmental and financial performance
- Manage the water scarcity linked to growing urbanization and climate changes

Its benefits include:

- Increase operational efficiency by up to 25%: integrates all process control in the water or wastewater infrastructure - from electrical distribution and motor and pump control, to chemical and biological treatment, safety, and energy monitoring. By combining real-time water network data, historical analyses and hydraulic modelling, StruxureWare for Water helps reduce operation costs and service interruptions while maintaining consistent water pressure and improving water quality.
- Reduce energy consumption by up to 30%: StruxureWare for Water optimizes energy
 efficiency up to 30 percent by combining energy and process control data which allows
 operations and energy managers to work together to optimize process demands and energy
 consumption. In addition, it provides visibility into enterprise and network performance, displays
 all measurement data and KPIs in real time, analyses results over time, and identifies areas for
 improvement.

The StruxureWare for Water suite consists of the following software applications:

- Resource Advisor: tracks and manages the enterprise's energy and carbon costs
- Network Operation: improves water management and decision making by combining real-time water network data, historical condition analysis, and hydraulic modelling
- Energy Operation: transforms data into essential energy information and reduces operating cost
- Plant Operation: combines energy and process data to get visibility into plant asset performance to identify areas for improvement
- Asset Operation/GIS: manages and maps all network assets in powerful geographic information systems (GIS)
- Power Monitoring Expert: collects and organizes data from the enterprise's electrical network
- SCADA Expert: manages the water network based on telemetry systems that transform data

into useful information

- Process Expert: integrates application control and supervision into a single environment
- Security Expert: protects people, facilities, and assets

3.5.6 TakaDu



TaKaDu⁵⁴ is an early adopter of the IoT (Internet of Things) concept, aiming to create an easy-toimplement cloud-based SaaS (software-as-a-service) solution, which could analyse and process the raw data measured by sensors in the water networks. TaKaDu uses big data analytics, based on sophisticated statistical algorithms, to provide in-depth visibility, real-time detection and quick insights into every, and any, type of "event". This includes - identifying leaks before they turn into large bursts detecting changes and trends in water pressure, anomalous usage patterns, supply interruptions, water quality issues, identifying faults in meters, valves and other assets - telemetry issues and data availability - spotting water theft, and automatic early warning of operational issues, like open valves and zone breaches. The aim of TaKaDu is to deliver tangible water and energy savings while helping utilities improve their managerial processes and customers' satisfaction, delivering a faster response time.

3.5.7 Microsoft – City Next



The Microsoft CityNext⁵⁵ initiative was created to help empower city staff and citizens to be their best. Through Microsoft CityNext, Microsoft partners offer city solutions that can help solve pressing challenges and support the goals and aspirations of health, government, and public safety organizations.

Microsoft CityNext energy and water solutions connect cloud, Big Data, mobile, and social technologies to help citizens, businesses, and governments create innovative, energy- and water-efficient solutions.

- Energy and Water
- Carbon Management

⁵⁴ http://media.wix.com/ugd/05a510_aee2a841f2794248b93634236355c3ad.pdf

⁵⁵ http://enterprise.microsoft.com/en-us/industries/citynext/

- Energy Management and Analytics
- Smart Grids
- Water and Wastewater Management

3.5.8 Tata – Intelligent Urban Exchange (IUX)



IUX69 is a modular, pre-integrated software solution sold to partners and systems integrators, telecom service providers, large engineering firms and city operations and maintenance service providers - to help cities accelerate their smart city programs, easily and cost-effectively, enabling them to achieve greater levels of social, economic and environmental sustainability.

The IUX platform, built for Big Data, collects and analyses data from multiple sources (e.g. flow, pressure, and level sensors and SCADA, meter data management, water management, Geographic Information (GIS), enterprise, and Leak Detection (LDS) systems) for real-time insights and next step recommendations. It provides a common platform across multiple domains (e.g. transportation, water with additional domains to be added) for a unified urban vision and shared intelligence.

IUX permits all city systems and entities to connect among them, providing the ability to connect a wide range of devices, sensors and APIs, and applications. Tata Consultancy Services (TCS) opens up the IUX platform for partners to develop customer applications that can be used in addition to prebuilt IUX use cases for ultimate flexibility and faster time to market. The IUX's Advanced Analytics Engine (AAE) provides the capability for partners to deploy their own custom analytics models quickly and efficiently with little to no programming required. It delivers advanced analytical capabilities for all available real time and historical city data, adding value to city open data.

IUX also incorporates domain-specific data models for Intelligent Water Management and Non-Revenue Water (NRW) Reduction Performance Management with pre-built use cases designed to solve real water conservation challenges and deliver real results including Opex savings, Capex reduction and reliable water delivery.

Through IUX Platform APIs, this solution enables city transportation integrators and partners to develop custom applications on top of IUX platform services and resources.

The benefits are:

• Comprehensive analysis, advanced situational awareness, forecasts, 'what-if' analysis and goal based performance monitoring

- Reduction of NRW Levels and prediction of NRW loss and losses mitigation
- Enhancement of the decision making
- Maximization of the effectiveness of planned initiatives
- Reduction of leakage impacts
- Prediction of pipe failure and prioritization of preventive maintenance

It also helps at improving operations and reducing costs by offering:

- Support offline and real time integration across fragmented systems
- Improve maintenance operations
- Predict failures
- Optimize Repair Opex
- Optimize Network Rehabilitation Capex
- Reduce capital expenses with as-a-Service subscription pricing
- Reduce IT infrastructure allocation with cloud based applications accessible online or on mobile devices

The TCS IUX Intelligent Utilities solution was designed specifically for water utilities, water networks and city partners. Only TCS offers:

- Industry solutions: Our customized solutions, created by water planning experts incorporate the latest technologies and wisdom from TCS' world class R&D.
- Faster Deployment: IUX's open standards platform enables faster implementation and integration with existing systems. The out-of-the-box Intelligent Utilities Application with pre-built use cases accelerate smart water deployments.
- Lower cost of ownership: IUX's modular, architecture lets you buy only what you need now with the option to add capabilities later. The common, scalable IUX Platform extends economically across multiple domains such as water and transportation for collaborative city initiatives.
- Simplified business and engagement models: IUX offers As-a-Service subscription pricing. It's cloud-based with applications that are accessible online or on mobile devices.

3.5.9 Oracle – Solutions for Water Utilities

ORACLE

Oracle offers a suite of solutions and tools for Water Utilities⁵⁶. Among these solutions are Leak Detection, Outage Isolation, and Planned Shutdown Management Tool. Oracle Utilities Smart Water Network Management provides a comprehensive valve operations management, from planning and

⁵⁶ http://www.oracle.com/us/industries/utilities/039809.htm

modelling through execution and analysis. Harnessing the solution's automated valve operations tool and study mode, water utilities can automate and improve emergency response, process and network efficiency, and safety.

This tool helps to improve the coordination and accuracy of valve operations for maintenance and emergency restoration. The Oracle's network model and valve operations management tool enables operators to record valve control actions electronically via interaction with the map for real-time execution or in study mode for planning.

Among the main benefits of the tool include the isolation of breaks to improve emergency response, to this end it provides:

- Speed leak identification in water main segments, including loops, branches, and dead ends, via improved network modelling
- Quickly contain leaks and bursts via automating isolation plan requests and valve control
- Understand valve operation impact through the use of private study modes to examine scenarios concurrently
- Extend valve reliability and pipe lifecycle by suggesting ideal operation plans
- Eliminate water hammer, back siphoning and back pressure during restoration

It also helps to improve pipeline operations and crew performance for planned and unplanned shutdowns, to this end it provides:

- Streamline preplanning of large distribution valve operations sequences in study environments and real-time models.
- For planned maintenance shutdowns, determine impacted customers and fire hydrants to allow proactive notifications
- Boost crew performance via step-by-step instructions for opening, closing, and tagging devices.
- Model the network in real time to assess contingency and land-use plans to account for breaks and emergency services

Oracle proposes Smart Meter Advanced Analytics for Water through the deployment of smart meters (Oracle, 2015). With this tool water utilities can extend their reach all the way from generation to the end customer. With smart water grids, utilities can now understand in detail how each piece of the network is stressed, connected and contributing to overall performance. The analytic tool based on Big Data techniques provides:

- Business-relevant tools for exploration and visualization of data.
- Relevant tools for both deep and rapid ad hoc analysis of the data.
- Capabilities to operationalize advanced analytics to be run on a daily basis on the live data.
- Support of data scientists familiar with both smart grid data and analytical tools to help the utility to develop and adapt the most reliable analytical algorithms.

3.5.10 Trimble - Trimble Unity Version 3.0



Trimble Unity⁵⁷ is a cloud-based, (GIS) centric software-as-a-service (SaaS) solution for smart water management. Version 3.0 includes new features and workflows and also offers an App Builder and new integration capabilities to simplify connecting mobile workers with maps and data from back office enterprise systems.

Trimble Unity offers a unified cloud-based and mobile collaboration platform for smart water mapping and work management to water, wastewater, stormwater and environmental water industry customers. The software is designed to automate a variety of workflows through individual "apps" that enable utilities to monitor real-time operations, deploy smart meters, assess the condition of assets, repair leaks to reduce NRW, and locate and map critical infrastructure using Trimble high-accuracy Global Navigation Satellite System (GNSS) mapping technologies. Trimble Unity can be deployed to assist utilities in reducing spills and environmental damage, extending the life of aging assets and enabling improved worker safety and productivity. These benefits enable utilities to address many of the significant challenges they are facing due to water shortages, flooding, budget constraints and environmental regulations.

The new version includes a variety of apps with enhanced features for automating and streamlining common water, wastewater and stormwater asset management activities and monitoring field operations. Customers are now able to use the included App Builder to create and customize their own apps, workflows and data collection forms to improve their organization's existing business processes. Version 3.0 adds new administration capabilities for managing mobile and office user roles, access rights and available apps. The product also includes new integration capabilities for allowing customers to connect Trimble Unity with their existing third-party back office customer service and asset management systems and provide a single GIS-centric field solution across their entire workforce.

Trimble Unity leverages the Esri ArcGIS technology across the product providing support for Esri GIS mapping in the office and field. Trimble Unity is available on iPhones, iPads, and Windows and Android smartphones and tablets as well as on Trimble rugged, high-accuracy mobile mapping devices.

The new version of Trimble Unity provides:

• New App Builder and Administration. Customers and partners can build custom apps, workflows and data collection forms with the new App Builder. A simple wizard-based tool

⁵⁷ www.trimblewater.com/unity.html

walks users with admin roles through the app configuration process, allowing the configuration of GIS data, basemaps, workflows and data collection forms. Forms are built using a drag and drop form builder tool supporting various data formats and business rules.

- Smart Outage Tracing. Identify and locate valves that are to be shut off to isolate a water main break quickly. The feature also includes the capability to skip valves that are inaccessible or inoperable. The valves, hydrants and affected customers can also be retrieved and included in the workflow.
- Work Management Enhancements. Dispatch multiple work orders or jobs at once from either the work list or the map. Supervisors and dispatchers can filter and prioritize the work, then batch dispatch multiple work orders based on spatial location, scheduled date, or priority.
- Work Order Integration. Extend the work order in Trimble Unity to include additional information from third-party systems. The information can then be accessible by the field technicians using the mobile application when performing the work. Work order extensions can include customer information, meter read history, or any other information required to complete the work in the field and is not available in the GIS.
- Work Order Tracking. Track work related information including capturing labour, equipment and material usage for cost tracking. This feature can be used to configure capturing work completion codes or any list of work related information.
- Asset Work History. View the history of all forms collected on a particular asset in the GIS. Users using the Trimble Unity Web application can tap on any asset and quickly access the history of all forms collected on that asset.
- Workflow Notifications. Easily access workflow actions to quickly progress work through the configured workflow, avoiding additional clicks. Notifications are now displayed on the mobile application when new work assignments are downloaded.
- Mobile Offline. Mobile workers can use Trimble Unity on their Android, iOS and Windows mobile and tablet devices when disconnected from a wireless data network and synchronize automatically when a wireless connection is available.

3.5.11 OSISoft – PI System



The PI System connects sensor-based data, operations and the people who rely on data to manage process efficiency, asset health, and quality and resource management. The PI System works through server-based technology and allows data to be instantly accessible to users wherever they are.

As a result, you achieve end to end operational visibility. The PI System comprises:

- PI Interfaces
 - OSISoft has developed over 400 standard interfaces to real time data sources such as OPC, RDBMS, ModBus, SCADA, OLEDB, etc.
 - PI Interfaces temporarily buffer data and then translate diverse communication protocols and collection intervals so data speak a common language.
- PI Server: Its server is very scalable being able to manage vast amount of data:
 - Collect large volumes of sub-second data
 - o Store up to 20 million streams of high fidelity data
 - Provides operational context to raw data streams.
 - Organizes data by asset topology so that data retrieval is more intuitive to users across the enterprise.
 - The PI Server also includes, auto-event capture, streaming, asset-based analytics, notifications and performance monitoring tools
- PI Tools: the system also provides tools to visualize and share data and information in order to be able to take more informed decisions. PI Client Tools address visualization and analysis needs of stakeholders across the organization and include:
 - o Graphical displays
 - Automated analysis and reporting spreadsheets
 - o Web-based, ad hoc trending that can be visualized on multiple devices

3.5.12 Visenti - Pipe Network Product Suite



Visenti provides a set of products in its software product suite to prevent the rate of pipe network failures and disruption and help in the achievement of normal operation. According to the needs of pipe network operators that face significant challenges in operating their complex and aging infrastructure efficiently, Visenti's product suite allows pipe network operators to reduce the pipe failure rate, improve efficiency, save time and money. The suite of software products are:

- LeakIntel[™]: this system identifies the pressure transients generated by potential pipe breakage and localizes the event to the faulty pipe with high likelihood.
- PascalView[™]: it provides on-line multi-frequency pressure data management, analytics and alerts that are critical for adequate and reliable pressure management in pipe networks.
- DataIntel[™]: it is the Visenti's data analytics solution, and it mines through the data supplied by a variety of sensors installed on water systems. It provides a wide range of real-time analytical capabilities to monitor, detect and notify on anomalies related to pressure variations, night flow,

water quality issues, demand fluctuations and consumer-level Non-Revenue-Water (NRW) tracking for revenue protection.

• OHMView[™]: is an Online Hydraulic Modelling Simulator that allows utilities to run operational simulations and analyse impacts of field operations before they are carried out.

3.6 Case Studies

This section will present successful case studies from various countries which have implemented smart water technology in their cities. A brief introduction on the solutions implemented will be presented, together with the benefits and lessons learnt.

3.6.1 Malta

In 2010, the Automated Meter Management Project (AMM) was launched in Malta.⁵⁸ The AMM system being deployed by the Water Services Corporation today is of the fixed-network type. It makes use of the always-on wireless broadband GPRS network to connect every consumer meter to a centralised water management system. A Meter Interface Unit (MIU) is installed on each meter through a pulser unit which transmits to a receiver gateway which communicates to the central system through the GPRS network. The meter reading ends up at the central system where the data is stored, analysed and used for bills and water management tools. The schematic diagram below shows the basic architecture of an AMM system.



Figure 45 Schematic diagram of the architecture the AMM system59

Using a solution from "SUEZ Smart Solutions", the Automated Meter Management in Malta uses a fixed network a fixed network consisting of 2-layer technology (RF transmitters, receivers). It uses 169 MHz VHF, an EU authorized channel for remote reading. It has long-range transmission capabilities (no need for repeaters), 15-year battery life with the MIUs having cross-meter compatibility. By the end of June 2016, over 86% (229k modules out of a total of 267k customers) have been installed.

⁵⁸http://www.wsc.com.mt/portals/0/Annual%20Report%202010/annual_report_2010_-_Water_Operations_2.pdf

⁵⁹http://www.siww.com.sg/sites/default/files/Session%203-1%20-%20Mr%20Luke%20Pace.pdf

The main objectives for WSC to implement the AMM are:

- Improve Billing
- Cash Flow + reduction/elimination estimated bills
- To access meter data remotely & continuously
- Customer oriented a communication platform
- Permits Total Water Balancing

The strategy being employed to drive smart metering in the water network includes:

- Better inter-department coordination to ensure all (old) meter replacements result in smart metering installation,
- Geocoding of all important features of the water network,
- Development of reports and software to analyse data being provided from smart meters,
- Correct monitoring and maintenance of entire AMM solution.

Through precise and real-time measurement of water consumption, customers are billed more accurately thus eliminating estimated meter reading, improving revenue collection and avoiding unpleasant surprises for customers. In addition abnormal usage, tampering of the water system and leakages are easier to be identified, enabling the utilities reduce the loss incurred on non-revenue water.

3.6.1.1 IUBS Programme

To ensure that Malta is able to deliver affordable secure energy and water while protecting the environment, the water utility (Water Service Corporation) and energy utility (Enemalta Corporation) partnered with IBM to implement the IBUS programme which is a Smart Grid project which integrates AMM, ERP and CRM together.

The lessons learnt from the programme are:

- AMM solutions are not always plug and play. There is a need to have strong relationships with vendors to allow solutions to be customized to meet needs.
- The Return of Investment (ROI) is inversely related to the duration of implementation. Thus, the less time it takes to get the solution to be deployed, the sooner the utilities can start reaping the benefits.
- Customer buy-in is required for faster installation. Tailored communication campaigns are carried out to ensure efficient implementation of the AMM system and to maximize the hit rate.
- To ensure the success operation of the Smart Grid, system knowledge is required in order to understand the process and the factors that need to be managed in order to yield positive results. Also, MDM and monitoring system are required to intelligent reports for operational and strategic agendas of the utilities.
- It has been reported that with the implementation of the AMM, there has been a net annual gain of €0.42M shown in Figure 46.

Annual expenditure before Project	A exp Pi	nnual enditure after roject	Tangibl benefit provide by Proje	le ts ed ect	Net annual gains after Project	Intang bene	ible fits
€0.6M	€1	I.73M	€1.55№	1	€0.6M - €M1.2 + €1.55M = €0.42M	73 Custor Relat bene	mer ed fits
Before			After				
Meter read	ders	€0.6	€0.6M pa		Field aintenance	ld €200k pa nance	
					Licenses	€80k p	a
					Upgrades	€50k p	a
				D	epreciation	€1.4M p	ba
		€0.6	Mpa			€1.73M	pa

Figure 46 Operating costs and profits for the AMN project⁶⁰

3.6.2 Singapore

In Singapore, the Public Utilities Board (2016) supplies 430 millions of gallons per day (MGD) of water to customers. The Water Supply Network (WSN) Department has in recent years embarked on a Smart Water Grid journey to ensure good water is supplied to its customers 24 h a day, 7 days a week. Singapore current technology, Smart technologies experimentation and its technology roadmap are listed in

Table 26.

⁶⁰http://www.siww.com.sg/sites/default/files/Session%203-1%20-%20Mr%20Luke%20Pace.pdf

⁶¹ http://www.visenti.com

Domains	Remarks			
	90 % by 2018 with 400 additional multi-parameter			
	sensors.			
	Existing Methodologies / Technologies:			
	 Depends on customers to act as sensors for water quality 			
	issues like discoloured water.			
Water Quality Monitoring	 Smart Technologies Experimentation: 			
water quality Monitoring	 Collaborated with Sandia National Laboratories⁶² to 			
	develop CANARY (EPA 2010 ⁶³), a water quality event			
	detection tool, in the distribution network.			
	\circ WSN aims to own a real-time water quality model by 2030.			
	Existing Methodologies / Technologies:			
	\circ $$ Mechanical water meters for billing customers, where the			
	low frequency of manual meter readings does not offer			
	sufficient granularity for understanding customer water			
	consumption patterns.			
	 Smart Technologies Experimentation: 			
Automated Meter Reading	 Tested various fixed network AMR technologies: 			
	 Short range systems with endpoints operating in 			
	unlicensed free Radio Frequency (RF) bands (UHF)			
	and their data concentrators using cellular 2G/3G			
	networks.			
	 Systems with endpoints directly using 			
	2G/3Gnetworks.			

Table 26 Singapore's current technology, Smart technologies experimentation and its technology roadmap

3.6.2.1 WaterWiSe Platform⁶⁴

WaterWiSe is a platform for real-time monitoring of water distribution systems that can be used by utilities to improve system management and operation by providing integrated measurement and

⁶²www.sandia.gov

⁶³ https://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=221394

⁶⁴https://dspace.mit.edu/handle/1721.1/92733

analytics.⁶⁵ It can operate as a self-contained system with its own analysis and management interfaces, or can be integrated into a water utility's existing infrastructure and geographical information platforms. The core WaterWiSe platform has two key components:

- i. Integrated Data and Electronic Alerts System (IDEAS),
- ii. Decision Support Tools Module (DSTM).



Figure 47 Overview of the WaterWiSe platform's functionality

Figure 47 shows the WaterWiSe platform comprising IDEAS and DSTM in context. Inputs to the platform are shown (both data and information), as well as a selection of beneficial outputs seen by the utility. The IDEAS and DSTM boxes both show a selection of applications that are enabled by each component. These components, discussed in more detail below, provide key services to help both water supply network planning and operations teams in the office and in the field.

Some of the benefits from the implementation of WaterWiSe include:

• Pressure anomaly detection and localization of pipe bursts through pressure transients, and numerous pressure abnormalities relating to both planned and unplanned system operations

⁶⁵ http://dspace.mit.edu/bitstream/handle/1721.1/92733/Allen%20et%20al%20-%20SIWW%202012.pdf?sequence=1

- Post-event analysis to trace back the sequence of events before a confirmed leak or burst event to understand which operations may have contributed to the leak
- Real-time visualization on demand an consumption as well as determination of optimal sensor placement using the real-time hydraulic network model in the platform.

3.6.3 South Korea

K-water (Choi et al.,2016) proposed the SWMI (Smart Water Management Initiative) as an innovative water management technology to supplement traditional water management technologies. SWMI is a smart water management technology that combines the accumulated advanced ICT of Korea with K-water's experienced water management know-how.

For the implementation of SWMI, a three-step strategy was proposed:

- i. K-Tech Tree, which involves the development of necessary technologies for SWMI implementation based on the current state of technologies.
- ii. STEP-ISP, which includes the standardization of developed and will be developed technologies depending on the technology types.
- iii. A standardized frame for applying technologies developed by K-Tech Tree and STEP-ISP.

K-Tech Tree

K-Tech Tree consists of three components which are technology classification, current state of technology, and technology development. As shown in Figure 48, classification was set up by departmentalizing in a step by step process. Once K-water's technologies were departmentalized, they were then investigated and linked to applicable classes which are considered as a room to contain technologies. The technologies which are required to develop or improve for the implementation of SWMI will be selected through this process based on the current state of technologies. Also, the plans for development required technologies will be established during this phase.

STEP-ISP

The STEP-ISP (Standardization Technology Enhancement Project - ISP) strategy was established to standardize technologies depending on their classes indentified in the K-Tech Tree. Figure 49 shows the concept of STEP-ISP standardization strategy of K-water. All technologies have been classified based on their types and characteristics where standardization strategies will be established and applied for each technology's types and characteristics.

 STEP-I refers to the strategy for standardizing the installation of infra and devices. Kwater, as a public organization, will provide the standards for the installation of infra and devices. Accordingly, private sector entities that pursue the development and production of relevant products will abide by the suggested standards. In order have a consensus among all concerned parties regarding the standards, consultations with the private sector was held for the discussions and be involved in the developing of the standards.

- STEP-S refers to the strategy for standardizing systems such as software and information. When there is a need for new software to perform certain task, it is often developed independently and later linked to the existing systems through a necessary part of the developed software or by adding new functions to the system. Due to the different programming languages, algorithms, and GUIs between the software and the system, efficiency for new software development and integration is very low. To solve this issue, a standard for developing software with the focus on the concept of modularization and framework is needed. This will greatly increases the interoperability of the systems.
- STEP-P refers to the strategy for standardizing operating and managing processes of facilities, devices and systems to ensure efficiency in data sharing and information exchange. In order to resolve these issues, standard manuals of all K-water's technological tasks will be established through the conversion of tacit knowledge to explicit knowledge. Standard manuals will be created from K-water's vast pool of technological know-how. At the same time, a standard manual management system will be developed for the systematic management of standard manuals for the purpose of distinguishing the roles and responsibilities between headquarter and branch offices.



Figure 48 Example of Technology Classification



Figure 49 Conceptual Diagram of the STEP-ISP Strategy

Application of Standardized Framework

The framework consists of a water management level assessment of a targeted region, result analysis, composing technologies and then applying them to improve vulnerabilities. It is composed of customized and modularized technologies to resolve water related issues in targeted regions of interest. The objective is to identify the vulnerabilities of the target region using key performance indicators. After which, the framework will be will be customize which will consist of modularized necessary technologies developed by K-Tech Tree and STEP-ISP to achieve the water resources management improvement goals of the targeted region. (Figure 50)



Figure 50 Standardized framework for target region

The expected outcomes from the SWMI include:

- More accurate weather forecasting by collecting and analysing information in real-time not only from rain gauges installed on the ground but also from precipitation data and satellites.
- Optimized flood and drought control through information sharing among different water management facilities and systemized operations
- Provides an optimal utilization system by combining all available water resource including underground water, sea water and rainwater not dependent on the supply capacity of water sources. This enables water supply on demand and water reuse, thus eliminating the need to construct additional large scale infrastructures such as dams.
- Real-time analysis of information collected from smart devices provides improved response time to any incident, subsequently reducing the risk of accidents and waste of manpower and time.
- Help in the decision process to improve the water management level through the proposal of correct and accurate directions for investment and business.

3.6.3.1 Test-Beds for Smart Water Management

Goryeong Municipality (K-water, Experiences of Implementation of SWM, 2015)

Goryeong City is the first city to be selected as a test-bed for smart water management. Located in the south-west of the Gyeongbuk province, Goryeong City has an area of 384 km² and serves a population of 31,000. The water infrastructure includes 450 km of water mains, 33 reservoirs and a water treatment plant handling a capacity of 35,000 m³ of water per day.

Water-NET was established to manage the water resource. Utilizing GIS and real-time data from sensors, Water-NET is able to supports decision-making in operational management that includes water quantity, quality, risk management and demand forecasting. In addition, pipe network analyses, leak detection, management of water flow rate, risk management and water quality as well as energy management are implemented using 390 sensors and 9,500 real-time data (SCADA).

Some of the smart water technology includes:

a) Smart meters

They utilizes the paging network which is capable of transmitting up to 2km using 650mW of emit power. Thus, repeaters are not needed in this case. The meters are to last for more than 8 years with the data collected hourly and transmitted four times a day.

b) Acoustic leak detection sensors

The fixed sensor can be easily installed near the water meter that collects leak sound from pipe.

Wireless communications will be the main means of transmitting real-time leakage monitoring data, where the data transmission components include repeater (radio frequency), data collector (CDMA) and the relay network (TCP/IP).

c) Ultrasonic smart water meters

They are used to improve the measurement accuracy for low flow conditions and can be installed in pipes of diameter 0.59-0.98 inch.

d) Mobile app

A mobile app is developed to provide hourly & daily usage to the customer. It also display the water quality in the water supply as well as facilitates bidirectional communication between the customer and K-water through a water community forum in the app.

Some of the benefits from implementing Smart Water Management include:

- Improved revenue water ratio by 3% in three months after commencing the project. This translates to a annual operating savings of more than US\$ 170,000.
- The number of ruptures and leakage accidents was reduced by 25% through the implementation of a water pressure and optimal operation plan

Paju Smart Water City (K-water, WATER, NATURE AND PEOPLE 2015 Summer, 2015)

The SWM strategy was also introduced in Paju City, in four apartment complexes in Gyeoha and one apartment complex in Jeokseong in Paju where around 12,000 citizens live. Water quality measurement instruments and CCTVs are installed in the water tanks in each household where the residents were able to receive real-time detailed information on the quality of the tap water. The results from this implementation are:

- a) 92.3% overall satisfaction of water supply reached where more than 90% of the citizens who participated in the survey showed a positive response
- b) Drinking rates of tap water for Gyoha and Jeokseong increased from 1% to 19.3% and when include the rate of drinking tap water after boiling it, the rate of drinking increased from 36% to 60%. It is important to note that the drinking rate of people with extreme distrust of tap-water, like those who do not even use tap-water for cooking, reduced from 23.3% to 11.3%.

It is noteworthy to know that there are some difficulties expected and encountered when implementing the project. One of such is the need to explain the importance of having clean water supply to the residents involved. It was surveyed that the residents were initially resistive to the project and felt they will be bothered by the project. To resolve and ease their concerns, the Paju Water Office decided to conduct the project in just five apartment complexes so that they can explain the benefits and importance of the project to the residents individually face-to-face.

In addition, the Paju Water Supply Office created I-water, an integrated water supply system in 2012 to upgrade the operational facilities and reduce operation cost. For example, about KRW 200 million and KRW 5.5 billion were saved through installation of high concentration hypochlorite generators in October of 2014, and the solution to operate advanced purification facilities in an optimal way, respectively. To ensure a stable water supply system, the Paju Water Office managed both multi-regional water supply system and the local water utilities (a total of 23) as a whole with the support of the Paju city government.

3.6.4 Netherlands

Dutch Digital Delta project is a big data project on how to efficiently manage flood control and the Dutch water system with the aim to reduce management costs of 10~15 %. This is a public-private R&D initiative between Rijkswaterstaat (Ministry of Infrastructure & Environment), the Local Water Authority Delfland (District of the cities of Rotterdam, Delft and the Hague), University of Delft, Applied Sciences Institute Deltares and IBM. It began in June 2013 with the public partners providing data to researches, SMBs and industries and IBM providing the technical experiences on water information system (IBM Intelligent Operations for Water) to realize the reuse of data, tools and solutions developed by the project. Three phases have been planned and carried out and are listed in Table 27 below.

Phase	Remarks			
	aimed at the unlimited and readily accessible provision of			
	water and climate services			
Research phase	 The work is being carried out by the Digital Delta consortium, 			
	which is drawn from the private sector, public bodies and			
	research institutions.			
	Implementation of the online open platform of the water sector			
	in the Netherlands for both public and private parties to			
	facilitate the exchange of information			
Transition phase	 To improve efficiency and the quality of water management in 			
	the Netherlands.			
	 To provide business opportunities for the private sector and 			
	cost savings for the government.			
	To realize a web service of finding and retrieving data for the			
	purpose of water management, focussing on data for water			
	quantity, water quality initially			
	 The Digital Delta mode of communication is already used in a 			
	number of applications:			
Operational phase	 At the Amsterdam-Rhine Canal / North Sea Channel, 			
	the information system is produce from data retrieved			
	via the Digital Delta web services (API).			
	 At Small-scale Water Supply (Dutch IJssel), the 			
	decision support system retrieved data via the Digital			
	Delta web services (API).			
Table 27 Phases of Dutch Digital Delta project				

3.6.5 United States

Below are some case studies that demonstrate the value of smart water management using big data technologies (Cheung & Nuijten, 2014).

- The role model sewer system in South Bend
 - The city of South Bend in Indiana started using IBM's Intelligent Operations⁶⁶ in 2012 to mitigate sewer overflows. This project's integration of hundreds of sensors was unique in the world and many (Smart Cities) are now looking to South Bend, Indiana as an

⁶⁶ https://www.ibm.com/us-en/marketplace/city-insights

example for improving their own sewer systems. The results of the system⁶⁷ have been remarkable: the system has saved roughly \$100 million by not having to enlarge the sewers pipeline infrastructure and saved around \$60 million in fines with better insights that prevented waste water overflows in rivers.

- Water conservation in California
 - In large agricultural areas such as in California, rainfall and water are extremely important as the area is known for drought. These drought conditions not only affect agricultural businesses, but also the citizens and thereby the other related businesses in the area. Silicon Valley has looked into Big Data technologies to conserve water in the region⁶⁸. An one-year pilot was started to deliver a Software as a Service (SaaS) tool to residents to empower them with the capabilities to crunch data and provide themselves and others with feedback and tips for cutting their water consumption. The pilot was funded by the California Water Foundation⁶⁹ and its basis had its origin from an independent study that shows that when participants received information about comparing water consumption to neighbourhood averages, their usage would decrease by 5% on average. This effort is part of a whole package to reduce the water usage by 20% state wide.
- Leak Detection
 - Company (Leak Defense⁷⁰) has developed a water leakage device for consumers similar to a smoke detector. The device is installed at the central intake pipe of a residential home to detect the inflow of water. Whenever there are irregularities, like a running toilet, the device can alert the homeowner from a distance with its Wi-Fi connection (ACE Private Risk Services, 2015).
- Storm Flood Map
 - The National Hurricane Center⁷¹ (NHC) used Big Data approach for providing advanced warning and detailed information about the emergencies in case of hurricanes and storms. To this end, they launched the Storm Flood Map in 2014 (NHC, 2014). Within 60 minutes of a hurricane warning, the new interactive map will provide detailed graphics of land and river systems, water infrastructure and flooding information. The public and first responders never have had this type of critical

⁶⁷ https://www.ci.south-bend.in.us/government/content/csonet

⁶⁸ http://www.metering.com/smart-water-meters-california-utilities-prefer-apps-to-big-data/

⁶⁹ http://waterfoundation.net/about-us/

⁷⁰ http://leakdefensesystem.com/

⁷¹ http://www.nhc.noaa.gov/

information before and it could potentially help save lives. The NHC plans to further develop the tool and is working towards implementation by embedding it in Google Maps.

3.6.6 United Kingdom

Yorkshire Water provides clean water and wastewater treatment services to 4.7 million people and 130,000 businesses in Northern England, delivering its services via 65,600 kilometres of pipelines. The company also manages 650 water storage facilities, 2,250 pumping stations and 86 wastewater treatment facilities. The geographic spread of this network includes both hilly and flat territories and the company draws water from both groundwater and river sources.

Yorkshire Water uses the OSISoft PI System to help support its planned growth, because it allows the utility to view its assets in an integrated way, supporting continuous improvement of operations as a whole. After implementing the PI System, Yorkshire Water realized an Enterprise Agreement would help them realize even more benefits. The PI System acts as a central translator for a wide range of device languages and protocols while providing a highly scalable infrastructure. The Enterprise Agreement provided additional support and resources for the Yorkshire Water thus furthering the deployment of the PI System, providing Yorkshire Water with a true, enterprise-wide, infrastructure. Yorkshire Water was able to quickly integrate its existing assets into the system—which includes nearly 60 technologies from more than 40 vendors.

3.6.7 Canada

The City of Calgary provides safe, reliable, drinking water to over 1 million residents in Calgary, Canada and local regional customers. With its vast network of pipes, water mains, plants, reservoirs, and pump stations, City of Calgary draws, cleans, treats, and delivers water to meet its customers' water demands. The utility also manages the collection, treatment, and safe discharge of wastewater. Providing these services is deeply connected to the region's watershed.

City of Calgary had been using the OSISoft PI System to collect real-time data about the status and performance of its entire water treatment and distribution network, including five water and wastewater treatment facilities and more than 200 distributed field devices. City of Calgary decided to expand its PI System to monitor the watershed that feeds the municipal water system and capture information such as river water heights, reservoir water heights, flow rates, and rainfall. This new data allowed City of Calgary to monitor the watershed in real-time and better predict potential floods. Today, City of Calgary operations, maintenance, engineering, planning and enterprise users can see precisely how much water is in the system from river to reservoir to pipe to sewer using their PI System analysis and visualization tools.

3.6.8 Summary of the case studies

The case studies validate the identified needs and expected changes required for the Water Industry to move towards Smart Cities and Smart Water Grids, where the Water Information System should be able to:

- Cope with Big Data with the implementation of smart sensors and AMI
- Have consistency/uniqueness of description in SCADA/EAM/GIS and better integration of these three tool categories to ensure interoperability
- Efficiently manage, analyse, and produce geospatial data and to perform highly developed analysis and visual production of geospatial data. (Geographical Intelligence)

3.7 Summary and analysis of the dominant solutions and trends

3.7.1 Private Sector

According to (Kim, Park, Choi, & Min, 2014) IBM in the private sector leads the development of SWG while interest from water-related businesses such as Siemens or Suez grows; IBM is globally heading the "smartisation" of the water management area by pushing ahead with development of smart water management solutions.

- IBM is developing data platforms that can monitor, on a real-time basis, the conditions of the Hudson River (500km. length) of the US, by installing state-of-the art sensor networks covering all sections of the river.
- In Brazil, IBM is developing geographical and spatial three-dimensional computer simulation systems that can predict the effects of utilization of land and water on the ecological system and can effectively manage the water.
- In the Netherlands, IBM is working on a project of monitoring the condition of flood inundation, which changes moment by moment, and constructing smart levees that will respond accordingly on a real-time basis.

HydroSense also provides SWG advancements through a low-cost, single-point solution for activity sensing mediated by a home's existing water infrastructure. (Froehlich, et al., 2012) HydroSense is based on continuous analysis of pressure within a home's water infrastructure. Specifically, it identifies individual water fixtures (e.g., a particular toilet, a kitchen sink, and a particular shower) within a home according to the unique pressure waves that propagate to the sensor when valves are opened or closed. It also estimate the amount of water being used at a fixture based on the magnitude of the resulting pressure drop within the water infrastructure. This represents a significant advance over prior research in several regards:

• It can be easily installed at any accessible location within a home's existing water infrastructure.

Typical installations will be at an exterior hose bib, utility sink spigot, or water heater drain valve. If unavailable or not easily accessed (e.g., in an apartment unit), HydroSense can also be installed at the water connection point for a dishwasher, clothes washer, or toilet. All of these are simple screw-on installation points, with no need for a plumber.

- Its analysis of pressure provides the unique capability of sensing both the individual fixture at which water is currently being used as well as an estimate of the amount of water being used. HydroSense is the first practical approach to enabling applications that require both. Its sensing of pressure is also less susceptible to ambient noise, as has been encountered in previous microphone-based infrastructure-mediated systems.
- It has been evaluated in several diverse homes, thus providing a more robust evaluation than any previous work on water-related home activity sensing. It is demonstrated its reliable segmentation of valve pressure events from the surrounding sensor stream, it shows reliable classification of valve open and valve close events, it shows the successful identification of individual fixtures with 97.9% aggregate accuracy, and it shows that an appropriately located and calibrated system can estimate water usage with error rates comparable to empirical studies of traditional utility-supplied water meters.

In general, it is hard to find private initiatives that provide final and complete solutions for the application of the SWG in the shape of product. In contrast all the solutions presented above are distributed and commercialized separately. It can be seen as a potential barrier for the deployment of the SWG paradigm.

3.7.2 Public Sector

There are some EU directives that promote the implementation of Smart Water technologies in urban environments. They are as follow:

- The Water Framework Directive 2000/60/EC creates a single system of water management, based around a natural river basin – which may form part of two or more member states, or local government areas. The directive sets objectives and deadlines for improving water quality and protecting water resources from over abstraction. It looks overall at the ecology of the water, its chemical characteristics and its quantity and flow characteristics.
- The Urban Wastewater Treatment Directive 91/271/EEC aims to protect the water environment from being damaged by urban waste water and certain industrial discharges.
- The Floods Directive 2007/60/EC requires member states to carry out flood risk assessments, create maps of flood risk and develop flood risk management plans.
- The Drinking Water Directive 98/83/EC sets quality standards for drinking water and requires drinking water quality to be monitored and reported.
- The Bathing Water Directive 2006/7/EC aims to protect public health and the environment by

keeping coastal and inland bathing waters free from pollution.

 The Sewage Sludge Directive 86/278/EEC aims to encourage the use of sewage sludge in agriculture and to regulate its use in such a way as to prevent harmful effects on soil, vegetation, animals and man.

There also exist R&D EU funded projects like UrbanFlood, which is a project investigating the use of sensors within flood embankments to support an online early warning system, real time emergency management and routine asset management. The UrbanFlood project is a EWS framework that can be used to link sensors via the Internet to predictive models and emergency warning systems. The data collected from the sensors is interpreted to assess the condition and likelihood of failure; different models will be used to predict the failure mode and subsequent potential inundation in near real time. Through the Internet, additional computer resources required by the framework are made available on demand. A number of live pilot sites have been used to prove the methodology. Dikes are equipped with sensor systems and the EWS service built up from a series of dike failure and flooding specific modules which include dike breach evolution and flood-spreading models. UrbanFlood investigates and shows the feasibility to remotely monitor dikes and floods, whether from nearby offices or from other countries and continents through secure use of web based technologies.

3.8 Challenges and Limitations for Smart Water Management

From the analysis of the current trends of smart water implementations, the major issues for the challenges and limitation for Smart Water Management have been identified:

- 1. Open Data & Big Data Management
- 2. Water Management Information System
- 3. Smart Sensors Technology

3.8.1 Open Data and Big Data Management

There are three main issues concerning Open Data and Big Data management:

- 1. Real-Time Data Integration
 - Real-time monitoring provides the users up-to-date information for fast decisions, thus reducing losses. This is especially in the case of work maintenance where utilities are able to dispatch maintenance crew to the exact location of the incident (be it leakage in pipe or pump failures) in minimal time.
- 2. Availability of Data
 - Open data, especially open government data, is a great resource that is largely untapped. Many individuals and organisations collect a broad range of different types of data in order to perform their tasks. Government is particularly significant in this respect, both because of the quantity and centrality of the data it collects, but also

because most of that government data is public data by law, and therefore could be made open and made available for others to use⁷².

- According to study by EU⁷³ Commission, if the Public Sector Information (PSI) policies were open, with easy access for free or marginal cost of distribution, there could have been a savings of up to EUR 40 billion through the direct PSI use and re-use activities.
- For the period 2016-2020, the direct market size for Open Data is estimated at EUR 325 billion for Europe⁷⁴.
- A report from the World Bank (2014) provides some examples of such savings:
 - i. In the United Kingdom⁷⁵, the estimated the direct economic benefits of public sector information at around £1.8bn a year, with an overall impact including direct and indirect benefits (such as time saved by access to real-time travel data) of around £6.8bn.
 - ii. In Spain (World Bank, 2014), a study found that revenue of 330-550 million Euros generated annually can be directly attributed to Open Data reuse.
- In Europe, Open Data⁷⁶ initiatives are starting to make an impact in respect to both public sector information, and scientific data, while the Research Data Alliance⁷⁷ has been established to accelerate and facilitate research data sharing and exchange at the global level. Also open access to different data sources can help to take decisions at a higher level and foster the decision taking.
- However, there is still much room for improvement. Study⁷⁸ shows that the EU28+ have completed just 44% of the journey towards achieving full Open Data Maturity and there are large discrepancies across countries.
- 3. Security and Anonymity of Data
 - The security and safety issues are important for intelligent sensors as they are elements of wireless sensor networks that communicate directly or indirectly with other. There are already layers of security in WS (HTTPS, SSL, WS-Security to mention a few), but it has to be assured that these security tools arrive to the

⁷²http://opendatahandbook.org/guide/en/why-open-data

⁷³https://ec.europa.eu/digital-single-market/news/review-recent-studies-psi-reuse-and-related-market-developments

⁷⁴https://www.capgemini.com/news/new-european-data-portal-is-a-key-step-in-seizing-multi-billion-euro-potentialof-open-data

⁷⁵https://www.gov.uk/government/publications/shakespeare-review-of-public-sector-information

⁷⁶https://ec.europa.eu/digital-single-market/node/70

⁷⁷ http://rd-alliance.org/about.html

⁷⁸https://www.europeandataportal.eu/en/content/open-data-maturity-europe
consumer, as security faults can be a major drawback in the adoption of interoperable open technologies.

 There should also be reliable standards and procedures in place to safeguard the anonymity of the data. Research has shown that sensitive user behaviour can be inferred even from seemingly harmless sensors (e.g., accelerometers, gyroscopes, or magnetometers). Thus it is of great importance that robust anonymity assurances are a must when data is being shared.

3.8.2 Water Management Information System

There are many models of the utilities business are available on the market, with most of them coming from software vendors, whose objective is selling their software package solutions and not on creating or ensuring interoperability of the system with others. Therefore, there is a need for an overall consistent approach made of an integrated model of the water business processes where the ideal Information System (IS) is based on Business Process (BP) model.

This consistent IS can be reach by a real integration and by gateways or interfaces. Targeting an IS, helps to establish a single definition and way of managing each data item. In other words, this consistent IS, together with standardised ontologies, is the key to real interoperability. The processes of generating or capturing data need to be managed and monitored and reference data and how they are shared within the information system has to be defined. But, above all, the target system should be fully aligned with the water business processes. The approach has been already promoted for example within the Smart Water Management Initiative taken by K-water. (Choi, Chong, Kim, & Ryu, 2016)

3.8.3 Smart Sensors Technology

One of challenges encountered by the utilities and the governments is the decision to implement smart sensors and what type of technology between AMR and AMI for their water systems. The factors for causing this dilemma are presented in the

Table 28 below:

Factors	AMR VS AMI		
	AMI systems tend to cost 10% to 20% more than AMR systems since the		
	former require a fixed network of data collectors, more complex software		
Cost of Implementation	and backhaul communications. ⁷⁹ Although in recent years, the price		
	difference between the two technologies has decreased significantly, it is		
	still wide enough for utilities to consider AMR instead of AMI.		

⁷⁹http://www.owasa.org/Data/Sites/1/media/customerService/ami-study-combined-documents.pdf

Factors	AMR VS AMI		
Payback Period	• The time for cost of recovery is long term. Thus, some utilities see benefits of smart technology as optional, rather than critical. ⁸⁰		
Size of Infrastructure	 Small to medium size utilities will be more favourable to consider AMI due to lower cost needed for equipment purchases and installation for fewer connections. (Between10,000 and 30,000 connections)⁴³ 		
Additional software development	 For AMR, there is little to no additional software development required (for example the billing system). For the AMI, in order to have the full benefits of producing useful information, systems like the meter interface unit, the AMI system server (or "head-end"), the meter data management system and the billing system have to work together harmoniously. This requires significant software development for the integration of the AMI systems with other systems. 		
Real-time Status of the System	 AMI system will be able to provide real-time information, unlike AMR system. It enables the utility access to real-time pricing, automated billing, remote control of water connections and proactive response to leakages. 		

Table 28 Factors utilities consider for implementation of Smart Technology

3.9 Recommendations and Action Plans

This section will discuss recommendations that will help to overcome the limitations and challenges faced by the utilities and the government. They will be classified into the following 3 categories:

- 1. Adoption of Smart Water Technology
- 2. Implementation of Smart Water Technology
- 3. Operation and Maintenance of Smart Water Technology

3.9.1 Adoption of Smart Water Technology

In order to engage the interest of utilities, governments and the public in Smart Water Technology, multiple strategies comprising of technical solutions, policy-making and awareness campaign and education are required.

The first action is to ensure the specifications for interoperability and data sharing across services

⁸⁰http://bv.com/Home/news/solutions/water/smart-water-technology-benefits-challenges-and-three-action-steps-for-utilities

(water, energy, etc) and their infrastructures. This can be achieve through the development of semantics tools to properly contextualize the business processes in the water domain (Water Uses and Services, Environmental Management and Natural Hazards Management) by using and adapting of existing ontologies (mainly sensors and real-time measures) and creating of new water-specific ontologies for those that are not available. To support the development of semantics tools, it is important to provide an open repository where all the ontologies are made available (free if possible).

The second action is to promote cross-domains data sharing (Water-Energy Nexus) by developing and providing Open Data interfaces and establishing Open Data policies.

The third action is to get the support for pilot projects on Smart Water technology. The outcomes of these pilot projects will contribute to the establishment of guidelines and best practices for future SWG implementation.

- For the governing bodies, besides offering the financial support, there should also be legislative support to ensure the security of the data collection, transmission and storing across all domains.
- For the utilities, proposed pilot projects should be self financing within 3-5 years. The pilot
 projects should start with a small-scale implementation (SSI) carried out within the 1 year of the
 project. This will enable the utilities to make use of the results of the SSI to learn, optimize and
 re-engineering the processes in the project for the later phases. Also, it will serves as a
 validation checkpoint that will reduce the risks, uncertainties and implementation time of the
 project.
- For the public, awareness campaign should be carried out by the government and utilities to
 ensure customer buy-in. Such campaign can include seminars and conferences, printed media
 and videos. This will help to facilitate the implementation of the AMM during the pilot project,
 thus optimizing the implementation time of the project.

3.9.2 Implementation of Smart Water Technology

For the implementation of Smart Water technology to be a success, there should be development of systems standards for cities and communities to ensure the interoperability solutions. Both the "inter" systems (like MDM, DSS) within the water system and the water system itself should not only be able to operate individually within its own set of operation protocols and standards, but also interact with other systems. In the case of the water system, there should be interoperability among the other Smart City systems. Recommendation includes:

 Develop Open Data initiative by making Open Data should be made easily accessible and free (if possible) to the researchers, as it will enhance and accelerate the development on the interoperability solutions • Definition of the Water Information System for all common business processes models of all the domains (Water Uses and Services, Environmental Management and Natural Hazards Management) of the water industry, at least at a macro level.

3.9.3 Operation, Maintenance and Optimizing of Smart Water Technology

The challenge of smooth operation, maintenance and optimizing of the SWG can be overcome by developing performance benchmarking on an EU level. This can be build on work by IWA Water Utility Efficiency Assessment Matrix and Effective Utility Management Collaborating Organizations and extend the benchmarking to consider the processes involved in the smart water grid. The following actions are recommended:

- Identifying key performance metrics and indicators for SWG
- Develop a benchmarking framework and assessment methodology
- Develop a supporting benchmarking tool
- Test and validate the framework across the utilities in EU
- Making the tool available to the water utilities and sector

Follow-up actions upon the development of the benchmarking framework and tool are:

- Providing for cross-utility comparisons of utility targets and performance
- Developing a process for future updates to the tool and self-assessment process

3.9.4 Checklist Tool for Smart Meter Implementation

Based on the market research by Frost & Sullivan⁸¹, a checklist tool is proposed to provide the water utilities and the government an overview on how committed they are to implement the smart water technology in their existing system.

⁸¹https://www.engerati.com/sites/default/files/Day3-0900-Fredrick%20Royan.pdf

The questions of the checklist are as follows:

Q1. How important is the mass uptake of the smart water technology and validated (proven) benefits?					
	Not at all	C Slightly	C Moderately	O Very	C Extremely
Q2. I	How important is th	e affordable cost o	f implementing the	smart water techr	nology?
	Not at all	C Slightly	Moderately	🔿 Very	C Extremely
Q3. I	How important is th	e reduction of frag	mentation in Data N	lanagement Mark	ket?
	Not at all	C Slightly	C Moderately	C Very	C Extremely
Q4. How important is the performance optimization (like leak detection, consumption behavior) of your water system?					
	Not at all	C Slightly	Moderately	C Very	C Extremely
Q5. How important is the public's acceptance of the smart water technology?					
	Not at all	C Slightly	Moderately	C Very	C Extremely
Q6. How important is the presence of government support for smart meter technology? (in terms of regulation and legislative)					

C Not at all C Slightly C Moderately C Very C Extremely

The scoring system of the checklist is as follow:

	Not at all	Slightly	Moderately	Very	Extremely
Qn 1	5	4	3	2	1
Qn 2	5	4	3	2	1
Qn 3	1	2	3	4	5
Qn 4	1	2	3	4	5
Qn 5	1	2	3	4	5
Qn 6	1	2	3	4	5

The score analysis is as follows:

Score	Commitment Level	Remarks	
6-12	Minimal	 You are not actively exploring Smart technology due to the high cost of implementation Financial support from the government or municipality can be a means of funding part of the implementation plan. In addition, a small-scale implementation project can be carried instead of the full-scale. 	
13-20	Average	 You are exploring Smart technology with the objective to optimize your water system However, you are concerns about the high cost and the fragmentation of the data management market. AMR would be a ideal starting point for the upgrading of your water system as it has proven actual real benefits and improved efficiency to the water system operations. AMI, the more expensive alternative, would be suitable if your water system endpoints are small to medium sized. (10,000 to 30,0000 endpoints). However, attention should be given to the interoperability of the implemented systems to ensure that it will be able to be easily upgraded in the future. 	
21-30	Highly	 You are actively exploring Smart technology with the objective to optimize your water system Since cost is not a critical concern, AMI solution would be the technology for your water system. However, attention should be given to the interoperability of the implemented systems to ensure that it will be able to be easily upgraded in the future. 	

In addition, this checklist tool can also be used for identifying the mindset of the utilities and governments on the implementation of smart water technology.

3.9.5 Action Plan

In addition, an action plan is proposed on how advance the development and implementation of Smart Water technologies. The actions are categorized into short terms, medium terms and long term goals.

No.	Activity	Challenges Addresses	Short Term (1- 2years)	Medium Term (3- 5years)	Long Term (>5 years)
1	Development of semantics tools to properly contextualize the business processes in the water domain	 To ensure the specifications for interoperability and data sharing across services (water, energy, etc) and their infrastructures. 	x		
2	Development of cross-domains data sharing (Water-Energy Nexus)	• To develop and provide Open Data interfaces and establishing Open Data policies so as to facilitate the data flow between different system domain	x	x	x
3	Development and support for pilot projects	 To establish best practices and guidelines on SWM implementation so as to promote adoption of SWM To raise awareness in SWM among the stakeholders (utilities, governing bodies and end-users) 		x	x
4	Development of performance benchmarking	 To identify key performance metrics and indicators for SWG in order to develop benchmarking framework and assessment methodology Provide benchmarking tool available to the water sector 		x	x
5	Development of systems standards for cities and communities	 To identify and develop interface standards essential for the integration of systems 	x	x	
6	Development of Open Data initiative for free flow and easy access of data	 To promote and accelerate the development on standards and ontologies on data To facilitate the integration of different systems 	x	x	
7	Provide review analysis and guidelines for the ICT solutions and systems in SWG	 To promote the established standards and best practices obtained from the pilot projects and their relevant experiences and research on operating and maintenance. 			x

4. Discussions and Recommendations

4.1 Proposed Smart Water Management Framework for Urban City

As mentioned in section 3.2, Urban Water Uses actually covers all the business processes for all the other sub-domains of water uses. Therefore, the proposed framework for Urban Uses can be used as a template reference for the other sub-domain of water uses.

In urban water uses, it can be classified into two main management criteria: quality and quantity. The overall framework is shown in Figure 51.

Figure 51 Overall Framework for Smart Water Management for Urban City

 Sensing Devices Layer: This is responsible for the recording of measurements using the sensing devices. The communication between the sensors and their data loggers are usually in the area size of HANs and NANs. This allows the use of short range wireless communication network (Wi-Fi or Zigbee) or wired network (PLC). It should be noted that in remote areas, longrange wireless communication network will be more applicable than short-range or wired communication network. However, this will bring about the issue of sensors' battery where constant power supply is often not available in such remote places, especially when dealing with measurement of water quality in water bodies.

- Sensing Adapters Layer: This is responsible for transmitting the recorded data from the sensors to the central system. The communications between the data loggers and the information system are usually in the area size of FANs, IANs and WANs. This requires mid to long range communication network, although short range communication networks can be used with the implementation of repeaters. It should be noted that Data Aggregation Points (DAPs) not only help to reduce the long range communication distance requirements, but it also help in reducing the data transfer volume by aggregating the recorded data from the various sensors and eliminating data redundancy.
- Data Layer: This is responsible for storing and managing the large volume of data collected from the sensors. In addition, it serves as the standardization point where the data collected will be processed such that data will be standardized with other smart city sectors' data domains. Currently, such cross sectors standards have been deployed by oneM2M⁸². Some of the benefits from the cross sectors standardization include:
 - Reduced deployment & operation costs through the sharing and reuse of infrastructure and field devices, cost-effective products due to shared R&D efforts and easier and cheaper integration and application development
 - Sustainable investments as there is no vendor lock-in and the utilities will benefit from further evolution of the standards in the long run
- Service Support Layer: This is responsible for providing the functions of operation support, application security management, workflow management, data exchange and sharing, the RFID middleware, the GIS support platform, modelling and simulations of the water system as well as the visualization of the results and analysis reporting.
- Application Layer: This is responsible for the decision-support systems where optimization decisions and management steps are taken from the analysis of the work done in the Service Support Layer. Examples includes intelligent regulation and optimization of water quality and quantity, efficiency dispatching of work service required and early warning of potential water shortages or overflow.

4.1.1 Framework for Integrated Urban Water Management Models

Integrated urban water management (IUWM) can be describe as the practice of managing freshwater, wastewater, and storm water as components of a basin-wide management plan. It builds on

⁸² http://www.onem2m.org/

existing water supply and sanitation considerations within an urban settlement by incorporating urban water management within the scope of the entire river basin.(Parkinson, Goldenfum, & Tucci, 2010)

The aim of urban water management is to create cities and towns that are resilient, liveable, productive and sustainable.⁸³ They interact with the urban hydrological cycle in ways that:

- Provide water security through efficient use of the diverse water sources available
- Protect and restore the health of waterways and wetlands
- Mitigate flood risk and damage
- Create public and private places that harvest, clean and recycle water, resulting in water resource, environmental and social liveability benefits.
- Provide water for productive, sustainable, liveable and resilient communities.

In order to achieve the above-mentioned goals, there should be a good implementation of a water balance system that is integrated with water supply and drainage forecasting models (both hydrology and hydraulic), asset management and decision support system.

4.1.2 Water Demand System

One important component of a good water balance system is an efficient and accurate water demand forecast system. Figure 52 proposed an overall framework of implementation a water demand forecast system.



Figure 52 Overall Framework for Water Demand Forecast System

In general, water demand forecast consist of three sources: Domestic Water, Industrial Water and

 $^{^{83} \} http://www.water.wa.gov.au/urban-water/urban-development/urban-water-management$

Agricultural.

For domestic water, it can be determined by two means, qualitative or quantitative. Qualitative method involves the expertise and view of water demand experts which is subjective and is usually used when there is no historical data available for quantitative methods. Under quantitative methods, there are various means and equations to forecast the domestic water demand. In the proposed framework in Figure 52, two methodologies are suggested:

- i. Time Series Analysis: It analyses a sequence of data set which is surveyed at a target point within time spaced at time intervals specified to obtain patterns and significant features (current trend, average, seasonality, random fluctuation and cycle pattern) of the data which can then be applied to predict future water demand. This method is recommended if there is sufficient historical data and the data follows a distinct trend. One disadvantage is that it is difficult to consider the influence of policy.
- ii. Causal Forecasting: It analyses a range of variables that are determined to influence the water demand under the assumption that the relationship between dependent and independent variables obtained through the analysis of past data applies to the water demand in the future. Typically, statistical models are used like regression analysis for the estimation of the relationships among variables.

For industrial water, various methodologies are available to forecast the demands. One such example is the Output Unite Method which consists of end demand module, industrial interrelationship module, per capita module (including return ratio), and reflects the changes in industry structure, per capita, and return ratio.

For the agriculture water demand, the various components are considered, paddy water demand, Upland water demand, livestock water demand and agricultural water demand based on the policy, agriculture products demand and the environmental change.

4.1.3 Water Supply System

A water supply system consists of the following components:

- Drainage basin which is an area of land where precipitation is collected and transported to a outlet
- Water bodies where raw water is accumulated, like lakes, rivers underground aquifer
- Drainage system which transport the raw water to the water treatment and storage facilities
- Water treatment facilities where treated water is transferred through water pipes
- Water storage facilities such as reservoirs, water tanks, or water towers.
- A water supply distribution network for supply water to the consumers (which may be private houses or industrial, commercial or institution establishments) and other usage points (such as fire hydrants).

 Connections to the sewers (underground pipes, or aboveground ditches in some developing countries), however the sewer system is considered to be a separate system, rather than part of the water supply system.



Figure 53 Overall Framework for Water Supply System

To ensure the water supply system is running efficiently, hydrology and hydraulic models are implemented to forecast water runoff (rainfall and groundwater) and required pressures to deliver the water in the distribution pipes system respectively. In Figure 54, a work flow diagram is proposed for the forecast systems of a water supply system. There are four types of modelling systems:

- **Hydrology modelling:** This deals with the estimation of the runoff from the rainfall in the drainage basin. Some of the available programs include MIKESHE (DHI), SHETRAN (Newcastle University) and SOBEK (Deltares).
- Overland modelling: This deals with the surface runoff modelling as well as the exchange of volume between water bodies and land. Programs include MIKE2D (DHI) and Telemac 2D (LNHE).
- Groundwater Modelling: This deals with the exchange with the surface runoff and groundwater as well as the exchange within the groundwater aquifer itself. Programs include FEEFLOW 3D (DHI), Visual MODFLOW Flex (Waterloo Hydrogeologic) and Groundwater Modelling System - GSM (Aquaveo).
- Water Distribution Modelling System: This deals with the estimation of the flow conditions within the pipe distribution such that appropriate actions can be taken to ensure the distribution system is operating at efficient conditions. Software includes EPANET (EPA) and Mike Urban (DHI).



Figure 54 Workflow Diagram for Water Supply System (Analytics Component)

To have real-time forecasting of the modelling systems, the hydrology model, the overland model and the groundwater model are integrated where at each time step of the model:

- i. The computed runoff from the hydrology model is fed into the groundwater model and overland model
- ii. The overland model will then use the incoming runoff data from the hydrology model to compute the overland flow. The computed infiltration amount from the overland model will be fed into groundwater model to compute the underground water exchange.
- iii. The groundwater model will use the infiltration results from the overland model to compute the exchange within the underground aquifer and will inform the overland model the newly computed the saturation of the underground aquifer.
- iv. The overland model will then use the update saturation information to compute the infiltration amount for the next time step.
- v. In the event when the underground aquifer is fully saturated, the groundwater model will inform the overland model the amount of water that is coming out from the aquifer at the downstream so that the overland model can use that information to compute the overland runoff exchange.

For the water distribution system, leak can be detected with the use water distribution models. This will be discussed more in details in the following section. Once the leak is detected, an alert will be sent to the operations so that decision for work intervention can be schedule.

The rationale for proposing different modules for different hydrology and hydraulic aspects is to compartmentalize the modelling process such that the software in each modelling component can be easily interchanged with another one. This allows the water utilities to have the freedom to choose whichever software that caters to its needs which will change in time and conditions of the city.

The required data for the modelling are as follows:

- Hydrology modelling: Climate data, Geographical data, Natural water bodies
- Overland modelling: Climate data, Geographical data, Natural water bodies, Soil data, Water infrastructures,
- Groundwater Modelling: Climate data, Geographical data, Soil data,
- Water Distribution Modelling: Water demand supply, water supply system, reservoir behaviour, decentralised water sources



4.1.4 Water Balance System

Figure 55 Workflow Diagram for Water Balance Modelling System

The water balance system consists of component water demand and water supply. The overall framework of the water demand forecast has been discussed in 4.1.2 and the overall framework of the water supply has been discussed in 4.1.3. It should be noted that the water supply should also consider water sources from water bodies (lakes, rivers, etc), desalination plants and recycle water plants. In the event that there is no measured data available, these sources especially the desalination

plants and recycle water plants can be forecasted using component-based models.

4.1.5 Water System for City

In a water system for city, the indentified water business processes categorises in 3.1.4 are closely involved in the smart water management framework. The following is a recap of the water business processes categorises:

- 1. Management of Plants: DWTP Management and WWTP Management
- 2. Management of Networks: DWNM, WWNM, SWNM and Real Time Networks Management
- 3. Asset Management
- 4. Work Management: Jobs interventions, field and plant maintenance works
- 5. Geographic Information (GI)
- 6. Measurements: Smart metering, laboratory activities and quality control
- 7. Customers: Billing and customer communication
- 8. Crisis Management



Figure 56 Workflow Diagram for Business Processes Categories in Water System

In the sensors layer, the data collected through smart sensing include:

- i. Water quality data that will be used in [Measurements] for the laboratory testing for quality control of the water supply, sewer discharge, etc.
- ii. Water quantity data that will be used in [Customers] for water usage and billing. It will also be used in [Management of Plants] and [Management of Networks] for the forecasts and designing of the plants and networks through modelling and simulations. The analysis results will applied in [Asset Management] for the operation and maintenance of the infrastructures.
- iii. Remote and Sensing data will be used in [Geographical Information]
- iv. [Customers] will also contribute to the sensors layer in terms of reporting of failure, leakages, contamination and anomalies in the water system

In the operations center layer, the business processes involved include:

- i. [Work Management] where receives commands from the operations center in the event where:
 - Infrastructure failure is reported from the sensors layers
 - Infrastructure failure is forecasted from the modelling and simulation module
- ii. [Crisis Management] which receives forecasts from the modelling and simulation module, information from Asset Management and monitoring data from sensors layers will evaluate the situation in the event of a hazard or potential hazard. It will provide the analysis result and recommendations to the decision support system, where warning alerts and evacuation announcements will be issued to the [Customers]

4.1.5.1 Recovery of the City from Flooding (Flood Resilience)

In the event of a flooding, the water system can provide significant support in the recovery of the city. During the flood event, the sensors can provide information on the locations where mitigations are needed the most. The modelling and simulation module can provide analysis information on potential locations that will be flooded where evacuation and mitigation plans can be formulated and disseminated to the public. This will greatly reduce the flood damage which will speed up the recovery time of the city after the flood event.

After the flood event, work maintenance can be efficiently carried out with the support of good asset management, up-to-date monitoring data from the sensors, damage analysis from modelling and simulation and good communication between the city and the public.

4.2 Leakage Detection in Distribution Pipe System

In urban water supply systems, a significant percentage of water is typically lost during the transportation from the water facilities to the consumers. The losses ranges from less than 10% in countries (Japan – $7.3\%^{84}$, Singapore⁸⁵ – 5%) with well managed infrastructure to greater than 40% in poorly managed systems.

Leakages in the water supply distribution system are caused by deterioration of the pipes through wear and tear, external pipe corrosion or mechanical damage caused by external loads on the pipes, like earthquakes, excavation works, contraction and expansion of pipes due to temperatures extremes. Typical leakage detection methods often employ the use of acoustics surveys by monitoring the vibration generated by the water under pressure escaping through a leak site. Recent developments have included installing pressure and noise sensors to monitor and detect such changes in the pressure and vibrations.

Leaks can be classified into three types of leaks, unavoidable leaks, unreported leaks (underground) and reported leaks (surface). Unavoidable leaks are those that cannot be detected through acoustic leak surveys. Leaks that can be found through surveys can be classified into those that are located underground and usually go unreported and those that are located on the ground surface which are reported. For the hidden underground leaks, proactive surveys have to be conducted by walking above the water pipes while listening for the sound caused by leaks.

4.2.1 Proposed Leakage Detection Using Pressure Gradient Indicator

In order to detect the presence of leakage in the distribution system, the pressure gradient within the water system will be computed using a hydraulic model. In this study, EPANET2.0 will be used for the hydraulic computation.





⁸⁴ http://www.mhlw.go.jp/english/policy/health/water_supply/8.html

⁸⁵ https://www.channelnewsasia.com/news/singapore/more-sensors-to-be-installed-in-pipes-to-reduce-water-loss-9181986

At a given time t, the pressure gradient (PG) is defined as:

$$PG(N_1, N_2, N_3, t) = \frac{N_1(t) - N_2(t)}{N_2(t) - N_3(t)}$$
 equ (2)

Where:

 $N_2(t) \neq N_3(t)$ N_1 , N_2 and N_3 are the pressure measurements at three different junction nodes with same elevation and connected by pipes

It should be noted that the three junction nodes should be of the same elevation and are connected by pipes. This is to ensure that the pressure gradient difference will not be affected by the elevation difference and will be influence by the flow in the pipes between the connecting nodes.

4.2.2 EPANET 2

EPANET is a computer program that is used to simulate hydraulic and water quality behaviour within pressurized pipe networks. A network consists of pipes, nodes (pipe junctions), pumps, valves and storage tanks or reservoirs. EPANET tracks the flow of water in each pipe, the pressure at each node, the height of water in each tank, and the concentration of a chemical species throughout the network during a simulation period comprised of multiple time steps. In addition to chemical species, water age and source tracing can also be simulated.

4.2.2.1 Hydraulic Module

EPANET contains a hydraulic analysis engine that includes the following capabilities:

- places no limit on the size of the network that can be analyzed
- computes friction headloss using the Hazen-Williams, DarcyWeisbach, or Chezy-Manning formulas
- includes minor head losses for bends, fittings, etc.
- models constant or variable speed pumps
- computes pumping energy and cost
- models various types of valves including shutoff, check, pressure regulating, and flow control valves
- allows storage tanks to have any shape (i.e., diameter can vary with height)

 considers multiple demand categories at nodes, each with its own pattern of time variation
- models pressure-dependent flow issuing from emitters (sprinkler heads)
- can base system operation on both simple tank level or timer controls and on complex rulebased controls.

The method used in EPANET to solve flow continuity and headloss equations that characterize the hydraulic state of the pipe network at a given point in time is called the hybrid node-loop approach (Todini & Pilati, 1987) and later (Salgado, Todini, & O'Connell, 1988) called it the "Gradient Method".

4.2.2.2 Water Quality Module

EPANET provides the following water quality modelling capabilities:

- models the movement of a non-reactive tracer material through the network over time
- models the movement and fate of a reactive material as it grows (e.g., a disinfection byproduct) or decays (e.g., chlorine residual) with time
- models the age of water throughout a network · tracks the percent of flow from a given node reaching all other nodes over time
- models reactions both in the bulk flow and at the pipe wall
 uses n-th order kinetics to model reactions in the bulk flow
 uses zero or first order kinetics to model reactions at the pipe wall
- accounts for mass transfer limitations when modelling pipe wall reactions
- allows growth or decay reactions to proceed up to a limiting concentration
- employs global reaction rate coefficients that can be modified on a pipe-by-pipe basis
- allows wall reaction rate coefficients to be correlated to pipe roughness
- allows for time-varying concentration or mass inputs at any location in the network
- models storage tanks as being either complete mix, plug flow, or two-compartment reactors.

4.2.2.3 Analysis Algorithm

The method used in EPANET to solve the flow continuity and headloss equations that characterize the hydraulic state of the pipe network at a given point in time can be termed a hybrid node-loop approach. (Todini & Pilati, 1987) and later (Salgado, Todini, & O'Connell, 1988) called it the "Gradient Method". The governing equations for EPANET's water quality solver are based on the principles of conservation of mass coupled with reaction kinetics.

4.2.2.4 Strengths and Limitations of EPANET

The strengths and limitations are listed in Table 29.

Strengths	Limitations
 Can use a programmers toolkit to run simulations and optimize the system Can model various types of valves and multi-speed pumps Consider demand fluctuations at each node Can model pressure dependent flows (sprinklers, leaks, irrigation systemsetc) 	 Unable to perform the following : Calculation of water hammer Simulation of pipe bursting Evaluation for the consequences of the presence of air inside the network Can determine chemical concentration at each node, but not along the pipe Calculates incorrectly the efficiency of variable speed pumps and, thus, power. (Marchi & Simpson, 2013)
Table 29 Strengths and	Limitations of EPANET

4.2.3 Model Data

EPANET2.0 is set up to validate that the pressure gradient can be used to detect the presence of leakages in the system. EPANET 2.0 is used for the hydraulic modelling of the system. The network of the system is of the water supply network from Siheung City in the Gyeonggi Province, South Korea.

It has a total of 1231 nodes with 225km length of pipes of roughness 80-130 (Hazen-Williams roughness coefficient). The simulation period is of 144 hours with both hydraulic time step and demand pattern of 1 hour. Three case scenarios are simulated:

- i. Leakage at Node 344
- ii. Leakage at Node 359
- iii. Leakage at Node 344 and Node 359



Figure 58 Pipe Network Diagram of Siheung City (EPANET)

To simulate the leakage, an emitter coefficient of emitter coefficient 10 [m^{1.5}/hour] is assigned to the node where the leakage is located. The leakages in all the three simulations occurred at time step 72 [hr].

Figure 59 and Table 30 show the locations of the measurement nodes and the leakage points and their general information respectively.



Figure 59 Location of the nodes in the pipe system network

Node ID	Function	Elevation [m]	Base Demand [CMD]	Emitter Coefficient [m ^{1.5} /hour]
333	Leakage Point	4.9	756	10
344	Leakage Point	5.1	577.44	10
452	Measurement Point – N1	4.8	439.2	-
544	Measurement Point – N2	4.8	27.36	-
733	Measurement Point – N3	4.8	144	-
760	Measurement Point – N4	4.8	963.36	-

Table 30 Properties of measurement nodes and leakage nodes

A typical water demand pattern with two peaks per day is applied to the model is shown in Figure 60 below.



Figure 60 Water demand pattern applied to EPANET model

The water leakages from Node N333 and N344 are shown in Figure 61 below.



Figure 61 Water leakage of Node 333 & N344

4.2.1 Results & Discussions

In all the 3 scenarios, there is a distinct divergence of the pressure gradient when the leakage occurs. This demonstrates that the proposed pressure gradient indicator is able to capture the change in pressure when leakage occurs.

However, the pressure difference before leakage occurs and after the leakage occurs is not a significant difference, and in real—life situations when the demand of the water supply has more noises due to multiple demand patterns of different consumers, there may be a problem in detecting this small change.

Despite this, it shows promising results as the simulated leakages are in the amount of 5-55m³/hr. As the leakages increase in multitude, the pressure gradient difference will increase as well, making it easier to detect it.



PG (N1,N2,N3,t) with leakage at Node N333

Figure 62 Pressure gradient of N1, N2, N3 and N4 at leakage at Node N333 using Eq 1



Figure 63 Pressure gradient of N1, N2, N3 and N4 at leakage at Node N344 using Eq 1











Figure 64 Pressure gradient of N1, N2, N3 and N4 at leakage at Node 333 and Node N344 using Eq 2

To further investigate the effectiveness of using the pressure gradient, four measuring nodes are used instead of the proposed three in the calculation of the pressure gradient. The definition of the pressure gradient is as follows:

PG
$$(N_1, N_2, N_3, N_4t) = \frac{N_1(t) - N_2(t)}{N_3(t) - N_4(t)}$$
 equ (3)

Where:

 $N_{3}(t) \neq N_{4}(t)$

 N_1 , N_2 , N_3 and N_4 are the pressure measurements at four different junction nodes with same elevation and connected by pipes



Figure 65 Pressure gradient of N1, N2, N3 and N4

Shown in Figure 66, when using four measuring nodes for the calculation of the pressure gradient, there is a smaller variation of pressure change when there is no leakage compared to the case of using three measuring nodes for the pressure gradient. This makes the change of pressure gradient when leakage much more distinct and easier to indentify.

The maximum change of pressure for all the three scenarios ranges from 25% (0.05m) to 50% (0.10m).





PG (N1,N2,N3,N4,t) with leakage at N333 & N344



Figure 66 Pressure gradient of N1, N2, N3 and N4 at leakage at Node 333 and Node N344 using Eq 3

4.2.2 Conditions & Improvements for the Pressure Gradient Indicator

It should be noted that in order for the proposed indicator to perform efficiently:

- i. There should be no pump working in the system as it "overwrites" the influence of the leakage influence on the pressure gradient, making it difficult to detect the pressure gradient changes due to the leakage.
- ii. There is no leakage in the system prior. This is because the proposed indicator depends on the difference states between before and after of the occurrence of a leakage in order to detect the pressure gradient changes. Without the "normal" scenario before the occurrence of the leakages as a baseline, the indicator does not work. One workaround is to use the real demand of the nodes in the water system to calculate

the "normal" scenario to be use as the baseline for the indicator to be compared against.

The proposed indicator can be further improved by:

- i. Redefining the pipe network size from District Metered Area (DMA) into more manageable sub-DMAs. Within the sub DMAs, there should be a water meter to account for the infow volume, and a valve to isolate itself from the others sub-DMAs.
- ii. The use of statistics models for the detection of leakages in the pipe. For example, Artificial Neural Network (ANN) models can be used to train with real data of scenarios of different network leakages to forecast the difference in pressure between the normal and leakage scenario.

4.2.3 Application for Real-Time Detection

For the application of the leakage indicator the water system, the following algorithm is proposed:

- 1. Start the monitoring system of the water distribution network (time t = 0)
- 2. At every time step t_n (n = 0, 1,2...), compute the pressure gradient for all the possible sets of 3 and 4 measuring nodes.
- 3. Plot the pressure gradient. If there is distinct change of pressure gradient from the previous time step:
 - a. Check if it is the first time happening:
 - i. If yes, send a alert "potential failure" to the operation center
 - ii. If no, send a alert "leakage detected" to the operation center
 - b. If no significant change is observed, proceed to step 2 and repeat for the next time step.

Figure 67 shows the workflow for the application of the leakage indicator in real-time. Additional rules can be added for the issuing of the warning alerts.



Figure 67 Workflow for the application of leakage detector in real-time

4.3 Water Demand for Environment

One of the overlapping interests of Flood resilience and Smart Water Management is the management of hazards and environment. The water demand discussed in 4.1.2 did not include the water demand for the environment. It is important to consider the water demand for the environment especially during the event of droughts where water recourses are limited. Also, in events like tsunamis and coastal floods where water sources are contaminated, the water demand for the environment has to be accounted and incorporated into the city water demand.

Water Demand = City Water Demand + Environment Water Demand

Where City Demand = Domestic Demand + Industrial Demand + Agricultural Demand

4.4 Evolution of Smart Meters

Smart meters in Smart Water Management play an important role in reducing the non-revenue water (NRW) and increasing the efficiency of the water utilities' operations. With more advanced meter technologies, water utilities are able to reduce operation costs while at the same time increase their operation revenue. Such technology improvements include:

- Reducing the cost of buying, operating and maintaining of the meters
- Developing of meters with higher measuring accuracy and capability of measuring a wide range of flow volume (high to low)

Figure 68 shows the distribution of the level of NRW among the utilities covered by IBNET. It can be seen that two-third of the global utilities have more than 30% of their water supply as NRW. The global average level of NRW is 35% and it is expected that for developing countries, the value will be in the range of 40–50 percent of the water produced. In addition, it is estimated that the ratio of physical losses⁸⁶ and commercial losses⁸⁷ for developed countries and developing countries are 8:2 and 6:4 respectively. (Kingdom, Liemberger, & Marin, 2006)



Figure 68 NRW Performance of Utilities in IBNET Database

4.4.1 Commercial & Residential Water Meters

For the water losses due to meter errors, 65% comes from residential water meters while the remaining 35% comes from commercial water meters (Parker, 2010). This shows that there is still room for improvements for the water meters. For commercial water meters, one of the main sources of water losses is from unaccounted low water flows. These commercial water meters often have a hard time

⁸⁶ Physical losses comprise leakage from all parts of the system and overflows at the utility's storage tanks. They are caused by poor operations and maintenance, the lack of active leakage control, and poor quality of underground assets.

⁸⁷ Commercial losses are caused by customer meter under registration, data-handling errors, and theft of water in various forms.

measuring low water flows and retaining accurate meter reads over time and continuous flow conditions. (SENSUS, 2015) Thus there is a need to have commercial meters capable of accurately measuring a wider range of high and low flows.

For residential metering, accuracy at low and intermittent flow is essential. The meters used in residential are either mechanical meters (displacement meters) or static meters (ultrasonic meters, electromagnetic meters).

	Displacement Meter	Ultrasonic Meter	Electro-magnetic Meter
Inherently linear response	•	•	• • •
No moving parts	•	• • •	• • •
Flexible orientation	•	• •	• • •
Accurate at low flow	•	• •	• • •
Tolerates dirt and debris	•	• •	• • •
Accurate long-term	•	• •	• • •
Low pressure loss	•	• •	• • •
Immune to disturbed flow	• •	• •	• • •
Stable over temperature	• •	• •	• • •
Immune to vibration	• •	• •	• • •
Measures intermittent flows	• • •	•	• • •

Performance: • low •• medium ••• best

Table 31 Comparison of residential meters technologies (SENSUS, 2017)

Table 31 compares the different dominant resident meters technologies and electro-magnetic meters is shown to have its measuring accuracy unaffected by temperature variation, vibration, particulates, air bubbles, and flow disturbances. This makes electro-magnetic meters a favourable choice for utilities looking to install water meters or upgrade their water meters in their water system.

4.4.2 Smarter Sensors with Edge Computing

Edge computing is changing how the IoT system is functioning. By allowing the data produced by the IoT devices to be processed and analysed at the edge of the network, it can help to reduce the backhaul traffic to the central repository (data center or cloud).

An example is the monitoring of a dam. Most of the data collected is data that comfirms the systems are working properly. Such data does not require it to be send over the network urgently. Edge computing allows this data to be compiled where daily reports are sent to the data center or cloud, thus reducing the transfer load by only sending important data over the network.

Edge computing also help to reduce latency because data does not have to traverse over a network to a data center or cloud for processing. This is especially true for water sensors where water data are recorded at small time intervals continuously 24/7.

4.4.2.1 Security Concerns

There are two opposing views on the security of edge computing. One side believe that the edge security provides more security as less data is being transfer over the network and stored in the data center or cloud. This reduces the vulnerability of the system if either of these environments (network, data center, cloud) is compromised.

On the other hand, others believe that edge computing increases the vulnerability of the edge devises (the sensors, cameras, etc.), where the devices can be hacked and the processed data is compromised. Thus, it is of upmost importance that data encryption, access control and use of virtual private network tunneling should be considered when implementing edge computing.

4.4.3 Blockchain Technology

The first blockchain was conceptualised by an anonymous person or group known as Satoshi Nakamoto in 2008. It was implemented the following year as a core component of the digital currency bitcoin, where it serves as the public ledger for all transactions on the network.⁸⁸

Don & Alex Tapscott, authors Blockchain Revolution defines the blockchain as an incorruptible digital ledger of economic transactions that can be programmed to record not just financial transactions but virtually everything of value. ⁸⁹ By allowing digital information to be distributed but not copied, blockchain technology created the backbone of a new type of internet. Originally devised for the digital currency, Bitcoin, the tech community is now finding other potential uses for the technology. ⁹⁰

Blockchain works by storing blocks of information that are identical across its network. This ensures that it cannot be controlled by any single entity, hence preventing any hampering or corruption to the data. Also, it prevents potential failures by providing redundancy in the case where one of the computing nodes is down. The durability and robustness that Blockchain technology provides is ideal for water supply management.

Blockchain can be used to track the water usage from the consumer which is essential the water balance in the city water system. It creates a database that works like Goggle Docs where it is

⁸⁸ https://www.economist.com/news/briefing/21677228-technology-behind-bitcoin-lets-people-who-do-not-know-ortrust-each-other-build-dependable

⁸⁹ https://www.linkedin.com/pulse/whats-next-generation-internet-surprise-its-all-don-tapscott/

⁹⁰ https://blockgeeks.com/guides/what-is-blockchain-technology/

constantly updated and available to all involved parties at all time in real time. This enables all involved parties to have access and knowledge to when and how much water is consumed where then water trading can be made and finalised in real time in a virtual marketplace. This concept will also work for trading between two different domains like energy and water where in the scenario of excess on-site energy generation, the excess energy can be "traded" to the water treatment systems instead of waiting until night when the energy is more expensive.

Some water-based blockchain initiatives have been carried out. In the United States⁹¹, Genesis Research & Technology Group has developed an Internet of Things (IoT) water quality sensor to permanently store tamper-proof water quality records on the Ethereum blockchain. The IoT sensor aims to reduce the carbon footprint associated with unnecessary transportation, and to enable unusable water to become usable again. By combining the Genesis water treatment system with the blockchain via the IoT solution, the United States Environmental Protection Agency (EPA) and communities around the world can have confidence that the information they see is real, readily accessible and verifiable. This in turn will make the fracking industry more transparent, discouraging wasteful and environmentally unfriendly practices.

Another imitative that is recently announced is in Australia where the city of Freemantle will conduct a pilot blockchain project by integrating the distributed water systems using blockchain technology. Their goal is to compile data on smart metering of water and create a trading system to make water usage more efficient, in addition to similar energy-trading platforms.⁹²

With the combination of Blockchain technology to proved security and transparency and edge computing reducing backhaul traffic to the central repository, water utilities will be able to implement smart water sensors that are more efficient and accurate for their water systems.

⁹¹ https://bitcoinmagazine.com/articles/genesis-system-wants-record-cleaned-fracking-water-blockchain/

⁹² http://www.sustainabilitymatters.net.au/content/water/article/smart-cities-with-water-and-energy-efficiencies-833877089

4.5 Smart City Connections

The International Organization for Standardization (ISO) provides up to four definitions for the term "Smart City" in the Joint Technical Committee (JTC) review on the specified topics of Smart Cities (ISO/IEC JTC 1, 2015). One of the definitions comes from SAC, a general working group of Chinese national smart cities standardization where it define Smart Cities as a new concept and a new model, which applies the new generation of information technologies, such as the Internet of Things, Cloud Computing, Big Data and Space/Geographical Information Integration, to facilitate the planning, construction, management and smart services of cities. Developing Smart Cities can benefit synchronized development, industrialization, informationisation, urbanization and agricultural modernization and sustainability of cities development. The main target for developing Smart Cities is to achieve:

- Convenience of the public services
- Delicacy of city management
- Liveability of living environment
- Smartness of infrastructures
- Long-term effectiveness of network security

The term "smart city" was first used in 1994 (Dameri & Cocchia, 2013) and since then, there has been many researches and publications on this topic. According to the "10 Year Rolling Agenda"⁹³ prepared by the Smart Cities Stakeholder Platform, the current objective of Smart Cities is to accelerate investment and the rate of innovation in cities in Europe with the aim of achieving social, economic and environmental objectives. Smart Cities are meant to:

- Increase the quality of life of city-dwellers;
- Enhance the efficiency and competitiveness of the local and EU economy;
- Move towards the sustainability of cities by improving resource efficiency and meeting emission reduction targets.

The European Innovation Partnership on Smart Cities and Communities Strategic Implementation Plan (SIP) was developed to draw both strategic and operational plans that guide all involved entities to work on some prior areas for the Smart City paradigm achievement. The SIP is focused on these three specific, vertical areas:

- Sustainable Urban Mobility: alternative energies, public transport, efficient logistics, planning.
- Sustainable Districts and Built Environment: improving the energy efficiency of buildings and districts, increasing the share of renewable energy sources used and the liveability of our

⁹³ https://www.yumpu.com/document/view/29687975/10-year-rolling-agenda-smart-cities-stakeholder-platform

communities.

• Integrated Infrastructures and processes across Energy, ICT and Transport: connecting infrastructure assets to improve the efficiency and sustainability of cities.

4.5.1 Next Generation AMI

One of the means to facilitate the smart city connections is to improve the AMI. Such improvements include:

- True end-to-end IPv6 communications across all platforms: This will transforms the system from a single application AMI network to a truly open and interoperable smart grid infrastructure where industry standard addressing is used between all endpoints and applications in electric, gas and water grid.
- Implementing of multi-channel spectrums for communication: This allows the prioritize
 of time-sensitive applications like closing of water gates in the event of flood to have
 dedicated channels to ensure low latency and reliable round trip performance of less than
 5 seconds.

4.5.2 Integrated Framework for Smart City Systems

It is important to consider the smart city connections when implementing the smart water management. Typically, when one think of the different systems in a Smart City, they envisioned the individual systems are compartmentalized and are connected to a central system via the information system. However, this is not the most efficient way of managing the Smart City as a whole. Instead all the systems should be integrated together from the bottom (Communication Network layer) all the way to the top (IoT Information System layer) as shown in Figure 69.



Figure 69 Integrated system framework for all smart city systems

Therefore when considering which types of communications networks and service platform to implement for the smart water management, it is important to consider the existing and planned infrastructure in the other sectors of the smart city, especially in the Building & Infrastructure and Security & Governance component as they implement sensing devices which are usually in the same area of interest (location, data frequency) as the smart water management.

In addition, having the integration from the sensing devices layer among the different components will improve the ease of achieving interoperability of the smart city information system and reduce the data redundancy and occurrence of data conflict or missing data.

Some of the connections between the different domains of a smart city are shown in the Figure 70. In the sensors layer, [Healthcare], [Security] and [Transportation] all contribute to the smart sensing of the water system.

[Security] provides video surveillance of water infrastructures through the vast network of traffic cameras and security cameras installed throughout the city. In addition, the cameras can offer power and communication network connections to the sensors as the cameras are often connected to the power grid.

[Transportation] provides visual reports and confirmations from the roads before, during and after an event of flooding. [Healthcare] on the other hand provide warning and alerts when contamination is detected. This enables the water system to issue commands to the relevant sensors to have a closer monitoring of the water quality.

Similarly, the data collected from the sensors also contribute to the above-mentioned domains. Water quality data from the sensors can inform [Healthcare] whether the water source is contaminated or not where it can issue investigations or warnings to the public. One example is the operation of restaurants: In the event where the water supply is contaminated, [Healthcare] can issue warning to the restaurants that their water source contaminated, so that the restaurants can take precautions and ensure the safety of their food. Also, the public can be notified of the situation which will prevent potential food poisoning.

[Transportation] will be able to divert their travel routes in the event of flooding from the monitoring data from the sensors. Roads that are flooded can be indentified in real-time so that [Transportation] can efficiently close down the flood roads and plan alternative routes for the ongoing traffic. This is especially important during evacuation of the city.

[Security] can receive information if the location is about to be inundated. This allows proreactions to protect the security systems from damage when the flood occurs.

Another domain of a smart city that is closely related to the smart water management is the [Energy] domain. As the sensors requires constant power supply to provide real-time constant monitoring, aligning the planning of sensors of the smart water management with the [Energy] infrastructure facilitates the operation of the sensors and help to eliminate the problem of power issues of the sensors. Similarly, the smart water sensors can share the same communication network system
of the [Energy] sensors, thus increasing the interoperability of the both systems and help towards fostering a data-sharing environment where all data is collected, channelled and transmitted to a centralize information system that is shared and utilized by all domains in the city.



Figure 70 Workflow Diagram for Smart City Connections

The cross-domains data sharing will be the first fundamental step in creating the ideal vision of smart water management with flood resilience principles. This will promote open data, not only between different domains, but also between public and private sectors and government and public (includes research institutes). With open data, standardizations and interoperability of the solutions and systems will have a higher chance to be realised.

5. Conclusion

In order to manage water more efficiently, the concept of flood resilience and smart water management are investigated and the available technologies and methodologies analysed and discussed. Flood resilience brought forth a new approach when dealing with floods. To reduce the risks of flooding in a sustainable manner, the most effective measures are the ones that can minimize the potential damage, rather than the traditional control and resistance measures. The focus when dealing with flooding is no longer focusing on the prevention of floods anymore, but rather on implementing systems on how to manage and mitigating the flood impacts.

Flood resilience present itself as an attractive solution for the managing of the present and future flood risks where they deal with uncertainties and offer more flexibility and opportunities in coping with flood than tradition measures. Flood resilience uses a combination of structural measure and non-structural measures to mitigate the flood impacts and damages. Although it is difficult to quantify the benefits of non-structural measures, there has been a successful case study that demonstrates the effectiveness of such measures in reducing flood damages and impacts:

- In Australia, it has shown that a city that is well prepared for flooding helped to reduced the flood damaged by 50%.
- In Japan, in a disaster drill, it has shown that citizens who were shown hazard maps evacuated one hour earlier than their counterparts who had not seen a map.

This shows that flood education and flood preparedness of a city is as important as structural measures in the mitigation of flood impacts.

In addition, the effectiveness of using a combination of flood resilience solutions was investigated through the use of a hydrological hydraulic model. The MOUSE model is to simulate the flood mitigation effectives of a combination of resilience measures like green roof, permeable pavements and underground storage tanks for a flood incident in Incheon Gyo catchment in South Korea. With the implementation of green roofs and green spaces, the maximum flood level reduced by 12% and it is expected to perform better in the future with better technology improvements in such solutions. In addition, solutions like implementing green spaces acts as buffer zones which help to decrease the flow velocity of the flood. This will help to reduce flood damage as research has shown that flood damages incurred decreases with flow velocity of the flood. In addition, this provides longer warning time for the city to react, which will also help mitigate the flood damages.

However, in order for flood resilience strategies to be effective, there should be up-to-date information of the city and its conditions like rainfall, water levels in rivers and seas, good communication systems for early warning systems and a centralized city system that integrate all the various components of the city. This is where Smart Water Management comes into the picture.

Smart Water Management combines existing water management techniques with cutting-edge ICT to enable more sustainable and efficient water management. One main component of the Smart Water Management is the implementation of the smart sensors where data is collected 24/7 and transmitted in real-time to a centralized control system. This requires a range of technologies from network communications to microelectronics to bid data management and analytics.

Analysis of the current trends of smart water implementations has indentified Open Data & Big Data Management, Water Management Information System and Smart Sensors Technology as major issues for the challenges and limitation for Smart Water Management. Case studies of successful implementation of Smart Water solutions validated such challenges and confirmed the requirements and expected changes to move towards smart water management include the ability to manage big data with the implementation of smart sensors and AMI; to ensure interoperability of the water system through consistency/uniqueness of description in SCADA/EAM/GIS; and to manage, analyse, and produce geospatial data and to perform highly developed analysis and visual production of geospatial data.

To provide the stakeholders on how advance the development and implementation of Smart Water technologies, an action plan is proposed for:

- Development of semantics tools to properly contextualize the business processes in the water domain: to ensure the specifications for interoperability and data sharing across services (water, energy, etc) and their infrastructures.
- Development of cross-domains data sharing (Water-Energy Nexus): to develop and provide Open Data interfaces and establishing Open Data policies so as to facilitate the data flow between the different domains
- **Development and support for pilot projects:** to establish best practices and guidelines on SWM implementation so as to promote adoption of SWM
- Development of performance benchmarking: to identify key performance metrics and indicators for SWG in order to develop benchmarking framework and assessment methodology
- Development of systems standards for cities and communities: to promote the established standards and best practices obtained from the pilot projects and their relevant experiences and research on operating and maintenance
- Development of Open Data initiative for free flow and easy access of data: to promote and accelerate the development on standards and ontologies on data
- Provide review analysis and guidelines for the ICT solutions and systems in SWG: to promote the established standards and best practices obtained from the pilot projects and their relevant experiences and research on operating and maintenance.

The thesis also proposed an overall framework of smart water management for urban city. It comprises of five layers:

- Sensing Devices Layer: is responsible for monitoring of the sensors. The communication between the sensors and their data loggers are usually in the area size of HANs and NANs. This allows the use of short range wireless communication network (Wi-Fi or Zigbee) or wired network (PLC).
- Sensing Adapters Layer: is responsible for the transmission of the observations from the sensors to the central system. The communication between the data loggers and the information systems are usually in the area size of FANs, IANs and WANs. This requires mid to long range communication network, although short range communication networks can be used with the implementation of repeaters.
- Data Layer: is responsible for storing and managing the large volume of data collected from the sensors. In addition, it serves as the standardization point where the data collected will be processed such that data will be standardized with other smart city sectors' data domains.
- Service Support Layer: is responsible for providing the functions of operation support, application security management, workflow management, data exchange and sharing, the RFID middleware, the GIS support platform, modelling and simulations of the water system as well as the visualization of the results and analysis reporting.
- Application Layer: is responsible for the decision-support systems where optimization decisions and management steps are taken from the analysis of the work done in the Service Support Layer. Examples includes intelligent regulation and optimization of water quality and quantity, efficiency dispatching of work service required and early warning of potential water shortages or overflow.

Within the services support layer of the smart water management framework is the urban water management models. They include water demand system and water supply system. For the water demand system, it is important to take into consideration of the water demand for environment. As for the water supply system, it is important to consider compartmentalize the modelling components of hydrological, overland hydraulic modelling and underground water modelling. This allows ease of interchanging any of the modelling modules to cater to the water utilities changing needs without overhauling the whole modelling system itself.

A leak detection indicator is proposed by computing the pressure gradient difference before and after the occurrence of the leak where the effectiveness of the indicator is validated through the use of a hydraulic model (EPANET 2). Future improvements can be achieved by redefining the DMA of the pipe system network into sub-DMAs where the pressure gradient indicator will be able to provide a more accurate analysis of the occurrence of the leak. Statistical models like Artificial Neural Networks can be trained with real data of scenarios of different network leakages to forecast the difference in pressure

between the normal and leakage scenario.

Lastly, it is imperative for smart water management be closely integrated with the other domains of a smart city for it to perform efficiently. This is in sync with the principles of flood resilience where it promotes integration of city and water management. Also, there is a need to rethink the idea of how they smart city connections should be. Instead of having the individual systems are compartmentalized and connected to a central system via its individual information system, the integration of the systems should begin all the way from the bottom, where sensing devices of all domains shared the same communication networks, and all the collected data are stored and processed in one centralized information system that is shared and utilized by all domains. One benefits of having such integration is the promoting open data, not only between different domains, but also between public and private sectors and government and public (includes research institutes). With open data, standardizations and interoperability of the solutions and systems will have a higher chance to be realised.

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