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RESILIENCE LEARNING FOR WATER SECTOR CULTURE CHANGE

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1 Introduction

Global threats such as climate change, population growth, and rapid urbanization are posing a significant challenge to water management in the UK (Butler et al., 2017). The approach to ‘carry on as normal’ will no longer be possible or acceptable and instead the water sector needs to create a reliable, sustainable and resilient water service. A resilient water sector is not just dependent on the development of new technology and equipment. People are an important and significant part of the water sector and are, therefore, integral to enhancing its resilience. A resilient workforce requires a range of properties, including people who are flexible, adaptable to new and unknown situations, transparent, effective communicators and strong team workers (White et al, 2013; Ofwat, 2017). Based on the resilience definition of Butler et al. (2017), the contribution to water sector resilience of the workforce can be defined as the degree to which people can minimise the level of service failure magnitude and duration of a water system when it is subject to exceptional conditions.

As definitions of resilience differ between disciplines—engineering (Butler et al., 2017) geography (Adger, 2000; Pelling, 2010), and business and management (Linnenluecke, 2015)—and the water sector is multidisciplinary, there is contrasting worldviews over, firstly, what is resilience, and secondly, how it can be implemented successfully in the water sector (Johannessen and Wamsler, 2017). Different components of the water sector, including the regulators, water service providers and professional institutes, as well as the people within these organisations, are at different stages of understanding and learning in their resilience journey. There is a regulatory requirement for the whole sector to be resilient, as well as the individual sections. In the UK, the Water Act 2014 places a duty on the water and wastewater sectors to “further the resilience objective”. It highlights a need for long-term planning of water, wastewater and service provisions under increasing global threats. Last year Ofwat released the ‘Resilience in the Round’ document (Ofwat, 2017) which stresses that resilience needs to be assessed holistically and go beyond the more traditional operational views of resilience to include financial, corporate and related natural environment, social systems, economy and other wider factors. A regime shift, similar to what is experienced in ecological systems, is required in the water sector to change its structure and function (Kemp et al., 1998).

This paper investigates barriers to creating a resilient water sector, focussing on the workforce. Firstly, it explores the definition of resilience and whether the workforce and customers are ready for a culture shift to create a more resilient sector. Secondly, it reports the threats that water companies are facing in making the shift to create a more resilient workforce. Thirdly, the resilience-building measures reported are mapped onto the Safe & SuRe framework (Butler et al. 2017), which enables interventions to be classified as either mitigation, adaptation, coping or learning and helps to illustrate how they act to minimise the consequences of any future threats (Figure 1). The paper concludes by summarising its wider contributions to knowledge, policy and practice.

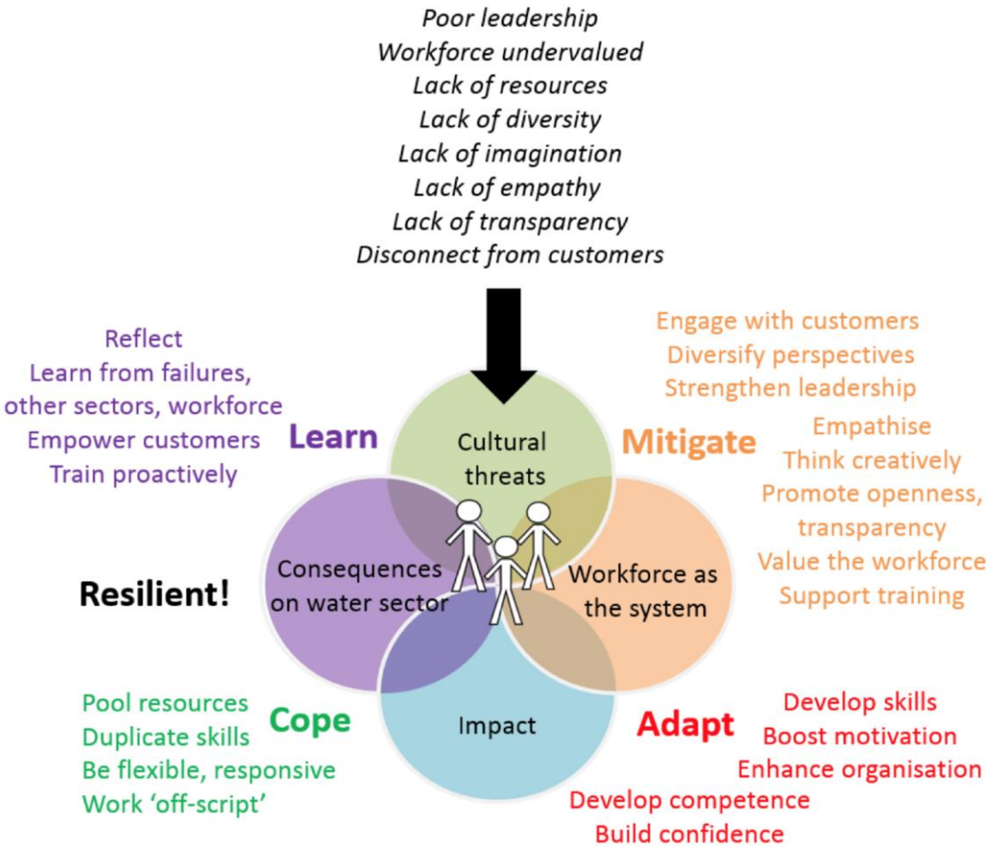

Figure 1: Mapping culture change-focused resilience interventions onto the Safe and SuRe framework

2 Methodology

This paper uses the Safe & SuRe framework (described in detail below) to map the resilience

learning for water sector culture change (Figure 1), from case studies which include five water companies, and the regulator Ofwat.

2.2 Case Studies

Water and sewerage companies: Semi-structured interviews were conducted with five water and sewerage companies (includes water and sewerage companies and water only companies). Four out of the five interviewees (i.e., company employees) were in director or managerial positions with more than 20 years of industry experience. To maintain confidentiality, interview participants whose quotes are presented in this paper are referred to as Water Company 1 to 5. Participants were asked to reflect on what resilience means to their business, how to implement culture change in their company, and to highlight some of the learning points including processes and metrics to develop a resilient workforce. Information gathered from the interviews were mapped onto the Safe & SuRe framework to assess the different approaches to engender learning and culture change across the water sector. Each interview lasted approximately one hour and was recorded and fully transcribed, providing a rich and extensive source of qualitative data

Ofwat: Since the late 1980s when the UK water sector was privatised, the Water Services Regulation Authority (Ofwat) has been responsible for overseeing the sector and setting price limits for water and sewerage services. Every five years Ofwat conducts a price review, and the next one is scheduled for 2019 (PR19). In preparation for this review Ofwat are exploring the operationalisation of resilience across the sector. This case study reflects on how the organisation is conducting this from the top down and the challenges of moving from risk management to resilience enhancement. In particular, we asked Ofwat if the definition of resilience was still evolving, what are the main cultural threats facing the water sector and to list any success stories in overcoming these threats. Understanding Ofwat's approach is important because it will influence how water companies themselves further the resilience objective.

2.3 Data Analysis

The first stage of data analysis involved careful reading of the interview transcripts followed by an iterative process of 'open coding' (Corbin and Strauss, 1990). We created nodes – combining segments of text reflecting similar wordings or activities – based on the Safe & SuRe Framework. Emergent themes within these nodes and across the five case study companies were then coded. In the final stage of data analysis axial coding was used to search for patterns and relationships within and between nodes and case study companies, as well as Ofwat (Strauss and Corbin, 1998).

2.4 The Safe & SuRe Interventions Framework

The Safe & SuRe interventions framework (Figure 1) provides a diagrammatic representation of the relationship between threats and their consequences, and enables opportunities for intervention to be identified in order to develop a more resilient system. The framework allows the role of and need for four types of intervention strategies – Mitigation, Adaptation, Coping, and Learning – to be determined. Combined use of these types of intervention enables water problems and challenges to be addressed in a holistic manner. The framework also provides a logical foundation for the analysis of reliability, resilience and sustainability, enabling greater consistency in assessment methodologies and methodical identification of opportunities for intervention. The four types of interventions used in the Safe & SuRe framework are defined in Table 1.

Table 1: Types of intervention in the Safe & SuRe framework

ıtervention	efinition
litigation	ny physical or non-physical action taken to reduce the frequency, magnitude or duration of a threat
daptation	ction taken to modify specific properties of the water system to enhance its capability to maintain levels of service under varying conditions
oping	ny preparation or action taken to reduce the frequency, magnitude or duration of an impact on a recipient
earning	mbedding experiences and new knowledge in best practice

Mitigation measures are typically long-term actions and must address a specific threat. For example, disengagement of customers is a potential threat to the water sector and may be mitigated by improvements in communication. Adaptation measures aim to reduce the level of service failures resulting from a given system failure mode, irrespective of the causal threat, and can be undertaken before, during or after the event. If the identified system failure mode is loss of knowledge, for example, a corresponding adaptation could be improved training and knowledge management. Coping measures address specific consequences and aim to reduce the vulnerability of the recipient to these. Purchase of insurance (a coping measure), for example, may be used to minimise financial losses (a potential consequence). Learning is necessary since the negative consequences of a threat cannot be eliminated entirely by mitigation, adaptation and coping measures. Unlike the other forms of intervention, it does not need to address a specific threat, system failure mode, impact or consequence. There are many approaches to learning and these can include learning from past events, developing pilot schemes to generate new knowledge for best practice and learning from others. Good data collection and effective communication strategies can also facilitate learning. In all cases, it is important that lessons are learnt from both good and bad practices.

3 RESULTS AND DISCUSSION

3.2 Resilience Definition

Before investigating resilience learning for water sector culture change, it is important to clarify how water and sewerage companies understand resilience. Of the five water companies interviewed, only two had a formal definition of ‘resilience’ that was closely aligned to the regulator Ofwat’s:

“Resilience is the ability to cope with, and recover from, disruption, and anticipate trends and variability in order to maintain services for people and protect the natural environment now and in the future.”

The remaining three water companies expressed that they were still exploring the meaning of resilience with respect to measurement and what it means to customers. Some of the informal working definitions and approaches to resilience included:

“If something goes wrong, the customers don’t even know that something has happened” (Water company Two)

“Cultural change is what we mean by resilience. Resilience is about people, process, recovery programmes” (Water Company Three).

The companies that are embedding and tweaking the Ofwat definition could be viewed as being more innovative. They are taking their time to reflect on how this definition needs to be adjusted to their company and environment. Ofwat stated that the definition of resilience is still evolving, with resilience being a journey. Although the current definition is not perfect, Ofwat will keep this for the near future while water companies complete the current periodic review. When Ofwat was asked if water companies should follow their resilience definition, they stated that there must be flexibility in the definition but there needs to be an audit trail to see the justification.

In a similar vein to previous research, there are many stakeholders and factors that shape the development of a resilient company. When asked to describe the main features of a resilient company, most interviewees described the process as holistic, incorporating all aspects of the company, including assets, infrastructure, customers, workforce, innovation, skills, technology, and effective data management. However, whilst firms recognised the importance of reflecting on all aspects of the company, they highlighted the difficulty in effectively balancing all aspects together and the significant economic cost in successfully achieving that. One company also highlighted the difficulties of joining all the aspects of resilience together and thinking about how they may depend on each other:

"The many aspects of resilience need to be joined with a focus on their interdependencies, the elements need to work smartly together with the customers at the centre" (Water Company Three).

Both Ofwat and the water companies state that the customers are at the heart of the resilience agenda. Customers need to recognise the importance and therefore the significance of resilience, which ultimately means they need to be brought into the conversation and the resilience journey. By engaging and integrating customers into the process, water companies are able to both learn and enhance its resilience, since customers become more aware of their actions and take responsibility, changing their water use behaviour which in turn contributes to the firm's behaviour.

3.3 Resilience culture change: are the customers and workforce ready?

Customers: The enhanced customer engagement by water companies in England and Wales over the past few years has been suggested to be a way to break the established dynamic between the regulators and the water companies (Heims and Lodge, 2016). The perception was that the price reviews were not stretching companies to be innovative enough. A review of Ofwat practices (Gray, 2011) highlighted the need for companies to take ownership of their decisions; customer engagement was seen by Ofwat as a way of providing a different type of challenge and for companies to reflect their customer views in their business plans (Heims and Lodge, 2016). Water companies have appeared to have listened to this request, with customers very much in the centre of resilience (as highlighted above). However, engaging customers into the resilience agenda is hard. Building resilience costs money; therefore, water bills will increase:

"Customer expectations need to be within the limitations of budget, with tension between affordability and satisfaction" (Water company One).

Businesses in general have changed their organisational structures to be more responsive to customer needs (Homburg et al, 2000; Plouffe et al 2016). Water companies need to manage customer expectations by effectively bringing them on the resilience journey. It was highlighted by one water company (Water company One) that they feel they are being compared to other companies that are built on the customer with a high level of service such as Amazon and John Lewis. Although the level of service provided to customers by their water company has stayed the same for many decades, customer expectations have increased, with the expectation that the company will be on call 24/7.

Workforce: A resilient company should switch from being reactive to proactive. Daily tasks will be focussed on preventative measures rather than on coping and 'firefighting'. However, this organisational change needs to have to have the support from the employees (Andrew and Mohankumar, 2017). One water company (Water Company Five) highlighted that many of the workforce, specifically the operational teams, enjoy the problem-solving aspect of incidents. It is an exciting aspect of the role where they are often seen as heroes. Re-connecting a community with a water supply after an interruption brings praise and a sense of accomplishment, along with the adrenalin rush in fixing the problem. However, a resilient organisation wants to reduce the number of incidents with job descriptions to focus on more routine tasks:

"Water companies need to make staff feel passionate and rewarded by doing the routine work very well instead of fixing a major problem". (Water Company Five)

3.4 The Safe & SuRe: Threats and Interventions

This section is split into two parts. The first will highlight the main cultural threats mentioned by the interviewed water companies. This includes weak leadership, resources, geography (rural communities) and changing staff profile. The second section will categorise the different types of resilience learning that are used by the water companies with the Safe & SuRe interventions; mitigate, adapt, cope and learn.

3.4.1 Threats and failure modes for resilience learning for water sector culture change

Leadership: Leadership was highlighted by two of the water companies as being essential to the attainment of resilience (Water company Two and Water Company Five). Leadership was even classed as "The biggest cultural threat" by one water company (Water Company Five). Leadership is important as it gives the company and workforce direction:

"Everything comes down leadership. If there is poor leadership then sub-factions will build up and the workforce will lose direction." (Water company Two).

This finding mirrors work by Hunt and Auster (1990), Berry and Rondinelli (1998), and Gonźalez-Benito and Gonźalez-Benito (2006) on managerial attitudes to environmental management. Whereby, support and commitment from top management is a key element of the implementation and success of proactive organisational behaviour.

Resources: The theme of resources came out in this study, in relation to people, power and technology. Automation is becoming increasingly ubiquitous in companies (Lee and See, 2004); with the water sector being no exception. As technology has improved, water companies have become more efficient, and staff numbers have reduced. One company interviewed gave an example of having nearly half the staff they had 15 years ago (Water Company Four). There are positives to the automation of water systems including the reduction of human error and increased efficiency (Mahalik and Nambiar, 2010), but when technology fails it can cause significant problems. Two water companies (Water Company Four & Water company Two) and Ofwat stated they were concerned that the workforce could be out of practice of doing things manually or lack the capacity:

"Although technology increases automation and efficiency it must reduce the flexibility of the company, with less capacity to absorb change in the short term" (Water Company Four).

"If all mobile phones/mobile masts go down – would many companies know how to operate their network?" (Ofwat)

This study found that as water companies are planning for their long-term strategy there are decisions over either creating highly automatic and independent sites which requires highly skilled people to conduct maintenance or creating very simple systems which are easy for most people (e.g. firefighters) to operate. Ofwat notes that if things do change with robotics and Artificial Intelligence, will water companies be ready to deal with it, with suggestions that the water sector is not as dynamic as other sectors and could lose out if they are not ready.

Geography (rural communities): When a water company covers a rural area, it can make operations more difficult in terms of site access and in raising awareness through the company. Rural areas in the UK are more challenging for communication with poor internet access and mobile signal (Townsend et al, 2015). Road networks are also not as extensive as compared to urban areas which can impact physical access especially during poor weather.

"It is easier to drive awareness in a densely populated area compared to a geographically dispersed company" (Water company One).

One water company noted that when covering a large area, there may be cultural differences between the workforce which can make communication and cohesion more difficult:

"People in different parts of the company may think differently if they live in different areas; this can make it feel like separate entities" (Water Company Five).

Changing staff profile: Traditionally, people would get a job for life, with little movement between companies during a career (Grigg, 2006). However, today the workforce is more transient with it being common for people to move between companies. There is more flexibility in the job market and the hooks for staying with one company are not as strong as they were in the past. The younger generation are more flexible and not interested in doing the same job, in the same way, everyday (Lave et al 2007). This means the younger generation are less likely to stay with one company for their whole career. This study found there was some debate within water companies over the types of 'hooks' to keep staff employed in companies. Should there be incentives to keep employers, or do water companies need to accept this is the new culture. The negatives of a transient workforce and the retirement of the long term employees is the loss of institutional knowledge (Grigg, 2006). There are real advantages of having staff with a long duration of service, mainly due to their experience and understanding of the company which can be passed onto the workforce:

"A water company does not work from a script, it takes time and experience to be competent" (Water Company Three and Water Company Two).

However, there are negatives of having an older workforce which has been suggested to include a lack of flexibility, reluctance to learn new skills or finding it more difficult and resistant to new technology (Johnson et al, 2007). These characteristics are important in creating a resilient and innovative company and therefore refreshing the workforce can be positive if there is retention of knowledge within the company.

3.4.2 Interventions to resilience learning for water sector culture change: Mitigation, Adaptation, Coping & Learning

This section will now categorise the different types of resilience learning used by the water companies with the Safe & SuRe interventions; mitigate, adapt, cope and learn:

Mitigation interventions in resilience learning for water sector culture change

Communicate and engage with customers: All water companies interviewed said that customers are at the heart of resilience. In particular, they expressed the importance of engaging with customers in order to understand what they perceive to be a resilient company and how this can be achieved:

"Understanding is very important and it comes from engagement, active listening and communication" (Water Company Three).

Firms employ a range of activities (e.g., focus groups, workshops) to communicate with customers to manage expectations. One company (Water Company Three), for example, conducts customer communication groups which can include talking to people on the street, workshops and focus groups to understand what the customers think of risk and resilience. Engaging with customers not only informs companies about perceptions on their social performance (i.e. whether they are a good corporate citizen in customers eyes), but it also increases the likelihood that customers and other stakeholders (e.g. regulator) will support investment and changes. Through engagement, customers develop a sense of ownership for the process, and thus want to see it be successful (Jaakkola and Alexander, 2014).

Communication and engagement with customers can be considered a mitigation measure as it aims to minimise the effects of disengaged customers (a potential threat) on the operation of water companies. However, it can also be a form of adaptation (e.g. when developing a sense of ownership) and also contributes to learning in the water sector.

Adaptation interventions in resilience learning for water sector culture change

Communicate and engage with workforce: Effective communication and engagement increases understanding and willingness to work effectively and accept any new policies or changes in a company. This can help to minimise the effects that any disturbances in the workforce system have on the level of service that they provide and is considered an adaptation rather than a mitigation measure as it does not tackle the root cause (i.e. threat) that results in the workforce disturbances. Water company four noted that clear communication and a strong vision was especially important when the company covers a large geographic area:

"A strong corporate vision can be especially important when a water company is covering a large area" (Water Company Four).

Technology has assisted to make communication easier with mobile phones, email and internal social networking tools such as Yammer within organisations. However, one water company (Water Company Three) highlighted that the employees still need to engage with the communications if they are to be effective in mitigating threats: for example, the workforce needs to actually read the relevant emails. Sometimes stronger levels of engagement are required, including workshops and meetings, but these take time and costs more money.

Two water companies (Water Company Four and Water Company Two) found that creating space and time for the workforce to mix can be powerful, especially when events are cross-department. They can also be helpful in breaking down barriers between the workforce and senior leaders – creating space for conversation and feedback.

"Water companies are divided with those out in the field and those in offices – getting everyone to mix during staff events is important" (Water Company Two).

Diversify perspectives; In today's society, diversity can be defined to include culture, gender, nationality, sexual orientation, physical abilities, social class, religion, socioeconomic status and age (Allen, 1995, Sadri and Tran, 2002). There has been considerable emphasis in companies to facilitate diversity, although the evidence to demonstrate the positives of having a diverse workforce is difficult to define and evaluate, it has been suggested that a diverse workforce will improve productivity, creativity and resilience (Armstrong et al, 2010; Kilian et al, 2005). Companies are seeing the need to have a workforce that reflects today's society and to gain the best available talent in the context of the workforce demographic trends (Prieto et al, 2009). Findings from this study have suggested that adaptation of the workforce to obtain a diversity of ages could help to minimise the loss of institutional knowledge as long standing employees begin to retire (as described above). However, to encourage young people, and to include those from a range of backgrounds, there needs to be career routes that are accessible and possible for everyone. Ofwat highlighted the return of apprenticeship schemes to water companies as being a success story to improving workforce resilience:

"It is rewarding to see apprenticeship schemes being available in water companies." (Ofwat)

"There are many roles in water companies that do not require a degree and these people need to be supported, for example through apprenticeships" (Water Company Three).

It was highlighted that workforce diversity needs to be throughout the company and more responsibility needs to be given to the younger workforce, which may encourage them to stay in the company:

"Diversity needs to be encouraged at all levels in the company" (Water Company Three).

Strengthen leadership: Investment in the managers and leaders with training programmes is important, as strong leadership can minimise the impact of many cultural challenges within a workforce. This study found that a strong leader includes someone with a strong vision, visible throughout the company, and someone who is a good communicator. One water company highlighted the need to spot the 'rising stars' and to encourage and train these employees into the leaders of the future:

"These are the employees that are supported and encouraged to stay in the company, with investment to develop their skills, train them to think outside of the box and teach them to work off-script" (Water Company Three).

Ofwat said that cultural threats are difficult to overcome without good leadership:

"Leadership inside the company should be able to spot the cultural threats- and put the management time and leadership into place- so the [company] is on its front foot" (Ofwat)

Although leadership is seen to be important, one water company highlighted that it is very difficult to measure and define good leadership:

"Very nebulous – almost like being a good parent – leadership is very important but how do you measure and define it? It is a journey" (Water Company Two).

In many sectors, it is normal for leadership training not to be monitored or measured, this is unlike other capital investments where the financial return on investment is important to consider (Avolio et al, 2010). It could be argued that without evaluation, it is more difficult for leadership training to be improved and could prevent the development of strong future leaders.

Improve knowledge management; Knowledge management has been an essential part of business since the nineties with the development of computers (Donate and de Pablo, 2015). Successful knowledge management is based on improving efficiency, processes, innovation and increasing productivity and quality (Nguyen & Mohamed, 2011). All of the water companies interviewed and Ofwat highlighted the importance of codifying knowledge as a way to adapt and be resilient to a workforce which is becoming more transient in nature, with an increased effort to manage out the single person dependencies:

“Avoid single points of failure in people, with people moving across the business so they have a broad knowledge across the business” (Water company One).

“Retention of knowledge of what a pipe or bit of equipment was designed to do and how it works needs to be available for a long period of time” (Water Company Five).

“Bright people are coming into water sector but they have a gap in experience. So many water networks have not been digitised – and a lot of knowledge is lost as people retire. The information can’t just be put in a report as most reports are put on a shelf and are difficult to access” (Ofwat)

Decision support systems have become essential in many businesses as they can be used to support complex decision making and problem solving (Shim et al, 2002). One water company (Water Company Four) has introduced a new decision support tool to assist with knowledge management. This builds resilience as decisions are based on something that can be measured and documented.

Provide well trained and experienced staff: Training and development for the workforce has a positive impact on the individual employer and team performance, while also improving the economic prosperity of the company (Aguinis and Kraiger, 2009). The investment in training and development of staff is essential for the workforce to gain new skills, improve job performance and develop emotive skills (Hill and Lent 2006, Satterfield and Hughes 2007). In this study, the water companies listed a range of courses and development programmes that are used to help to develop their workforce skills. It was also noted by one water company (Water Company Three) that there should be flexibility in the business structures to enable young people to develop as individuals and help them understand and use their strengths through experience and training, while improving their weaknesses, which will ultimately increase the resilience of the workforce. Ofwat highlighted that it was good to see coaching and mentoring being used in water companies, not just as a tick box exercise but because they generally believed it helped the workforce.

It is important that training is available and accessible to employees but it is also important that the benefits are documented (Aguinis and Kraiger, 2009). This is recognised by water companies but there were also questions on how this is possible with emotive skills:

“Training and skills should be monitored to enable management to build up a larger picture of the technical skills within the company” (Water Company Five).

“How to measure empathy? Very subjective” (Water Company Two).

Two water companies (Water Company two and Water Company five) highlighted that the development of technical skills shouldn’t be forgotten, with discussion of emotive and engagement skills, as it is difficult to find staff with the right technical skills. Ofwat also referred to the EU Skills Group Annual Review (2017) and noted that the water sector needs to be competitive to get the right people with the right skills.

“It is easier to employ staff with good social skills than someone with the right technical skills” (Water Company Two).

Coping interventions in resilience learning for water sector culture change

Utilise good will: To an extent a company’s long-term success is built upon the employee’s contributions, with the employer-employee goodwill being essential to commercial success (Roslender and Dyson, 1992). This study has found that the “can do, will do” culture in water companies is very powerful. All the companies interviewed stated that when things go wrong, the workforce are good at responding, with the Operation teams in water companies being highlighted as very committed people:

“It is personal for the workforce, and when there is an incident, it is taken seriously with a sense of pride and responsibility” (Water Company Three).

Engaged employees are crucial to the success of a company, bringing motivation, ideas and willingness to go the “extra mile” (Moreira, 2013). Results found that engagement is important during an incident in helping the water company cope and reduce the consequences on a water system. However, many of the water companies interviewed noted that the top management can take advantage of this 'good will'. During the interview with Ofwat, they discussed the willingness of employees to help during incidents, for example employees might expect to stay up two nights in a row, twice a year. However, employees will not want to stay up two nights in a row once a month. Ofwat continued to state that this leads to the wider resilience question, of how often is the company exposed to having to deal with response and recovery. Companies need to have a resilient infrastructure that can deal with shocks without going into mode of incident operation.

In response to managing 'good will', many of the water companies interviewed are attempting to formalise the structure to reduce the dependence on certain members of the workforce. For example, starting an Emergency Volunteer List in which employees can sign up and training is given to support various tasks and functions which may occur during an incident.

Ensure flexibility: Findings have suggested that an organisation cannot be agile without the existence of an agile workforce (Sherehiy et al, 2007). The ability of a workforce to work 'off script' and be flexible has been highlighted by the water companies in this study to be an important coping mechanism. When an incident occurs the workforce needs to be resourceful to minimise impact. Having well trained and experienced staff that are flexible and personally committed to what they are doing is essential in dealing with an incident. A limitless amount of effort can be put into building resilience but when something totally unexpected happens, the workforce needs to be prepared to cope:

"Having procedural approaches to resilience is fanciful as all droughts and floods are never the same" (Water company Two).

The water companies also highlighted that the impact of an incident is as much dependent on society as the actual event. Society changes through time, and coping methods used during a drought in the 1970s would be very different from those used today. This highlights the importance of bringing the customer on the resilience journey.

Learning interventions in resilience learning for water sector culture change

Produce failure/learning reports: All of the water companies interviewed conducted some type of learning or failure report after an incident but none of the companies stated that their companies were good at learning:

“Failure still has the old-fashioned understanding. [The water sector] is in contrast to the aviation industry which has a no blame policy. Although failure is natural it goes against human nature, we want to succeed” (Water company Two).

It was highlighted that sometimes it’s difficult to do root cause analysis if blame is held on to. An hypothetical example was given:

“if it’s cold (freezing) and a pipe bursts then this is held on to instead of investigating further” (Water Company Five).

Findings from this study suggest that the water sector could improve their learning by looking more outward to other sectors and to other countries. This study did find a success story in the water sector where learnings and case studies are shared across the Health and Safety departments who meet every quarter. This transparent and open approach could be expanded to other departments in the water companies.

Embed learning:

“Embedding findings can be difficult” (Water Company Five).

Water companies in this study noted that they are usually good at finding and fixing, but less good at making the lessons stick. Problems can come around again and people revert to type and forget. The size of the company can impact their ability to make changes from learning reports, one company stated,

“Having a large organisation makes it more difficult to embed changes if there is no one monitoring” (Water company One).

One water company built up a library of historic incidents, which highlighted the number of near miss events. This helped them to think holistically and on a long-time scale. The immediate response after an incident is to invest to prevent the incident from happening again but this may be a knee jerk reaction:

“[Recent incidents can] skew resilience more than it ought – you need to take a step back and assess the probability of it happening again compared to other risks and threats” (Water Company Four).

4 CONCLUSIONS

People are fundamental in creating any paradigm or regime shift. However, people are complex, with different histories and drivers, making it difficult to implement culture change. This paper explores the challenges, opportunities and learning points from the top down (Ofwat) and bottom up (water and sewerage companies) to explore the shift in creating a resilient workforce culture. Findings suggest that resilience is a journey, it needs to be holistic and both the customers and workforce need to be on board for it to work. The main threats and failure modes for resilience learning in the water sector were highlighted as leadership, resources, geography (rural communities) and the changing staff profile. The Safe and SuRe framework worked a powerful toolkit to raise awareness of the need to tailor approaches to engender learning and culture change across the water sector. Mitigation methods included communication and engagement with customers. Adaptation methods included engagement with workforce, diversification of workforce to ensure that the workforce is a reflection of society, strong leadership, importance of knowledge management and the provision of well trained and experienced staff. Coping interventions included the employee's good will and flexibility in the workforce. While, learning interventions included the production of learning and failure reports as well as the importance of embedding learning.

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Water network resilience assessment: internal and external costs valuation for a cost benefit analysis

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Keywords: Resilience; cost benefit analysis; water networks, accountancy, consumer’s prefrences

Context of the water utilities

Water utilities are increasingly interested in the issue of the security of water supply, both in terms of quantity and of quality. They mainly consider two threats: climate change on the one hand and extreme events such as draught, flooding or intentional acts (i.e. explosion, contamination) on the other hand.

Early warning in the event of a big pipe burst or a contamination and real time monitoring are similarly developing at bid spread in bigger utilities with the pending question of their costs and their benefits in terms of performance and security. The issue of crisis management is also predominant.

Resilience assessment has developed since the 11th September 2001 events. EPA and USEPA have conducted studies on risk and crisis analysis (Cincinnati) and in Europe several projects dealt with the question of security around the subject of hydraulic simulation and sensor placement and risk analysis considering several contaminants (SECUREAU, SMART on-line WDN). The on-going franco-german project RESIWATER also focuses on these issues. The article presents the first results of a cost-benefit analysis of resilience scenarios of the water production and distribution system for different events.

Objectives of Resiwater project

Within RESIWATER (www.resiwater.eu), we are looking at the resilience of the water production and distribution system for three types of extreme events: (i) the physical breakdown of one part of the network or of the production infrastructures in case of intentional or natural events such as an explosion, a flood or an earthquake, (ii) an intentional contamination or accidental water pollution and (iii) cascade effects such as power disruption or cyber-attack involving water distribution disruption. These case studies are applied in 3 Utilities, one in Germany and two in France.

Cost benefit analysis CBA as a resilience scenario decision tool

In our approach we will compare the pro and cons of a specific resilience scenario, ie a cyber-attack, on Strasbourg Eurometropole network.

CBA is an appropriate tool since it allows comparing the strengths and weaknesses of several hypothetic scenarios to the ones of a reference scenario.

In our case, the reference situation is currently the way a crisis is (or would be) tackled and managed by a given Utility. The two resilience scenarios are (i) one that allows the Utility to achieve a quick recovery of the water supply and/or distribution (ie to quickly reach its performance level) and (ii) one with a lower recovery phase, but that may be more sustainable since this gives time to develop and implement a new project (for instance with new technical and localization focuses).

CBA relies on valuation of costs and benefits of hypothetical scenarios, with respect to the reference one. All these costs and benefits are expressed in monetary terms. The time horizon is a crucial issue here since costs and benefits of the different scenarios have to be compared on a common temporal footing; a discount rate is then applied.

We distinguish internal or direct costs for the utility (i.e. costs that are “inside the system”) and external or social costs (i.e. externalities that are defined as uncompensated (positive or negative) side effects of an economic action (Baumol and Oates, 1975) and affect consumers.

To the best of our knowledge, CBA has to date never been used to help decision making regarding water supply infrastructure resilience scenarios. Our work tries to fill this gap and relates to researches on risk analysis using CBA (Hutton et al., 2007)

Internal/direct costs refer to the expenses of the Utility (materials, labour, power, etc.) attributed to the implementation of a program or a policy. As the operating budget of the water Utility is independent, its revenues come from the water bill. They will be assessed within an accountancy full costing methodology looking at the four step of resilience scale time: prevention, crisis management recovery and as well as new post crisis measures.Within the ResiWater project, the full costing methodology (Brown et al., 2007) was experimented on several crisis cases (big burst, water contamination, water production pollution) (Werey et al., 2017).

In order to assess the benefits for users, an internet-based survey on domestic users is underway aiming at assessing their preferences and measuring their Willingness-to-Pay (WTP), i.e. the largest sum of money users are agreeable to pay for the resilience measures expressed as an additional charge on the water bill. This survey relies on the Choice Experiment (CE) method (Louviere et al., 2000). As such, this method allows eliciting WTP for attributes used to describe each option into the choice sets but also reveals the trade-offs between the attributes. We alreadyexperimented this method for sewer networks failures impacts (Rulleau et al., 2017)

Expected results and conclusion

At the end, all costs (internal/direct and external/social costs) and benefits (internal or external/social benefits) of “Resilience +” and “Resilience ++” during the timeline of the programs will be fed into the CBA. In other words, the prevention phase, the crisis management and the post-cyber-attack recovery were all included in the assessment. Analytically, costs and benefits of the two resilience programs will be compared to the costs and benefits provided by the BAU situation. Expected results might show that users react differently depending on the proposed resilience program characteristics, its timeline and/or its relied cost.

To the knowledge of the authors, CBA has to date never been used to the issue of the resilience of the water production and distribution system to extreme events. Our work tries to fill this gap and connects to researches on risk analysis in the water Utility sector using CBA (e.g. Hutton et al., 2007). More precisely, we use a structured and quantitative method to determine the worth of “Resilience +” and “Resilience ++” relative to the BAU (i.e. the current) situation and *which option is* most economically efficient. Thus, by providing an accurate internal cost valuation and information regarding consumers' preferences and WTP, we offer new insights for informed judgement and decision-making.

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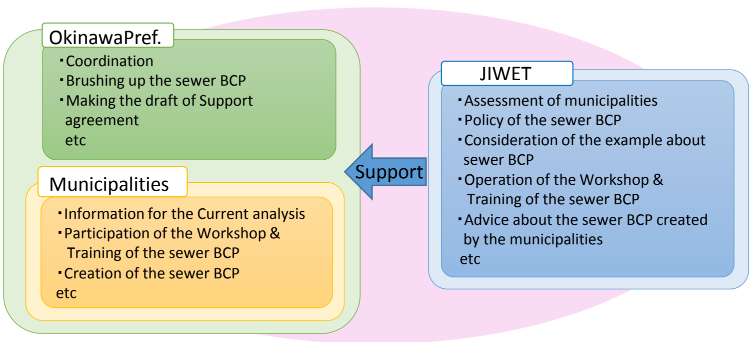
Support on Formulating Sewage BCP and Training for Small and Medium Local Public Organizations

Manato Yamaguchi, Nobuyuki Tanabe, Tsutomu Uchida

1 Introduction

Sewage BCP aims to maintain and recover sewage functions rapidly and to a high level under the constraints of resources (such as people, goods [equipment, fuel, etc.], information, lifelines, etc.) in the event of a large-scale disaster. Japan is one of the world's most earthquake-prone countries, and sewage BCPs are actively being formulated in order to improve the disaster resistance capabilities of sewage systems. The Japan Institute of Wastewater Engineering and Technology (JIWET) conducts survey research on disaster countermeasures at sewage facilities, and provides support on formulating sewage BCPs and training for small and medium local public organizations. JIWET provides support on formulating sewage BCP and training for small and medium local public organizations. This paper reports on the case of Okinawa Prefecture. The characteristics of Okinawa Prefecture can be stated as "damage from tsunamis is likely," "it is an island region," and "external support is likely to be slow," making it a microcosm of the island nation of Japan. In this paper, based on knowledge gained from supporting the formulation of sewage BCPs for Okinawa Prefecture and municipalities in the prefecture, we report on methods for efficiently formulating highly effective municipality sewage BCPs that take into account factors such as geographical characteristics.



2 Implementation structure and implementation flow

Implementation structure is illustrated in Figure 1, and implementation flow in Figure 2. Participants were Okinawa Prefecture, municipalities in the prefecture, and JIWET. Respective roles included the following. Okinawa Prefecture coordinated the municipalities, the municipalities formulated sewage BCPs, and we held study sessions on sewage BCPs, created templates for sewage BCPs, and advised the municipalities. Through a workshop, municipalities studied and discussed basic policy and so on regarding sewage BCPs. In the study group, we presented lectures concerning our knowledge of sewage BCPs (disaster support activities, etc.) to municipalities

3 Results of Research

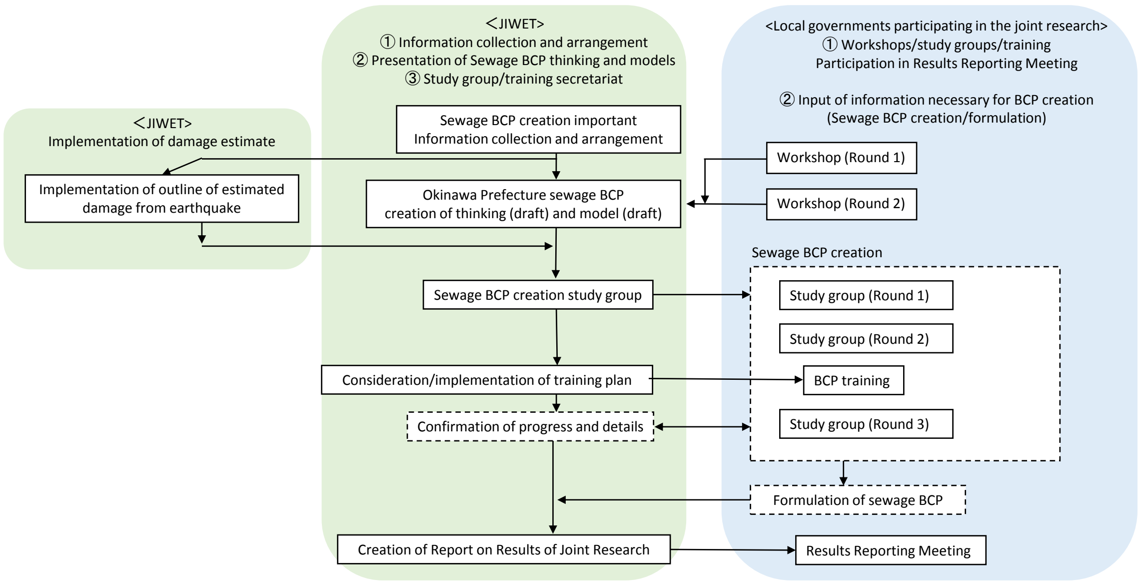


Figure 2. Implementation flow

3.1 Formulating sewage BCP

With the aims of sewage BCP formulation and a smoother "spiral up" process in local governments in Okinawa Prefecture, in addition to basic matters concerning sewage BCPs, we prepared topics such as "Proper form of sewage BCP and earthquake/tsunami countermeasures" and "Thinking on Okinawa Prefecture sewage BCP creation." The main content is summarized below.

3.1.1 Proper form of sewage BCP and earthquake/tsunami countermeasures

(1) Basic policy

We showed the following as basic policy on sewage BCP and earthquake/tsunami countermeasures in Okinawa Prefecture from now on.

- Sewage BCP formulation that can be begun soon shall be the highest priority measure.
- Earthquake resistance of facilities with safety, health, and/or evacuation functions (treatment plant management buildings, etc.) shall be a priority matter.

- The making of facilities earthquake/tsunami resistant shall be prioritized according to their functions and implemented step-by-step. Along with that, in facilities where function would become inadequate, function shall be supplemented through disaster mitigation measures.

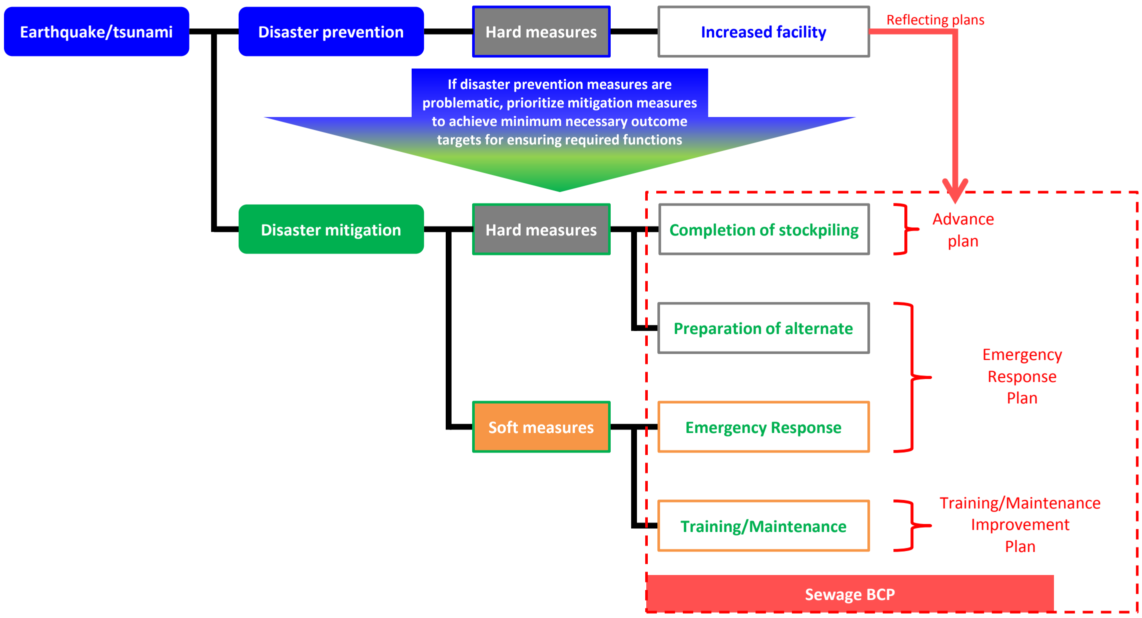


Figure 3. Sewage BCP and earthquake/tsunami countermeasures structure

(2) How to proceed with disaster prevention measures

In accordance with priorities for required functions, perform step-by-step: seismic inspection, earthquake/tsunami resistance retrofitting design, earthquake/tsunami resistance retrofitting construction. Work on increasing facility longevity and increasing earthquake/tsunami resistance may be performed simultaneously at a location in consideration of improving efficiency. Until earthquake/tsunami resistance is accomplished, supplement function with disaster mitigation measures.

(3) How to proceed with disaster mitigation measures

As a disaster mitigation measure, first formulate a sewage BCP based on existing resources. Based on annual updating of the sewage BCP, according with the improvement of hard and soft measures, work step-by-step to reduce the allowable downtime for overall sewage treatment function and aim for early service restoration following a disaster.

The Mid-term Business Plan, which can be called an upper-level plan of the long-term restoration plan, describes the major points of performing life extension of the facility and working toward normalization of the restoration and renewal cost as "measures towards deterioration of facilities".

3.1.2 Okinawa Prefecture Thinking on sewage BCP

(1) Sewage BCP formulation policy

In Okinawa Prefecture, the estimates are 25 for seismic motion and 16 for tsunami damage. The earthquakes/tsunami covered in a sewage BCP should be the most damaging earthquake covered in the regional disaster prevention plan, etc., with which it should align. In areas where tsunami damage to sewage facilities is expected, create emergency action plan covering both cases ① when there is no tsunami damage and ② when there is tsunami damage. ① For the case when there is no tsunami damage, create a plan assuming maximum earthquake damage as described above. ② For the case when there is tsunami damage, out of the tsunami in the regional disaster prevention plan and the all-agency BCP, etc., assume the tsunami having maximum effect.

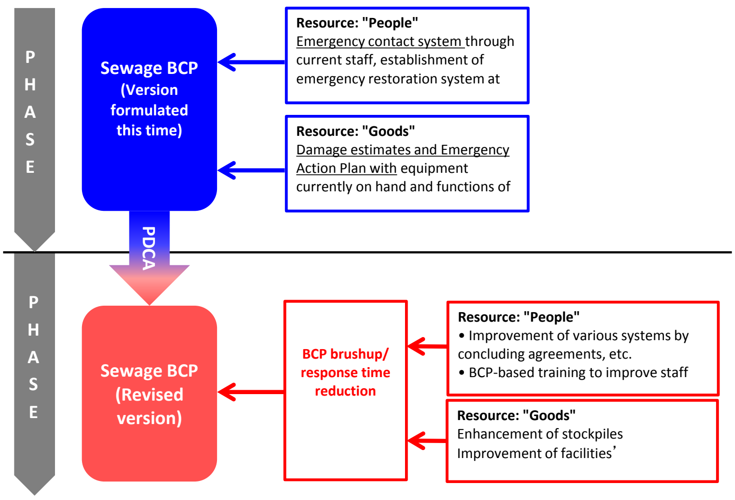


Figure 4. Illustration of sewage BCP improvement

However, because earthquake damage from a fault displacement that causes a tsunami is not currently shown, in the case of a local government where damage from an earthquake accompanying fault displacement is projected to be light, "Consider only tsunami damage to facilities, etc.," and in the case of a local government where damage from an earthquake is projected to be heavy, "Combine maximum damage to facilities, etc., from an earthquake and a tsunami." As for tsunami arrival times, assume the shortest possible time and use that in evacuation plans, etc.

(2) Arrangement towards emergency response plan

Emergency response plans are created in the following order: I Selection of priority work during emergencies, II Deciding of response target time, III Compilation of emergency response plan.

I Selection of priority work during emergencies

As for priority work during emergencies in the case of sewage, which is an important lifeline supporting urban functions, the goals set are ensuring safety, ensuring public health/preserving the living environment, and preserving water quality in public water. Thinking on priority work during emergencies is shown in Table 1. When setting priority work during emergencies, it is necessary to constantly consider and feed back "allowable downtime" and "response target time" into the decision. Within the priority work during emergencies, disaster response work required at the time of a disaster should be performed even if it is difficult to do alone and outside support is necessary. Because there will be information exchanged concerning the status of the work situation, add the collection of information about the work as priority work during emergencies.

Table 1. Thinking on priority work during emergencies

Sewage function to be protected	Work to maintain function	Priority level	Estimated timing of implementation (Without tsunami: reference)
Ensuring safety	· Establishment of command and coordination/information gathering structure · Collection and transmission of information on the state of damage (Transmission to residents is through the municipality and the headquarters of disaster control for sewage)	A	Within 1 day
Ensuring public health Preserving the living environment	· Emergency inspection, surveys, and measures on pipelines (important main lines) and treatment plants/pumping stations	B	Within 3-7 days
	· Primary inspection and urgent restoration (commencement of work) of treatment plants/pumping stations	C	
Recovery of sewage function	· Emergency restoration	D	Within 25 days (Considering water supply restoration, etc.)

II Deciding of response target time

In the deciding of response target time, for each derived priority work during emergencies, consider the social impact and set the allowable downtime while considering resources constraints and set the response target time.

Grasp of allowable downtime

In the case of tsunami damage, allowable downtime conceivably may differ depending on the state of damage and when the tsunami warning was lifted. Because it is difficult to set that in advance, a case study of thinking at that time was prepared.

- Set the approximate time of sewage function (emergency restoration) with reference to the time of water supply restoration
- Judging by the case of the Great East Japan Earthquake, lifting of the tsunami warning will come a day later, so set allowable downtime starting then
- Allowable downtime is taken to be the same regardless of the presence or absence of a tsunami. If response target time would be exceeded by a large margin, deal with it by taking advance measures

Deciding of response target time

Policy on deciding response target time is summarized below.

- Perform advance measures to the extent possible and decide "response target time."
- Of disaster response work, consider that work that begins with the arrival of support teams (generally on the second day) can be completed by assembled staff and the support teams within the allowable downtime. In other words, the amount of a resource projected to be short after the arrival of the support team is taken as the amount requested at the time of request for support.
- Assembling of staff when there is tsunami damage (disaster occurs at night or on a holiday) ordinarily begins when the tsunami warning is lifted. Individual local governments may make changes in accordance with their situations.
- "Response target time" must be decided as an actually possible response time, so reality is to be faced when setting an appropriate time.

- When there are only a few staff members concerned with sewage, things that can be handled by the assembled staff and things that can only be handled after support arrives must be appropriately distinguished.

III Compilation of emergency response plan

Along with showing priority work during emergencies and response target time in the compilation of an emergency response plan, the following matters are to discussed in advance in municipalities and sewage departments.

- Consideration of the personnel and timing prioritizing sewage response
- Response to sewage overflow areas
- Priority in pipe investigation
- Consideration of policy on treatment plant/pump station restoration
- Policy on responding to mass media, etc.
- Policy on responding to requests and complaints from residents

(3) Plan compilation towards spiral-up

After creation of an emergency response plan, it is essential to verify its feasibility. To accomplish this, it is possible to work to improve ability to execute the plan by considering and partially implementing safety confirmation training, creation of manuals for each item of priority work during emergencies, and so on based on the plan. Furthermore, when put into action, work and training methods that were not imagined at the time of formulation are sometimes derived. It is therefore necessary to appropriately formulate the advance plan, education/training plan, and maintenance improvement plan in order to raise the overall level of the emergency response plan and sewage BCP.

Advance plan

It is necessary to compile an advance plan as a measure to improve the "response target time" in the emergency response plan. It is desirable that the advance plan promptly implement things that are doable. Matters considered particularly important are shown below.

- Backup of important information
- Stockpiling of equipment
- Securing and authorizing means of communication during a disaster

- Disaster support agreements

Education/training plan

The education/training plan is formulated with the aims of ensuring implementation of the post-disaster response procedure based on the emergency response plan and anchoring the sewage BCP. The results of education and training must be appropriately summarized and linked to the maintenance improvement plan.

Maintenance improvement plan

The maintenance improvement plan undergoes regular content confirmation, review and consideration, and updating. Its purpose is to keep the sewage BCP up to date and raise the overall level. Matters set in the maintenance improvement plan must undergo general checking based on the implementation status of the advance plan and the education/training plan.

3.1.3 Workshop

We held a workshop for participants to discuss and consider basic policy for the sewage BCPs created in this joint research.

[Implementation details]

- We reported the results of the survey that we performed in advance.
- Along with presentation and explanation of the thinking on sewage BCP creation in Okinawa Prefecture (draft) created by JIWET, there was an exchange of opinions.
- Through group work on topics set based on a survey, there was discussion of wide-area mutual cooperation and so on (storing and sharing important information, lending of equipment possessed, support agreements for intra-prefectural cooperation in time of disaster, mutual cooperation on emergency, primary, and secondary surveys, and mutual cooperation on sludge disposal).

- Through group work, mutual support agreements among local governments, support agreements with the Japan Sewer Collection System Maintenance Association, and support agreements with the Japan Sewage Works Agency (Sewage Works Agency) were deliberated. Furthermore, the sort of BCP-related information that should be shared was deliberated.

3.1.4 Study group

A discussion-type study group was held so that participating local governments can create comprehensive sewage BCPs based on local conditions.

[Implementation details]

- JIWET discussed and shared information it obtained from its disaster support activities after the Kumamoto earthquake and knowledge it gained from its own survey of local governments harmed by the disaster.

- JIWET explained trends regarding sewage BCPs and the state of formulation in each prefecture, the objectives of sewage BCP formulation and an overview, details, merits, and methods of joint research.
- Reflecting the knowledge it has obtained to date, survey results, workshop opinions, etc., JIWET presented and explained the details of "Thinking on Okinawa Prefecture sewage BCPs" and "Sewage Business Continuity Plan <Earthquake/Tsunami Damage

Figure 5. Workshop

- Using the "Priority work during emergencies setting and response target time setting sheets" created by JIWET, local governments practiced deciding priority work during emergencies and response target time based on local conditions.

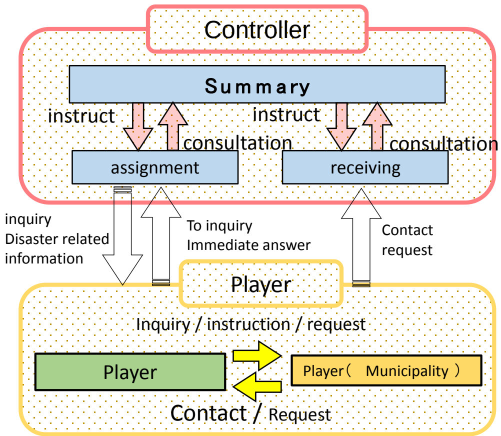
- We explained the creation of manhole key (cover opening and closing bar) lists and manuals as references for local governments and support teams.

3.2 Consideration and implementation of simulation training

Implementation of training based on sewage BCP action plans is cited as a brush-up method to raise the effectiveness of the created sewage BCPs. This training is very important. In addition to brushing up sewage BCPs, it practices actions to be taken at the time of a disaster, which can be expected to spread knowledge of and speed up response, leading to a stronger crisis management structure. In this joint research, in order to expedite information transmission and raise sewage BCP effectiveness, we performed simulation training with role-playing elements based on scenarios that reflect issues shared in the workshop and study group, as well as in JIWET's sewage BCP formulation/training implementation support.

- 99% percent of participants said it was "Helpful (A little helpful)"
- 71% percent of participants said they will "Rethink (Consider rethinking) sewage BCP"

Figure 6. Study group underway

very 

Obtaining those results makes the training significant.

Figure 7. Implementation structure of simulation training

Figure 8. Simulation training underway

[Knowledge obtained from the training]

- Regarding resources (people): "Staff familiarity with the sewage BCP is inadequate," "Methods to confirm the safety of staff members needs to be more specific,” "Links with other departments must be strengthened," "We need more people than we imagined to answer telephones, so it is necessary to secure personnel at the response base"
- Regarding resources (goods): "Because we are an outlying island, there are issues with the procurement and bringing in of goods," "We need a fuel arrangement list," "We had not confirmed the expiration date of solid chlorine"
- Regarding emergency response: "The content of the contact we are supposed to make in an emergency is unclear," "We do not know the storage location of tools such as flashlights needed during an emergency," "The method of writing on the whiteboard must

be decided," "A model for information compilation must be created," "Transmission means other than telephones are necessary"

- Regarding advance measures: "Reexamination of the information and equipment to be given to support teams is necessary," "The extent to which local governments can respond must be clarified," "Creation of a diagram for the extent of each group’s primary survey is necessary," "agreements with private-sector companies are needed”

That knowledge would not have been realized by simply creating a sewage BCP on a desk. Much of the content was confirmed by training in a simulated disaster, so we found that it is necessary to combine sewage BCP creation with training.

4 Conclusion

Through this research, Okinawa Prefecture and local governments in the prefecture cooperated, enabling efficient sewage BCP formulation. During the formulation, a study group was implemented, grasping disaster countermeasures and exchanging opinions, which raised disaster awareness. Furthermore, joint practical training on sewage BCPs, with implementation of sharing of disaster information and role-play simulation training, Led to the formulation of highly effective BCPs with mutual support and disaster maintenance and repair agreements

Young Professionals and the Water Sector

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Keywords: Engagement, Involvement, Motivation

The water sector is facing new challenges worldwide. Clean water is an indispensable resource for humanity and an elementary part of an intact environment. At the same time, the availability of water is an important location factor that decisively affects the economic development of regions. As a result of the changes in climate, a growing population in some parts of the world, as well as the growing demand for food and energy, the availability of and the demand for water and water infrastructure will be drastically exacerbated in the coming decades. Due to the longevity of the predominantly pipe-based infrastructure for water supply and wastewater discharge, possible solution concepts must also be developed and implemented at an early stage for the future problems.

These challenges show the need for involvement of the younger generations. Young people should be involved in the decisions of today as they will, ultimately, own the outcomes. It is clear that the water sector should invest in recruitment, management and development of young staff, as well as put them at the forefront of design, development and implementation of current change processes. Additionally, they also play an important role in driving action towards a sustainable future in their organizations, sectors and communities. This presentation will show the perspective of different young water professionals (YWP) about the involvement and motivation of other young water professionals. It will educate attendees on how to attract and mentor YWPs to the Water Sector, and how to keep them engaged.

Research towards a long term restoration plan for sewage pipes

Hiroaki, Nishisaka

1. Purpose of Research

A certain city in the Kyushu region (western part of Japan) commenced a project on a separate sewer system in the year 1966 with the total conduit length as approximately 1,745 km (from the sewerage register system information collected in the year 2016), and the population diffusion rate as 62.6% (as of the end of the year 2016, from this city HP). Soon, there will be pipes that would have reached their standard durable life of 50 years, and their number will only increase in future.

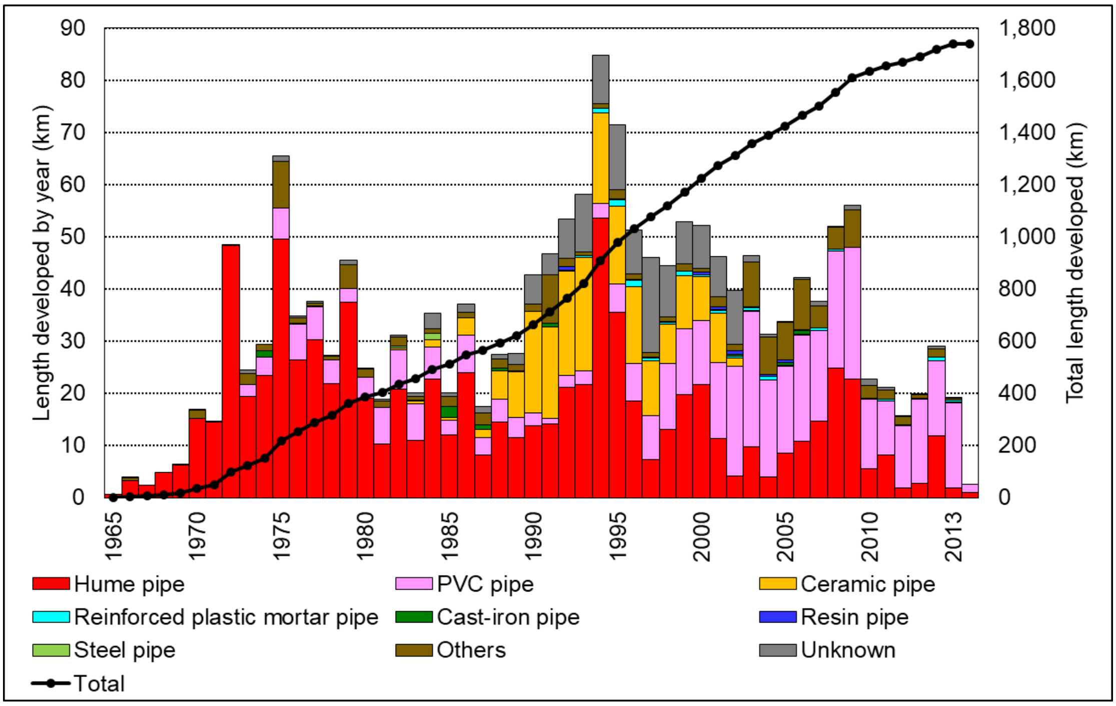

Figure 1: Transition of the total developed conduit length

Based on this background, a plan to extend the durable life of pipes has already been established in this city, and planned restoration is being implemented, and at the same time, a "City Sewage Project Mid-term Business Plan" has been formulated, and efforts are being made to resolve the issues of the sewage project.

In future, in order to implement a sustainable sewage project, it is desirable to perform a survey aimed at preventive maintenance, and take appropriate measures including maintenance, repair, and restoration. The survey of pipelines that form the main constituent of the conduit facilities is generally a qualitative visual examination involving TV cameras and underwater navigation. Particularly, it is difficult to perform quantitative evaluation of the strength of the existing small-diameter pipes having a diameter of less than 800 mm. In order to formulate a plan that eliminates risks such as road cave-ins, it is necessary to accurately understand the state of deterioration of existing pipes, and investigate the existing pipes that reflect the condition of the pipes across the entire city.

Therefore, the purpose of this research was to use the impact elastic-wave inspection method by which a non-destructive and non-open cutting, as well as quantitative survey can be implemented, and to perform life estimation of aged pipes, and formulate a long-term restoration and renewal plan.

- Research Content

① ***Material collection and arrangement***

We collected and arranged the material necessary for performing this research. The reference material is shown below:

• Information about the upper-level plan

• Information about the related plan

• Information about specifications

② ***Implementation of survey***

We arranged material such as the installation status of pipes in the city, and selected the route. At that time, we selected a survey route of approximately 2,000 by also referencing to electronic data, such as GIS, etc. and the past TV camera survey results. Before implementing the survey, we cleaned the pipes from inside, and removed the sediment and deposit, etc. from the pipe walls. Thereafter, we implemented an expanded wide-angle camera survey and an impact elastic-wave inspection method survey.

③ ***Arrangement and consideration of survey results***

We performed urgency determination for each of the visual survey performed by an expanded wide-angle camera, the impact elastic-wave inspection method survey, and the comprehensive evaluation based on these two surveys, and also based our consideration on these. The urgency determination of the impact elastic-wave inspection method survey was performed according to the procedure described below.

(1) Understanding the frequency distribution and high frequency components ratio

(2) Estimating the virtual fracture load and virtual pipe thickness

(3) Evaluating the soundness of each pipe

(4) Evaluating the degree of safety of pipes (entire span)

Note: “Urgency” is an indicator showing the soundness of function and state of pipe. Urgency I is a state in which prompt measures are required. Urgency II is a state that requires countermeasure as soon as possible (about five years or less). Urgency III is a state where it is only necessary to consider the countermeasure timing while confirming the deterioration situation.

Note: “The impact elastic-wave inspection method survey” is a new evaluation method that can quantitatively grasp the remaining strength of the pipe by applying a light impact to the pipe.

④ Estimation of target durable life of existing pipes

The soundness rate (ratio of urgency with respect to all pipes) was estimated for each elapsed year of the surveyed pipes. In this research, the number of years when the ratio of urgency I to II for which measures must be taken within five years reaches 50% of all pipes is set as the life when restoration is needed (average life of existing pipes = Target durable life).

⑤ Formulation of a long-term restoration plan

① Setting a development block

We have set the unit (block) for implementing maintenance and management, as well as restoration in consideration of the number of elapsed years and regional characteristics of the pipes across the entire sewerage planned region of the city.

Moreover, the priority order of the block unit was set with reference to the concept of risk evaluation.

② Forecast of the volume of long-term restoration project

During the forecast of the volume of the long-term restoration project, several basic scenarios like the scenario of performing restoration based on the standard durable life of pipes, the scenario of suppressing the ratio of urgency I to II to a fixed value, and the scenario of performing restoration in accordance with fixed budget restrictions were set, and the best scenario was selected based on these.

- Results of Research

① Document acquisition

① Information about the upper-level plan

The Mid-term Business Plan, which can be called an upper-level plan of the long-term restoration plan, describes the major points of performing life extension of the facility and working toward normalization of the restoration and renewal cost as “measures towards deterioration of facilities”.

② Information about specifications

The information about specifications is accumulated and managed in a unified manner through a sewage conduit facilities ledger system. This research has been arranged by collecting the information accumulated in the ledger system as a Shape File, and reading it through the GIS software. Note that the arranged information includes the below.

(1) Sewerage system

(2) Number of elapsed years

(3) Types of pipes

(4) Pipe diameter

(5) Flow method

(6) Installation method

(7) Usage classification

(8) Implementation of survey and restoration

② *Implementation of survey*

① Selection of survey route

The selection conditions of the survey route were as shown in Table 1 with the purpose of ensuring that there is no bias.

Table 1: Survey route selection conditions

Item				Under corrosive environment	Under general environment
Sewerage classification				Wastewater	
Pipe type				Hume pipe	
Pipe diameter				200 mm to 700 mm	
Installation method				Open-cut method	
No. of years elapsed	Around 10 years			○	—
	Around 20 years			○	—
	Around 30 years			○	○
	Around 40 years			○	○
	Around 50 years			—	○
Usage classification	Sea-side	Residential areas	Around 60%	—	○
		Commercial areas	Around 20%	—	○
		Industrial areas	Around 20%	—	○
	Mountain-side	Residential areas	Around 60%	—	○
		Commercial areas	Around 20%	—	○
		Industrial areas	Around 20%	—	○
Aim of survey length				300 m	1,700 m

② Implementation of survey

Under both corrosive environment and general environment, some of the candidate routes are replaced by the spare route during the survey. The survey results are shown in Table 2.

Table 2: Survey results

Surveyed route length (m)

Environment classification	Nominal diameter									Total
	200	250	300	350	400	450	500	600	700	
Under corrosive environment	7	121	135	43	0	0	31	0	0	337
Under general environment	40	1,195	0	55	17	172	56	232	0	1,767
Total	47	1,316	135	97	17	172	88	232	0	2,104

Number of surveyed spans

Environment classification	Nominal diameter									Total
	200	250	300	350	400	450	500	600	700	
Under corrosive environment	1	4	4	1	0	0	1	0	0	11
Under general environment	1	33	0	2	1	3	1	4	0	45
Total	2	37	4	3	1	3	2	4	0	56

③ *Arrangement f survey results*

① Visual survey by expanded wide-angle camera

The visual survey was performed by an expanded wide-angle camera rather than a conventional TV camera. As for the judgment, the results of the visual survey are shown in Figure 2 based on the maintenance and management policy (Actual Practice).

The urgency rank was relatively lower under the corrosive environment as compared with the general environment. This can be attributed to the fact that number of samples under the corrosive environment is only 11 spans, which is relatively and absolutely less as compared with the 45 spans under the general environment.

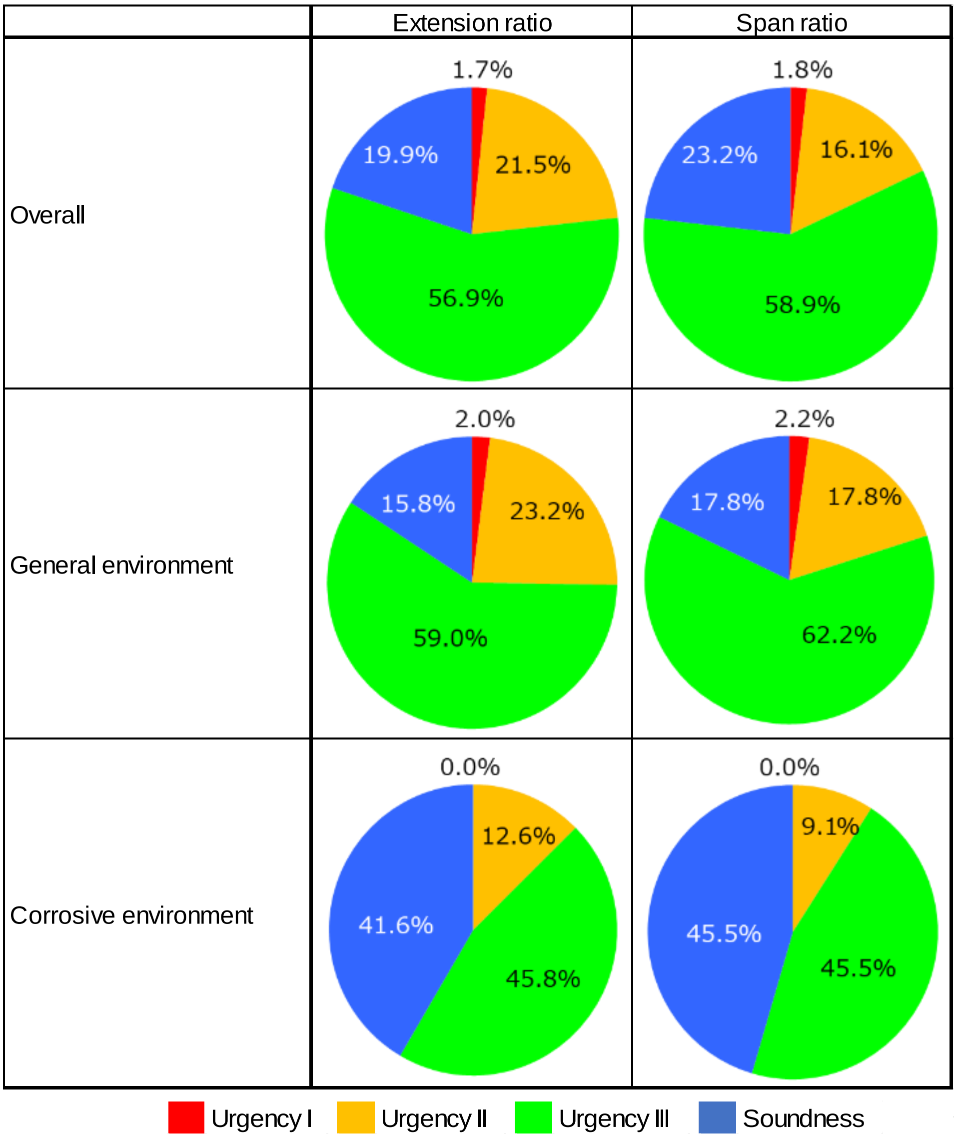

Figure 2: Urgency determination results of visual survey

② Comprehensive evaluation based on impact elastic-wave inspection

The results of a comprehensive evaluation based on both the visual survey and impact elastic-wave inspection method survey are shown in Figure 3. The "Conduit Diagnosis and Technical Material based on the Impact Elastic-wave Inspection Method" was published in March 2012 for the impact elastic-wave inspection method, and the judgment was made based on it.

In contrast to the fact that urgency I was almost nonexistent in the visual survey, its ratio became 1/4 or more in the comprehensive evaluation, indicating a significant increase. This could be due to the evaluation of the strength of the pipes with the impact elastic-wave inspection method survey, which could not be evaluated by the visual survey, and the reflection of the results.

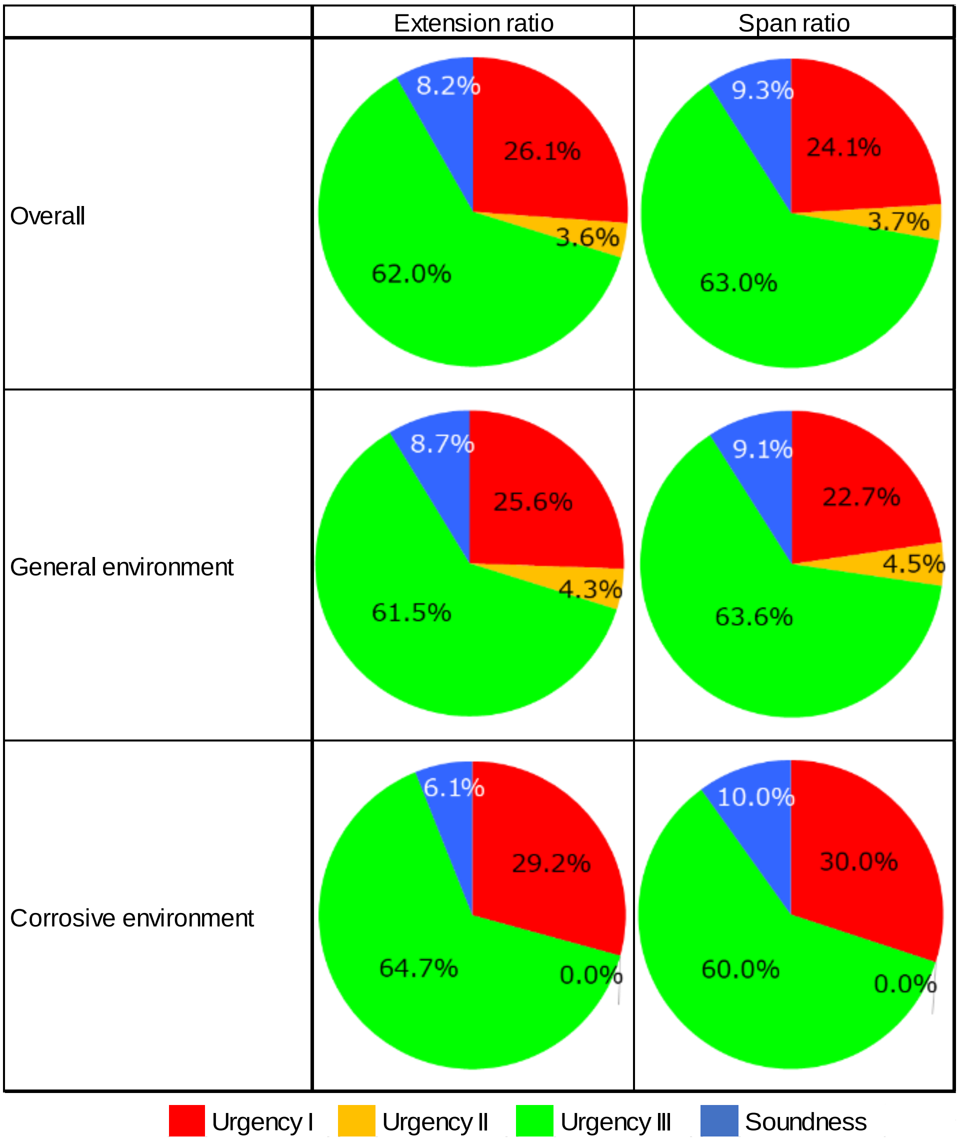

Figure 3: Urgency determination results of comprehensive evaluation

④ Estimation of durable life of existing pipes

The soundness rate was estimated by using the results of the comprehensive judgment.

In this examination, the soundness rate was estimated by using Weibull distribution approximation, but the data of a single year was converted into the weighted mean value for a 5-year interval. The results of the estimation of the soundness rate are shown below.

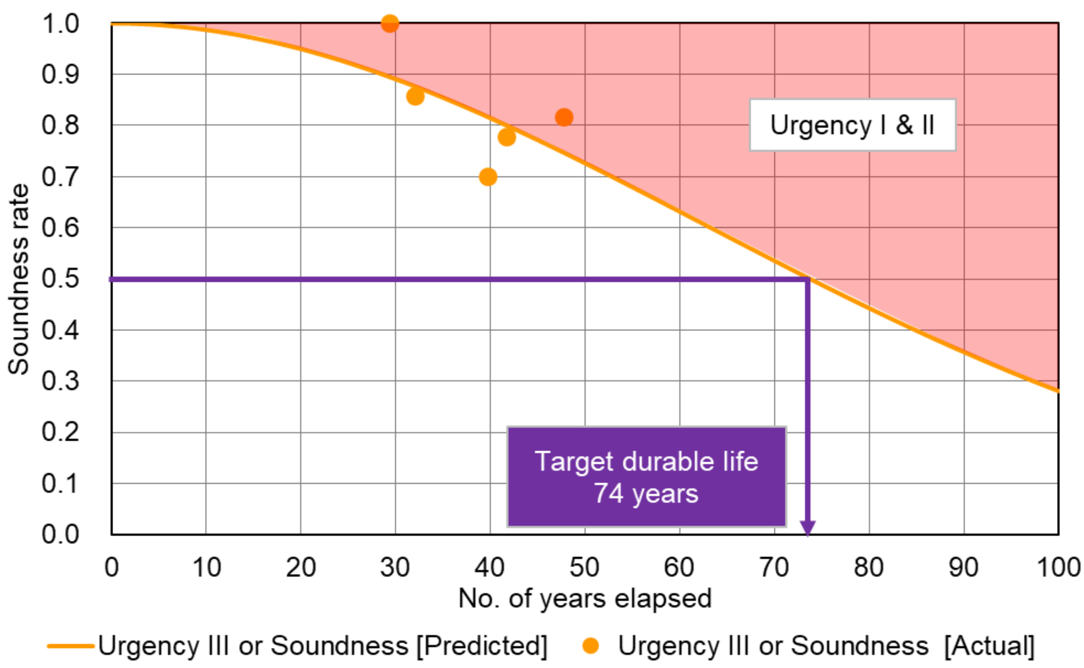

Figure 4: Results of estimation of soundness rate

⑤ Formulation of a long-term restoration plan

① Setting a development block

28 development blocks were set for implementing survey and restoration on the basis of the 18 areas in this city with public sewerage systems (umber of treatment areas), and in consideration of the area boundary, so that there was no bias with regard to the number of elapsed years of each block. Figure-5 on the next page shows the classification of the 28 blocks with Hume pipes and ceramic pipes.

② Setting the scenario of the long-term restoration project

(1) Setting the restoration conditions

- Set the Hume pipes and ceramic pipes as the restoration targets.
- Target durable life is 74 years.

- Exclude pipes that have been restored once from the restoration target.

(2) Setting the basic restoration scenarios

We examined the scenario of performing restoration based on the standard durable life, the scenario of maintaining the ratio of urgency I and II at a fixed value, and the scenario of setting the annual restoration length and project cost to a fixed value. (Table 3)

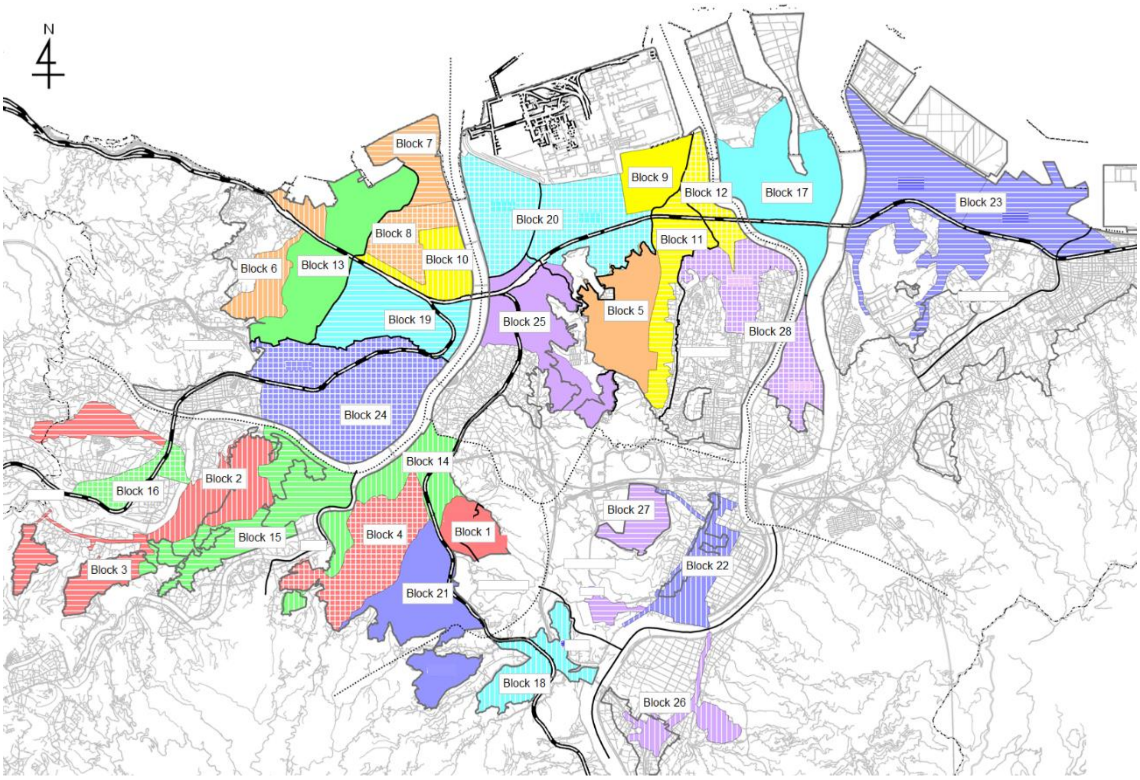

Figure 5: Classification of 28 blocks

Table 3: Basic scenarios

Scenario no.	Scenario description
Scenario 1	Restoration at standard durable life (50 years)
Scenario 2-1	The proportion of urgency I and II is maintained in the current state
Scenario 2-2	The proportion of urgency I and II is allowed up to twice the current state
Scenario 3-1	Restored at 500 million yen (about 4.6 million $, about 3.7 million €) /year
Scenario 3-2	Restored at 1 billion yen/year (about 9.1 million $, about 7.4 million €) /year
Scenario 4-1	Restored at 7 km/year
Scenario 4-2	Restored at 8 km/year
Scenario 4-3	Restored at 9 km/year
Scenario 4-4	Restored at 9.5 km/year
Scenario 4-5	Restored at 10 km/year

(3) Deciding the scenarios

We considered the restoration project period from the following viewpoints:

- For the initial 10 years, we plan to reduce the project cost.
- The year of start of restoration period 1 is the current year (2018), and the year of end (2102) shall be the year obtained by adding the initial 10 years and the target durable life of 74 years.
- In restoration period 2, PVC pipes and corrected pipes are also restored.

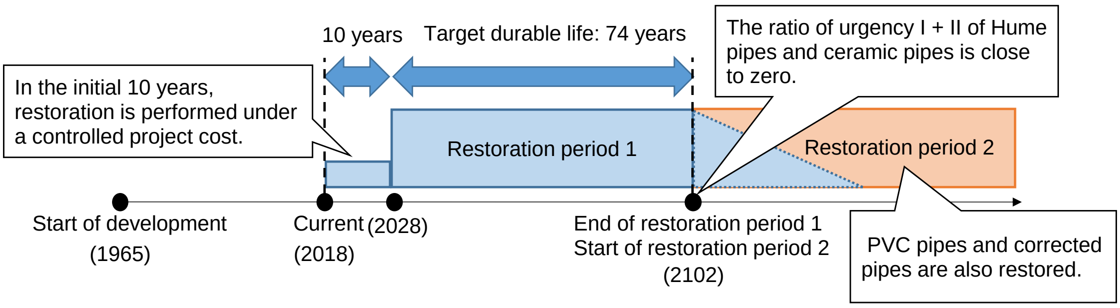

Figure 6: Examination of the long-term restoration plan

(4) Recommended scenario

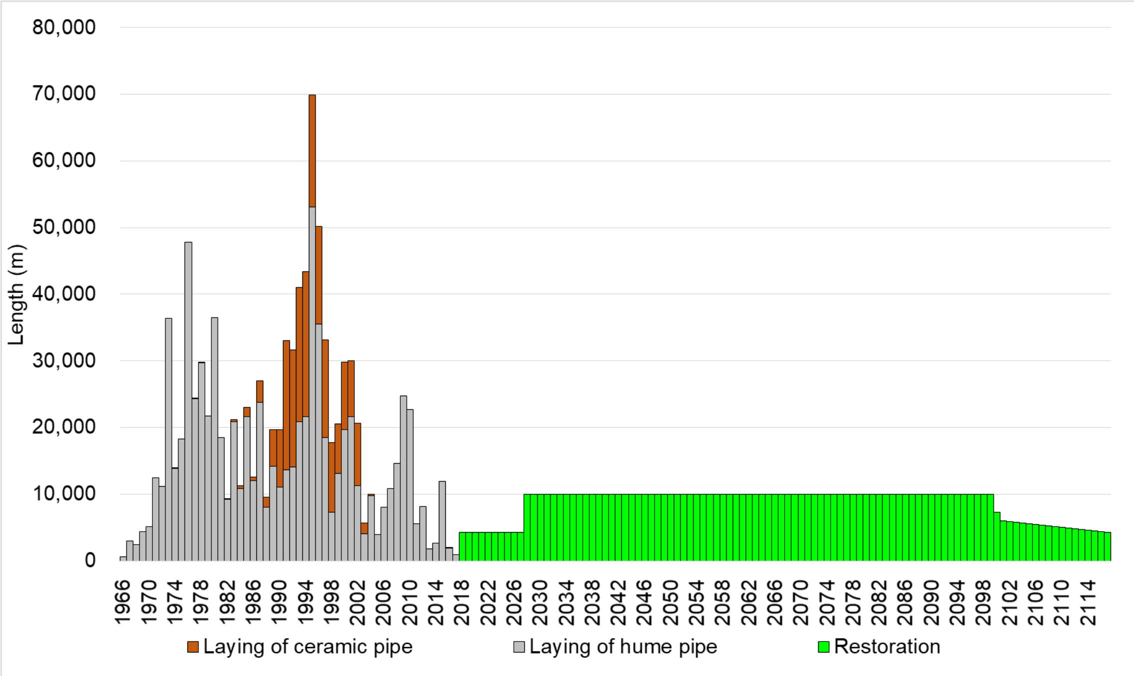

Figure 7: Laying and restoration length by year

We set the following recommended scenario 4.3 km/year restored in the first 10 years, and thereafter, 10 km/year. The recommended scenario was prepared from the basic restoration scenarios described in ② (2) and the concept shown in Figure 6.

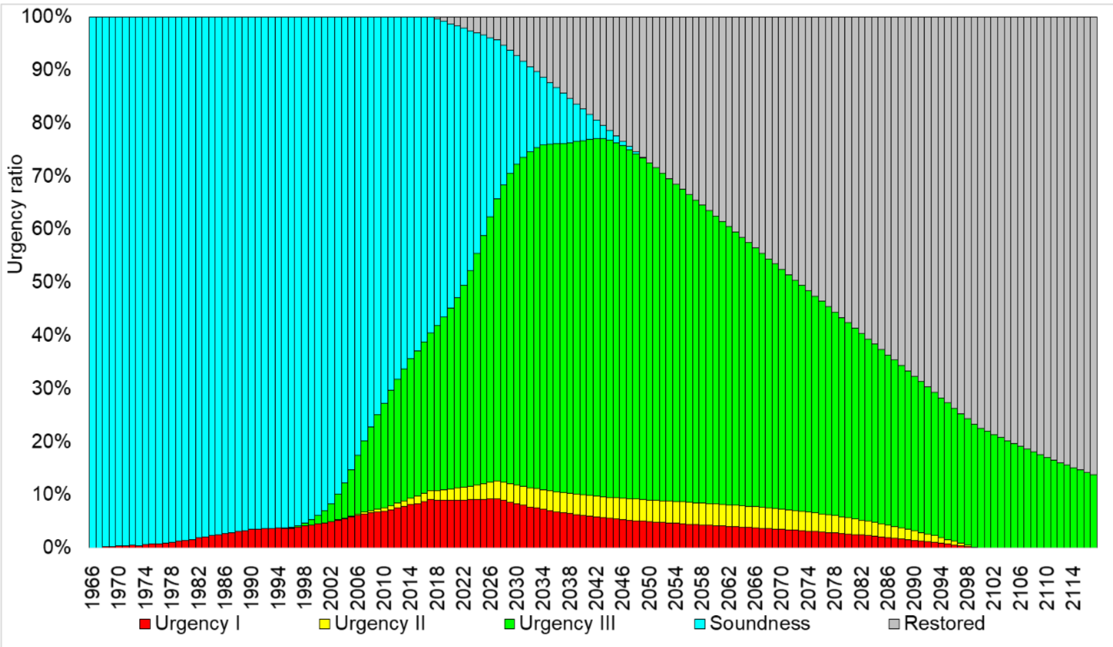

Figure 8: Urgency ratio by year

③ Setting the priority of the development blocks

We performed examination with reference to the evaluation method of risks based on “Guidelines on Implementation of Stock Management of Sewerage Projects - 2015 Edition - (Sewerage Department, Water and Disaster Management Bureau, Ministry of Land, Infrastructure, Transport and Tourism, Japan and Sewerage Research Department, National Institute for Land and Infrastructure Management, Ministry of Land, Infrastructure, Transport and Tourism, Japan)”.

In the current examination, the “population density” was assumed as the index of the damage scale (influence) and the “Ratio of urgency I and II” was calculated as the probability of occurrence (likelihood of a defect), and the priority order of the development blocks was set based on the magnitude of the product of the “population density” and the “Ratio of urgency I and II” as the risk.

Table 4: Priority order of each block

Block	Occurrence probability (tendency for a defect to occur)		Damage level (impact)		Composite evaluation	
	(1) Ratio of urgency I and II	rank	(2) Population density(persons/ha)	rank	(1)×(2)	rank
Block 8	12.8%	8	159.5	1	20.37	1
Block 1	20.6%	1	69.8	5	14.40	2
Block 5	18.4%	3	70.6	3	13.01	3
Block 10	8.4%	11	153.9	2	12.86	4
Block 6	15.6%	6	69.2	6	10.81	5
Block 4	17.4%	4	51.8	11	9.00	6
Block 2	18.7%	2	36.4	17	6.80	7
Block 3	17.1%	5	38.1	16	6.52	8
Block 9	12.7%	9	43.8	13	5.55	9
Block 11	8.6%	10	54.9	9	4.74	10
Block 13	8.1%	14	54.6	10	4.42	11
Block 19	5.8%	19	69.8	4	4.02	12
Block 20	5.5%	20	68.2	7	3.77	13
Block 7	14.5%	7	23.1	22	3.36	14
Block 12	7.9%	15	28.1	20	2.22	15
Block 15	8.2%	13	21.0	24	1.73	16
Block 24	2.6%	24	61.7	8	1.60	17
Block 14	8.3%	12	18.0	25	1.49	18
Block 17	6.7%	18	21.5	23	1.43	19
Block 21	5.5%	21	25.3	21	1.38	20
Block 23	4.2%	23	29.6	19	1.23	21
Block 18	6.9%	17	13.7	26	0.95	22
Block 16	7.4%	16	9.5	27	0.70	23
Block 25	1.2%	25	45.6	12	0.56	24
Block 26	0.7%	27	41.1	14	0.31	25
Block 28	0.8%	26	39.3	15	0.30	26
Block 22	5.1%	22	4.4	28	0.23	27
Block 27	0.6%	28	29.9	18	0.18	28

④ Summary of the long-term restoration and renewal plan

The summary of the long-term restoration and renewal plan was performed under the following conditions, in combination with the conditions described until the previous section.

- The design shall be performed the year after the degradation survey, and restoration shall be performed the year after that. (However, the period of design and restoration may be shifted in some cases in order to normalize the project cost.)
- The degradation survey shall be performed for pipes that have surpassed 30 years or more as of the survey year.
- The length of urgency I and II in the survey year shall be the length to be designed or renewed.

Figure 9 shows an image of the project cost put together by year.

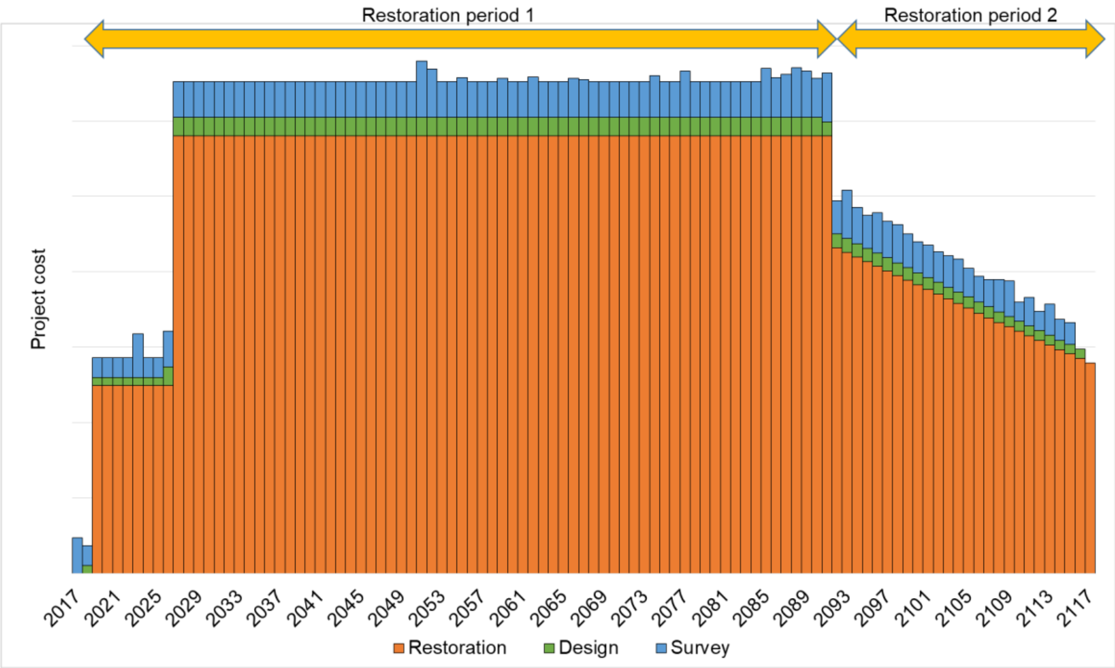

Figure 9: Image showing the project cost by year

Note that the long-term restoration plan shown here reflects the survey results of the currently existing pipes, and the survey results are expected to change (become more accurate) as the project advances in future. In future, it is desired to revise the long-term restoration plan by revising the estimated soundness rate at the time of revision of the long-term plan for a period of 5 to 10 years.

➢ Conclusion

In this research, the soundness rate was estimated based on the survey results, and the long-term restoration plan was implemented based thereon.

In future, it is scheduled to summarize the maintenance and management plan for inspection and survey based on the above results. These results are desired to be used as the basic material for the formulation of the plan for the stock management that this city will undertake on a full scale from here.

On the topic of the service-life of sewers and pipelines

Bosseler, Bert

Introduction

Many network operators are confronted with the following question: What service-life should be assumed for sewers and pipelines in order that technical and commercial requirements are fulfilled? How can even long-term strategic issues of urban development, intergenerational equity and the "Smart City" be taken adequately into account in this context? How can a system operator make the right decisions?

Attention to detail and determination are obviously needed here. Attention to detail, in order to comprehend the correlations between the many diverse requirements, compile the necessary information, pursue network development, estimate service-lives and thus derive requirements for the durability and flexibility of the system. Determination, in order to evaluate the alternatives for action in terms of their intergenerational equity and degrees of freedom and to also justify this to the present generations. Because: a fair apportionment of risk also means that future generations cannot only be burdened with an "obligation to use old facilities not yet paid off", but must also be enabled to inherit flexible systems, by means of which future challenges can be overcome.

All this must be viewed against the background of current political discussions: The UN Sustainable Development Goals (SDG)[1] agreed in 2015 and the closely associated Paris Agreement of late 2015[2] aim extremely topically and also extremely specifically at improving the sustainability of municipal infrastructures (see UN SDG 6, 9 and 11), with corresponding calls for implementation at national, regional and local level (see Article 7, Paris Agreement[2]). Adaptability aspects play a particular role in this context (see Article 2, Paris Agreement), while the question of selection of the "right" service-life is also becoming increasingly contentious.

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1 UN: Sustainable Development Goals (SDG) – 17 goals to transform our world. http://www.un.org/sustainabledevelopment/sustainable-development-goals/ (retrieved 08.03.2018)

2 UN: Adoption of the Paris Agreement. Framework Convention on Climate Change. Conference of the Parties. Twenty-first session. Paris, 30 November to 11 December 2015. https://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf (retrieved 08.03.2018)

Service-life

The term "service-life" can, firstly, literally be understood as a technical variable; it involves the scheduled utilisation of the sewer for a specified period of time. This technical variable is also generally interpreted in the water-management industry (see [KVR]) as "expected useful life", i.e., with a view to the

- **Past**, in the form of the service-life of components and structures for which empirical data ("actual service-life") is already available, with the result that a kind of "average" of the service-lives customary up to now is used here.
- **Future**, as the service-life generally used in the planning of new structures and components ("estimated service-life"), i.e., the period of time for which the structure or component is intended to perform its assigned function within the network as a whole without any change.

Service-life is then selected as a reference variable for cost appraisals, in order to permit comparative assessment of the total of the construction and operating costs accruing during this period for the purpose of diverse implementation variants (see [KVR]).

The danger of false conclusions

The technical variable of "service-life" can be used, on the one hand, to perform comparative assessments of different variants (see [KVR]) or to define requirements for the durability of structures and components, but it also serves, on the other hand, as the basis for commercial calculations, such as the specification, for example, of depreciation times and calculation of sewage-disposal charges. It is now frequently observable in discussions among specialists that the terms used are interchanged or are all equated with the term "service-life", i.e., those involved speak, for example, of "service-life" and include the aspects of durability, funding, depreciation, etc., in their argumentation. Misunderstandings and false conclusions can then be the result. One example is the following progression of three, in which both the premise and the conclusion are erroneous:

Depreciation period = Service-life ∧ Service-life = Durability
=>
Depreciation period = Durability

Durability alone is not enough

Adequate structure/component durability is a necessary precondition for attainment of the service-life. It should, correspondingly, be not less than the planned service-life, with the inclusion, where appropriate, of the maintenance work necessary during the service-life, with the following **requirement** as the result:

$$\textit{Durability} \geq \textit{Service-life} \qquad (1)$$

Durability alone will, however, not assure service-life, as we can see, for instance, in the ongoing renewal of the telecommunications infrastructure. In this example, the old existing copper cables do, in principle, still remain sufficiently durable and technically utilisable, but system-utilisation requirements have now changed so radically that the copper cables must nonetheless be replaced with fibre-optics cables. Similarly radical changes are also becoming apparent for the sewerage system, as a result, for example, of the requirement for the separation of sewage and grey water from rainwater[3] and the growing problem of severe precipitation events. Only rarely can the development of such requirements be estimated in a generalised form; the recommendations currently available for estimation of service-lives (see [KVR]) involve correspondingly wide scatter, with figures for sewer structures ranging from a few decades to more than a hundred years.

Care needed for selection of commercial depreciation period

In Germany, the principle of prudence applies with priority in the selection of a purely commercial depreciation period, i.e., in the present case, the requirement that losses of asset value be distributed at a maximum across the expected useful life. Ultimately, the losses in value can also be recovered only in this period via the use of the facility. The "principle of prudence" assumes the "prudent businessperson", who in case of doubt calculates not greater than, but instead lower than actual circumstances in the measurement of assets and liabilities in the legally mandatory annual statement of accounts[4]. The following further **requirement** thus results:

$$\textit{Service-life} \geq \textit{Depreciation period (comm.)} \; (2)$$

[3] In Germany, also a legal requirement under the Water Management Act, Article 55 (2)

[4] http://www.wirtschaftslexikon.co/d/vorsichtsprinzip/vorsichtsprinzip.htm (retrieved 08.03.2018)

This cautious approach runs up against limitations from a fiscal-law viewpoint, however, since greater rates of depreciation of assets also inevitably diminish annual trading profit and thus tax liability for the particular year. Orientation around the data in the so-called AfA ("wear-and-tear depreciation") tables published by the federal ministry of finance is customary in this context in Germany[5]. No official AfA tables exist for the specific field of wastewater disposal, however, since municipalities bearing the duty of wastewater disposal are not liable for tax. The empirical data for service-life published by the German Working Group on Water Issues of the Federal States and the Federal Government (LAWA; see [KVR]) is therefore generally used as an orientation point for depreciation period. Adoption of this service-life as the depreciation period may be rational, in particular, if it is incorporated directly into the calculation of charges.

Charges determine intergenerational equity

The calculation of charges determines who must ultimately pay for the structure, i.e., which generation will be burdened with the costs of the investment. Here, an "appropriate depreciation"[6] is expected in principle. Each generation[7] should pay its share of the facilities and services used. The aim of a charge calculation is, correspondingly, to determine as accurately as possible the service-life actually to be anticipated for the charge-relevant structure/component, in order that each succeeding generation will be required to cover only the losses in value accruing in its own period of utilisation and that a fair apportionment of costs is achieved. The following therefore applies for the distribution of loss of value, here frequently also referred to as "depreciation", assumed in the calculation of charges[8]:

$$\textit{Depreciation period (charges)} \approx \textit{Service-life} \qquad (3)$$

This concept must, however, be subject to the criticism that the consequences of long-term tying down of capital are not taken into account for the future generations. Subsequent

[5] See http://www.bundesfinanzministerium.de/Content/DE/Standardartikel/Themen/Steuern/Weitere_Steuerthemen/Betriebspruefung/AfA-Tabellen/afa-tabellen.html (retrieved 08.03.2018)

[6] Explicitly legally governed, in KAG Article 14 (3) in Baden-Wuerttemberg, for example, Status: 15.12.2015 (dejure.org)

[7] The interval between two generations (generation interval) is, in Germany, for example, currently around thirty years. "The size of the coming generations is decreasing significantly - every generation of children is now around one third smaller than its parents' generation", see Bevölkerungsentwicklung 2013, Bundesinstitut für Bevölkerungsforschung: http://www.bib-demografie.de/SharedDocs/Publikationen/DE/Broschueren/bevoelkerung_2013.pdf (retrieved 08.03.2018)

[8] Also legally governed in North Rhine-Westphalia in NRW KAG Article 6 (2), status: 30 July 2016 (recht.nrw.de): "Depreciation which is to be uniformly measured on the basis of expected service-life or asset usage".

generations will have to continue using the structures set up by their predecessors at least until the end of the service-life planned by the latter - ultimately, the future generation is the only probable "customer" for this infrastructural service. This fact also differentiates infrastructural systems from tradable assets, which can be transferred to other interested parties at their market value, restoring to the previous owner the freedom to make new acquisitions. In our case, this freedom no longer exists since, due to the unsaleability of a single sewer length, that length would, in the case of replacement, have to be completely written down and the entire depreciation financed within a single economic year[9]. Future generations' freedom to overcome their own problems using their own solutions is thus significantly diminished, a clear contradiction of the definition of sustainability and intergenerational equity[10].

Selection of pipe material should not result in "mandatory use"

The term "service-life" of sewers is also associated in some cases with specific pipe materials, such as vitrified clay, concrete, plastic, cast iron and diverse rehabilitation materials. Their durability is usually meant, and this is generally equated, on the basis of our above-mentioned misunderstanding, directly with service-life. As already noted, it is simply not the case that the pipe-material selected determines how long a specific length of sewer can be used in the manner intended.

Where, however, selection of the pipe material is used for definition of service-life, irrespective of future hydraulic and system requirements (e.g. separate collection of sewage and storm water), future generations will, effectively, be subject to "mandatory use" of pipe products until the expiry of the durability of such products. System modifications to meet future demands, as a result, for example, of climate change, demographic trends, migration and urban development, are thus made more difficult (see the above deliberations on sustainability and intergenerational equity).

[9] Here, the terms "special depreciation" and "extraordinary depreciation" occur, since the entire residual commercial value (procurement/production costs minus depreciation up to this point) must now be completely recognised as depreciation in the year of withdrawal from service. It can then be financed from charges either not at all or only within several years (see, for example, KAG NRW, Article 6 (2), calculation period: three years).

[10] See the Brundtlandt Report, UN 1987, http://www.un-documents.net/our-common-future.pdf (retrieved 08.03.2018): "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs".

Service-life as a target for rehabilitation

The misunderstanding that "Service-life = Durability" also frequently occurs in the selection of rehabilitation methods. The conceptual service-lives stated in the guideline [KVR] for repair, renovation and replacement are, for example, frequently interpreted as "durability of the completed rehabilitation projects", despite the fact that there is no proven correlation between type of provision (replacement, renovation, repair) and the durability of the products offered. Only a requirement for the durability of the products, which must then be met by product suppliers, can be derived, if anything can, from the type of rehabilitation. Such a derivation of requirements for classification in acc. with [KVR] is shown below by way of example:

New construction/replacement: According to [KVR], 50-80 (100) years are stated here as expected useful life. Here, the complete (re)construction of a new line is involved, and all functions of the sewer, such as structural safety, operational reliability, tightness and durability can be designed for current network requirements. The expected useful lives can also be selected correspondingly high. Requirements for the durability of the products used are then the result of this selection.

Renovation: Here, [KVR] states a range of 25-40 (50) years as the expected useful life. This can also be easily explained, particularly with comparison to the above-mentioned figure for replacement: the focus in renovation is generally on complete sealing of the damaged section of sewer to eliminate infiltration and exfiltration. Renovation in acc. with [EN752] is distinguished by the fact that the existing structure is incorporated into the rehabilitation. This also means, however, that hydraulic performance will remain largely unchanged. And only few renovation methods are capable of restoring or even improving the structural safety of the pipe/soil system. The planning horizon ("estimated expected useful life") for a renovation project will, therefore, generally be significantly below that of a replacement project: the planning target for an old sewer (hydraulics and structural safety) is extrapolated unchanged for a further period. Requirements for the durability of the products used follow.

Repair: Here, a bandwidth of 2-15 years is stated in acc. with [KVR] for expected useful life. This is also comprehensible in planning terms, since a repair is, in acc. with [EN752], by definition a local solution. The overwhelming part of the sewer length is, correspondingly, left in unchanged condition and thus continues to determine the residual service-life of the sewer as a whole, including the part repaired. The technical aim of repair is thus, essentially, the elimination of extreme defects until scheduled abandonment, renovation or replacement of the sewer length. The probability of the presence of local damage requiring repair becomes greater as the age of the sewer length increases, with the result that, in the case of a repair, only short residual operating times may be anticipated until the next work, estimations for this being, for example, 2-15 years.

We can ascertain, by way of summary, that the selection of the rehabilitation procedures (repair, renovation, replacement), with corresponding planning factors for service-life, result from system management and system development, and that only then can requirements for the durability of the products used be derived, and not vice versa. This can also mean that differing durability requirements may be made for one and the same product, depending on the type of rehabilitation procedure selected and expected useful life. An example is provided by projects performed on sewer laterals:

Top-hat section and injection-grouting methods may be used both as isolated solutions for the *repair* of a connecting socket and as an element in a liner-based rehabilitation (*renovation*) for connection to the liner-rehabilitated main sewer. The durability requirements are correspondingly divergent, despite the fact that they will still apply, in principle, to the same technology/the same product. Corresponding tests will, for example, then investigate the extent to which individual products actually meet these differing requirements (see [IKTW04], [IKTW14]).

Smart City: Service-life in the system of systems

Intensive work is going on at international level for the development of technical standards aimed at better describing the sustainability, including the "smartness", of municipalities, and also at making these variables quantifiable. A particular role is played in this context by the developments within the relevant Technical Committee (TC) of the International Standards Organisation (ISO), the ISO TC 268 / SC 1, "Smart Community Infrastructure" (see ISO TC 268[11]), which in 2016 published for the first time a policy paper entitled "Common Framework for Smart Community Infrastructures" (see ISO TR 37152[12]). This report was also

11 ISO: ISO/TC 268 Sustainable cities and communities http://www.iso.org/iso/iso_technical_committee?commid=656906 (retrieved 08.03.2018)

12 ISO: ISO/TR 37152 Smart community infrastructures -- Common framework for development and operation http://www.iso.org/iso/catalogue_detail.htm?csnumber=66898 (retrieved 08.03.2018)

drafted with the intensive involvement of European standardisation organisations (those of the UK, France and Germany, in particular), and its tight linking to the political targets initially discussed permits the expectation of a high level of regard.

ISO TR 37152 explicitly mentions five fields of municipal infrastructure which must also be observed holistically and in interaction with each other, with a view to a "system of systems": energy, telecommunications, waste, transportation and water (see Figure 1). Particular importance attaches here to orientation around the relevant social stakeholders and to continuous monitoring and feedback. The service-lives of components, subsystems and systems must be selected flexibly, and with the system as a whole in mind.

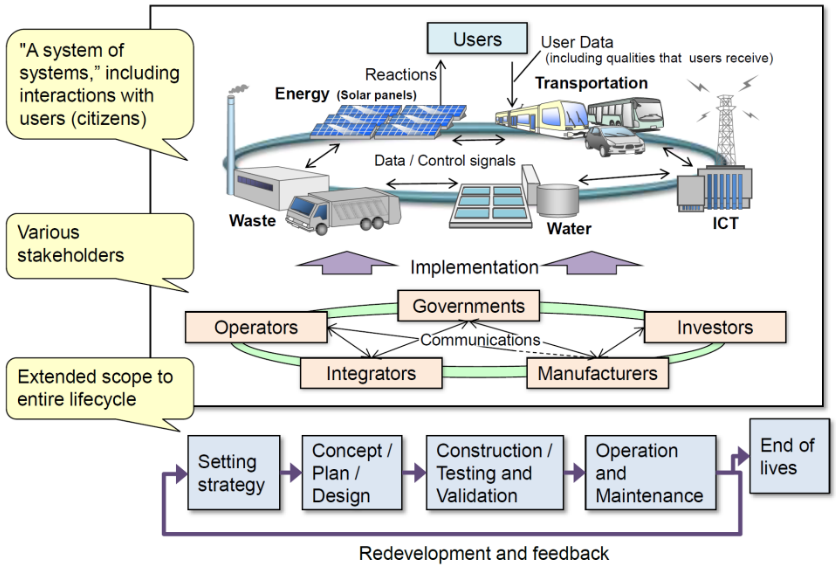

Figure 2 - Characteristics of smart community infrastructures

Figure 1: Fig. 2 as per ISO TR 37152

Challenges concerning the selection of the service-lives of sewers and pipelines thus result at three levels:

System of systems: The timing of work on the system, and thus the service-lives of the individual system components, must be harmonised with the aims of the overall system. This is true both of synergies in new construction and rehabilitation and of the coordination of operational measures and the management of interactions between the systems. This is even now being implemented on a small scale in the municipalities, in the context, for example, of regular meetings for the coordination of underground-engineering activities. This applies, in technical terms, to the selection, for instance, of the methods to be used, such as trenchless procedures to avoid disruption of other infrastructures, and open-cut methods for the exploitation of synergy effects.

Interaction with stakeholders: Orientation of system performance around the requirements of the various stakeholder groups, including citizens, investors, authorities and government, necessitates great flexibility and adaptability in system operation and system performance, taking account of both potential quantitative and qualitative changes. This applies, in sewer management, to increases and/or decreases in discharge volumes, for example, changes in the overflow-discharge behaviour of combined-sewer structures, new requirements for occupational health and safety, greater demands for long-term retention of value and also improvement of the structural safety of large sewers and greater demands on the functionality of sewer laterals. The service-life of an "obsolete" system solution can thus be drastically shortened. Modularity, compatibility and renewability are the required characteristics.

Service-life cycle: Here, there is a pronounced link to Asset Management, with the aim of optimising the overall efficiency of a system throughout its service-life. Selection of the service-life is thus orientated around the overall optimum of system performance and construction, operating and maintenance costs. Behaviour is changing from passive "toleration" of burdens toward maximum service-life and to active management of the (service) lifecycle, including verification of processes and validation of system performance by means, for example, of acceptance inspections, guarantee inspections, continuous condition monitoring and operational checks.

Open questions

Against the above-described background, the network operators[13] linked with the IKT ask themselves the following questions, for example:

What **data bases** are needed for estimation of the service-life, durability and depreciation period, and how can the correctness of this data be assured? This involves, for example, questions concerning planning and valuation, and also, associated with these, the acceptance of rehabilitation work, and possible charge tolerances.

[13] The IKT organises the KomNet municipal network of wastewater-management organisations (with approx. 50 members at present, www.komnetgew.de) and the “IKT-Association of Network Operators”, with more than 130 members (http://www.ikt-online.org/about-us/ikt-association-of-network-operators/ (retrieved 08.03.2018)).

How can **pipe-material selection** be better founded? Criteria such as adaptability, modularity and compatibility are gaining in importance, alongside the traditional durability and robustness for installation and operation.

How can **decision-making processes** be better coordinated? The issue of service-life gives rise to diverse requirements for the durability of sewers and pipelines, their depreciation periods and calculation of charges. These must be assessed in advance. There are, in this context, pronounced interactions with other underground-engineering and infrastructural provisions. Decision-making processes must be harmonised and coordinated with one another in the long term.

Definitions

Durability: "Durability" states for what period a structure or component will fulfil defined performance targets, such as structural safety, operational reliability and tightness, for example (see [BoH]). This concerns, in particular, the ability to withstand internal and external loads and stresses. Durability also depends greatly on quality of installation, signifying that the corresponding risks should be recognised and reduced at an early stage [see VSB]).

Depreciation period (comm.): Depreciation reduces the commercial value of an asset by a defined amount annually, in order to take account of losses of residual value resulting from ageing and operation. The organisation's balance sheet will thus show an ever lower valuation for the asset as time progresses. These annual losses in value are recognised as losses in the current economic year and must be balanced out by income in the same period. Shorter depreciation periods and thus higher commercial decreases in value per year thus increase pressure on the organisation to recoup the lost value at an early stage and thus, where necessary, also to create the basis for future reinvestments. Longer depreciation periods reduce current pressure to recover losses and thus shift it into the future.

Depreciation period (charges): The losses in the residual value of the asset are distributed in the charge calculation across a certain charge period (depreciation) and are financed by the charges levied during this period. This depreciation may also be orientated around reprocurement costs (calculated depreciation), with a view to the reprocurement of the asset. As far as the depreciation period selected is concerned, the rule is that long periods will mean that future users will bear more of the costs of an asset than in the case of shorter periods.

Financing period: The term "financing period" is generally understood to mean the period of repayment of a loan (debt capital). Financing period is zero if a project can be financed entirely using internal capital. The financing period of a loan can also be shortened by replacing one loan with another ("refinancing"). The selection of financing period is thus more a question of financial-management optimisation and has the aim of having the necessary funds available at the right time and at the lowest possible cost.

Lifetime: This term, due to its ambiguity, can lead immediately to misunderstandings. It relates, on the one hand, to the period for which a living organism, such as a human being or an animal, lives and, on the other hand, is used in technical contexts to denote the period of time for which a piece of equipment or a system will function without impairment[14]. It is therefore correspondingly necessary to critically question the application of methods for determination of lifetimes from the one sphere (e.g. life insurances) to the other sphere (e.g. "ageing" of technical systems). The term "lifetime" should, for this reason, be avoided in principle here, and only the concept of "durability" pursued further.

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Reservoirs and Sustainability – When One Does Not Equal the Other

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ABSTRACT

The DeKalb County Department of Watershed Management (DWM) is a water and wastewater utility. Starting as a rural county in 1822, DeKalb County is now a major Metropolitan Atlanta County with over 750,000 residents, thirteen (13) incorporated cities, and rapidly increasing density.

As asset management for renewal and long-term capital re-investment are reviewed, leadership typically looked at pipes, lift stations, and treatment plant units. During asset management reviews, risk evaluations, emergency operations planning, and continuity of operations planning, DWM looked at people, pumps, pipes, electricity, flooding, etc. as the primary sources of risk to our system, generally associated with severe weather events. As such, previous DWM leadership missed the single greatest threat to DWM’s ability to provide reliable drinking water to our stakeholders – a single intake and reservoir system.

As a conscientious utility and to ensure a reliable source of water, DWM built reservoirs to ensure short-term supply. The dams for these reservoirs were placed adjacent to the Scott Candler Water Treatment Plant (SCWTP) located within a major metropolitan area with the inherent, but little understood, risks. Additionally, as those reservoirs were built, and expanded, long-term sustainability and resiliency issues were overlooked as well as other issues such as interbasin transfer requirements, alternative water sources, and emergency interconnections.

DeKalb County intakes water for the drinking water system from one source, the Chattahoochee River. The River is controlled by the US Corps of Engineers to provide water for hydroelectric generation, navigation, and to supply the Metropolitan Atlanta area and other downstream users with drinking water. As drought becomes more frequent and more common, this has led to the “Water Wars” between Georgia and neighbouring States over access to and the amount of withdrawal from this source. DeKalb is in a more precarious

position than most pulling from this source as not only is over half the water returned to a different river basin (no longer allowed for new source permitting), the intake for the system to the reservoirs was designed assuming unlimited water. Therefore, in drought, the water level in the river can drop to levels at which the intake is not designed to operate. DeKalb has already experienced river flow rates where only one (1) of six (6) intake pumps could operate.

Another major risk come from the dams for the reservoir’s themselves. An Emergency Action Plan, or EAP, is a formal document that identifies potential emergency conditions at a dam and outlines procedures to follow to minimize damage and potential loss of life. When DeKalb County developed EAPs, the extent of predicted damage from a dam failure was identified as catastrophic with a high probability of a large loss of life. The lack of awareness and planning became one of the highest risk to continuity of operation, not only from the three (3) DWM owned dams, but the additional fourteen (14) high hazard dams in the County, nine (9) of which are privately owned. Each of the one hundred sixteen (116) dams in DeKalb County can cause infrastructure damage in the event of a failure, with forty (40) of the dams holding back enough water to cause catastrophic damage if breached.

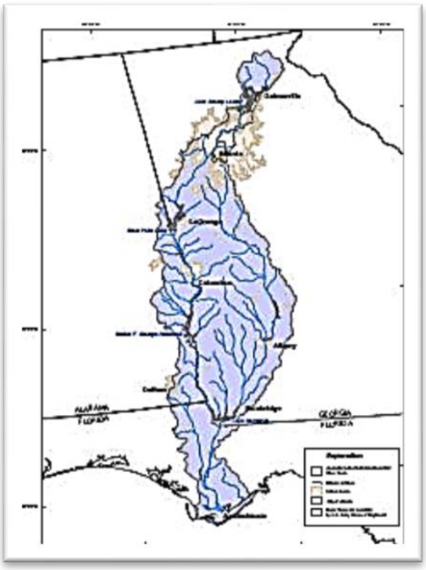
This paper outlines a new understanding of sustainability, resiliency, and risk, often overlooked, by a water utility. It will provide an overview of the issues surrounding Reservoirs including Dam ownership, single source water supply, risk management, and long-term planning experienced by one utility.

1.0 INTRODUCTION

The DeKalb County Department of Watershed Management (“Department” or “DWM”) was established in 1942 to centralize water and wastewater services throughout the county. The Department currently services over 5,000 miles of water and wastewater pipes in the county system with many pipes over 75 years old. Major facilities operated and maintained by DWM include the Scott Candler Water Treatment Plant, the Pole Bridge Advanced Wastewater Treatment Plant, the Snapfinger Advanced Wastewater Treatment Plant, the John A. Walker Memorial Raw Water Pumping Station and various lift stations, booster stations, and water storage tanks.

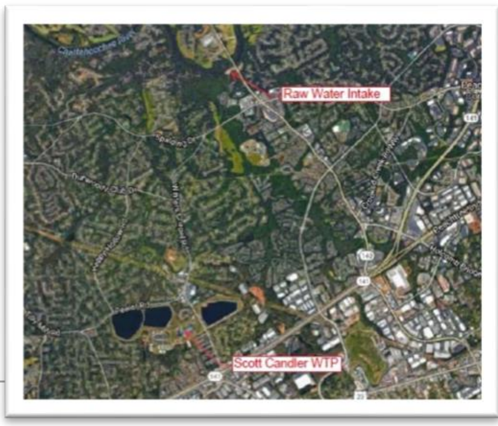
The County obtains water from the Chattahoochee River system. The Chattahoochee River originates in northeast Georgia and flows through the northern portion of the Atlanta metro area to the western boarder of the state near LaGrange, Georgia. The river then flows southward along the Georgia/Alabama boarder where it is joined by the Flint River south of the Florida line to form the Apalachicola River, which discharges to the Gulf of Mexico (Figure 1). The basin also has several impoundments used for hydroelectric generation with the most upstream impoundment being Lake Sydney Lanier that was formed in 1956 by the construction of Buford Dam. The lake is used to provide hydroelectricity, downstream flows for navigation, flood control, and water supply for the city of Atlanta. The United States Army Corps of Engineers (USACE) manages the operations the operations of Buford Dam to meet the various needs. Currently, 12 counties and various municipalities rely on the Chattahoochee River flows for water supply.

Figure 1. Apalachicola, Chattahoochee, and Flint (ACF) River Basin



DeKalb County intakes raw water from the Chattahoochee River through the John A. Walker Memorial Raw Water Pumping Station (Figure 2). The intake is designed for up to 200 million gallons per day (MGD) and permitted to intake 140 MGD, 757 megaliters per day (MLD) and 530 MLD, respectively and employs six 60 MGD pumps. Raw water is transported through three transmission mains to the reservoir system at the Scott Candler Water Treatment Plant (SCWTP).

Figure 2. John A. Walker Pump Station and Scott Candler Water Treatment Plant



As part of adding resiliency to the water system, the County centralized water treatment services to the Scott Candler Water Treatment Plant and built a raw water sto REPLACE ir in 1940. As growth continued in the County, the reservoir, Reservoir 1, was r 979 and two additional reservoirs were added, Reservoir 2 in 1979 and Reservoir 3 in 2003. The three reservoirs (Figure 3) have a combined storage volume of 954 million gallons (MG) or 3611 megaliters, which equates to approximately 11 days of water supply under an average use of 85 MGD or 32 MLD total volume or about six days using the effective volume.

Figure 3. Scott Candler Water Treatment Plant Raw Water Storage Reservoirs

The SCWTP is the only water treatment plant within DeKalb County and supplies water to more than 750,000 residents and businesses. The plant is designed to treat 160 MGD (606 MLD) and is permitted to supply 120 MGD (455 MLD). Distribution to the county ranges from around 75 MGD (284 MLD) to 100 MGD (379 MLD) based on seasonal variations of use with an annual average of about 85 MGD (322 MLD). DWM operates over 2500 miles (4023 kilometres [km]) of pipes in the water distribution system with 43 MG of finished water storage distributed throughout the system (not including elevated tanks used for pressure regulation).

The Georgia Water System Interconnection, Redundancy and Reliability Act (WSIRRA) was signed into law in May 2010. This law required the state to develop emergency contingency plans for water supply including raw water sources and to identify the potential for interconnections and system redundancy. As part of the development of the Georgia Environmental Finance Authority (GEFA) Water System Interconnection, Redundancy and Reliability Act Emergency Supply Plan, September 2011 interconnections and other potential sources of potable water were identified. Table 1 presents the capacity of the intergovernmental interconnections available to DeKalb County.

Table 1. DeKalb County Existing Drinking Water Interconnections[15]

[15] Source: GEFA. 2011. Georgia Environmental Finance Authority (GEFA) Water System Interconnection, Redundancy and Reliability Act Emergency Supply Plan, September 2011. Prepared by CH2M Hill and Jacobs.

Location	Interconnection Government	DeKalb Line (inches/ centimeters)	Intergovern-mental Pipe Connection (inches/ centimeters)	Capacity (MGD)	Capacity (MLD)
Dunwoody Club Drive and Kimbrough Court	Fulton County	8/20.3	12/30.5	1.13	4.28
Peachtree Industrial Boulevard and Winter Chapel Road	Gwinnett County	16/40.6	24/61	4.51	17.07
Waterford Way and Pleasant Hill Road	Rockdale County	8/20.3	8/20.3	1.13	4.28
I-20 Access Road	Rockdale County	12/30.5	12/30.5	2.54	9.61
Flakes Mill Road	Henry County	8/20.3	8/20.3	1.13	4.28
Clark Drive and County Line Road	Henry County	8/20.3	8/20.3	1.13	4.28
Moreland Avenue and Conley Road	Clayton County	12/30.5	12/30.5	2.54	9.61
Peachtree Road and East Club Drive	City of Atlanta	8/20.3	12/30.5	1.13	4.28
Interconnection total availability				15.24	57.69

DeKalb County has developed a robust water system to supply water to residents and businesses. However, previous leadership did not consider the limitations of the system in emergency planning. Upon review of the system several potential issues were identified:

1. Long-term litigation between Georgia, Alabama, and Florida over water use within the ACF Basin limits the operation of Buford Dam, water withdrawals from the

Chattahoochee River, and the amount of water that can be transferred from the ACF to the South River Basin that flows to the Atlantic Ocean as opposed to the Gulf of Mexico.

2. The raw water intake was designed to withdraw water above a specified river elevation. Changes in the operation of Buford Dam and recent severe droughts have shown that, at times, the river elevations drop below the design elevation limiting the quantity of water that can be withdrawn.
3. The county has many pipes that are undersized and again with some pipes more than 100 years old and a 30 to 40 percent more than 50 years old. Aging infrastructure has had increasing number of failures resulting in county-wide impacts.
4. The county has one intake structure and one water supply source. Should catastrophic contamination within the river or failure at the SCWTP occur and persist beyond the storage within the reservoirs, the county would not be able to supply water.
5. Interconnections with intergovernmental partners is limited and of insufficient volume to provide emergency water supply.
6. No comprehensive water and wastewater Master Plan to use as a roadmap for future capital improvement or asset management.
7. The dams for Reservoirs 1, 2, and 3 are high hazard dams that should a catastrophic failure occur, would result in loss of life, property and potential severe damage to the distribution system as the major distribution transmission mains are downgradient of the dams.

DWM leadership recognized these limitations and have been preparing emergency plans that incorporate modification designs to the intake, master planning to site a potential second water treatment plant and water main replacement plans, and the development of Emergency Action Plans (EAPs) to address response actions for possible dam failures of the reservoirs.

2.0 PLANNING: RELIABILITY AND RESILENCY

To address the limitations identified, DWM began a series of planning efforts that have resulted in development of a path forward. These efforts have largely been placed into three buckets: 1) Water supply intake study; 2) Master planning to address water supply redundancy and system rehabilitation; and 3) Emergency planning.

2.1 Stage/Discharge Intake Study

In late summer and fall of 2016, north Georgia experienced an extended period of little to no rainfall. In response to this drought period, the State of Georgia declared a Level 2 Drought. This declaration required DWM, along with the other effected areas of the county, to initiate drought response. Response activities required increased education on water conservation and implementation of various water conservation measures such as mandatory public education, requiring water to be served only on request in food service establishments, limitations on irrigation, limits on the use of fire hydrants to fire safety and public health, and providing water conservation devices for showers, fawcett's, and other devices to customers.

In addition to the 2016 drought, the USACE had implemented relatively new operational procedures at Buford Dam. To protect the water supply within Lake Lanier, the USACE reduced discharges to the Chattahoochee River downstream of Buford Dam. As a result, water elevations at the John A. Walker Memorial Raw Water Pumping Station reached record lows.

The raw water pumping station (Figure 4) was designed to have a nominal water elevation of

Figure 4. DeKalb County Intake Structure on the Chattahoochee River

864 feet mean sea level (msl). Sill elevations of the intake bays for the 6 pumps were set at 862 feet msl. This design was based on the previous operations of Buford Dam that required a flow target of 850 cubic feet per second (cfs) at the U.S. Geological Survey (USGS) gage at the confluence of Peachtree Creek. This location is approximately 27 river miles downstream of the intake. In 2015, the USGS revised the Water Control Manual for the ACF Basin to allow a reduction of flow to 650 cfs at Peachtree Creek to preserve more water in the lake during drought. As a result, the water elevations at the intake dropped below 864 feet msl. At this elevation, only two of the six pumps at the intake can operate due to the risk of cavitation and the two can only run at reduced pumping rates. Lower river elevations limit withdrawals to one pump that can deliver at most 30 MGD. Since the low river flows occur in the summer and early fall, water demand is at a peak level. In 2016, water demand was reduced from a normal year's operation of 100 to 110 MGD to around 95 MGD due to the Level 2 drought declaration.

To assess the threat to raw water supply from drought, DWM conducted a stage/discharge study for the intake[16]. This study found that after review of various scenarios (current and future ACF consumptive water demands with historical hydrology; current and future ACF consumptive water demands with basin inflows reduced by 10 percent), operational modeling shows that Chattahoochee River stages at the DeKalb intake fall below elevation 864.0 about 5% of the time, or about 18 days per year on average in the most conservative scenario. Extreme low stages of 863.0 or lower occur only about 0.1% of the time, or less than 1 day per year on average. However, river stages of 864.0 or lower are most likely to occur during extended dry periods, and as a result may persist for a month or more at a time.

Since the effective volume of the water supply reservoirs at the SCWTP can supply about six days of water at 85 MGD (322 MLD), if drought persisted, there would be insufficient water supply for the county even with stringent water conservation measures in place. This finding indicated the vulnerability of the intake to low water levels. Another confounding problem was the degree of sedimentation that occurs directly in front of the intake. Due to site-specific hydraulic conditions, most notably an existing rock weir immediately upstream of the intake, sediment settles out in front of the mouth of the intake and disturbs the intake systems’ components and associated downstream equipment. The design of the intake did not take into account for these hydraulics that deposits sediments directly in front of the intake bays.

Recommendations from the study identified several temporary and long-term potential measures to address concerns around decreasing river levels in the Chattahoochee River and sediment deposition issues. The development and analysis of these alternative mitigation measures were based on river modeling efforts that have produced historical stage-frequency and stage-duration relationships at the intake. Recommendations included:

Sediment control:

1. Construction of a river vane, made of concrete or steel sheet pile that would serve to divert sediment from the mouth of the intake
2. Construction of engineered log jams, anchored or tethered to the banks of the river to create scour pools for deposition of fine sediments

[16] DWM. 2017. Stage/Discharge Intake Study at Scott Candler WTP Raw Water Intake. July 2017. Prepared by Arcadis U.S., Inc.

3. Reconfiguration of the existing rock weir upstream of the intake structure to redirect sediment away from the intake
4. Deconstruction of the existing rock weir upstream of the intake, involving removal of rocks that create eddy currents and sediment deposition at the intake for transporting sediment further downstream

Intake modifications:

1. Modifying the existing pump station structure wet-well and extending the vertical pump can shafts at two of the pump locations
2. Installation of a companion axial-flow pump station upstream of the existing pump station structure that would pump flows into the existing intake

Temporary or emergency measures to supply water under extreme low flow conditions:

1. A floating barge/pump system that would pump water to the existing intake; the feasibility of this approach is contingent upon adequate depth of flow in the river (under low-flow conditions) sufficiently near the intake to supply the raw water pump station; sedimentation at the intake could potentially complicate this approach.
2. An inflatable dam that would increase river flow depth at the intake as needed during periods of exceptionally low river levels; time required for installation of an inflatable dam would be short, though expedited permitting might be required; alternatively, it might be possible to obtain a conditional permit for an inflatable dam in advance, with conditions to be met prior to installation specified.
3. Hiring a pump vendor to provide a packaged pump station that could be mobilized in an emergency scenario to pump raw water into the existing intake structure.

2.2 Master Planning

The Department finalized a Capital Improvement Projects (CIP) Plan in 2010. The CIP Plan consisted of $1.345 billion of projects to improve the water and wastewater systems. This CIP was based on growth patterns and projections prior to the US housing crash of 2010. As growth patterns changed and increasing density focused on different areas of the county than originally projected, DWM began the development of a Comprehensive Water and Wastewater Master Plan (W&WWMP) in 2017. The goals of the W&WWMP are to clearly identify currently projected growth rates and densities. The W&WWMP will attempt to:

- Determine where the water distribution system is inadequately sized to provide drinking water and adequate fire system flow
- Assess water age, chlorine residual, and disinfection by-products throughout the county
- Develop water main replacement plans based on need to provide redundant connections (looping of the system) and replace problematic mains with excessive breaks
- Determine the potential for additional intergovernmental interconnections
- Assess a location for a redundant water treatment plant and alternative water source
- Assess condition and capacity of the wastewater collection system
- Determine long-term renewal and replacement programs
- Address areas with excessive infiltration and inflow
- Determine potential siting and sizing of a wastewater treatment plant for the northern part of the county where wastewater enters and is treated by the City of Atlanta through and intergovernmental agreement that expires in approximately 15 years

In 2011, the County entered into a federal court ordered Sanitary Sewer Overflow (SSO) Reduction Consent Decree (CD). The CD backed by the Clean Water Act, requires the county to eliminate SSOs. The initial cost estimates for the needed rehabilitation of the wastewater collection system was around $600 million. This only included the higher priority areas of the county. It is anticipated that at least another $200M to $300M will be needed to address some of the other areas within the county. Therefore, in-depth planning and growth estimates were needed to begin to address the deficiencies in the water and wastewater systems.

To improve water resiliency, DWM will focus on three key concerns. First, what needs to be done to ensure water supply is available should: 1) the intake on the Chattahoochee River be compromised; 2) a catastrophic failure occur at the Scott Candler WTP; and 3) what needs to be done to the distribution system to prevent area wide outages of water due to main breaks.

In initial planning efforts, DWM is looking for a site in the South River Basin. Due to Georgia’s long-term water litigation with Alabama and Florida over water within the ACF Basin (Tri-state Water Wars), DeKalb is limited in the quantity that may be discharged by the County’s two wastewater treatment plants. Both plants are located south and east of the eastern continental divide and discharge to the South River that flows ultimately to the Atlantic Ocean. Because one the key complaints in the Tri-state Water Wars is the need for freshwater outflows in Apalachicola Bay (Gulf of Mexico) to support the oyster industry, DeKalb is limited to a maximum cap of 56 MGD of interbasin transfer of water from the Chattahoochee Basin to the South River Basin. While currently, DeKalb discharges less than this quantity, future growth projects show the potential for this cap to be reached in the near future.

Figure 5. Bellwood Quarry – Raw Water Reservoir (before construction)

One of the alternatives under consideration is to site a new plant in the southeastern portion of the county that would employ pump diversion to withdraw water from the South River and store it in a reservoir built adjacent to a new water treatment plant. DeKalb County is underlain by shallow crystalline granite rock as part of the granite of Stone Mountain. Because of the granite that underlies most of the eastern part of DeKalb County, several granite quarries exist. This alterative would pump water into a quarry, which would be large enough to hold five to ten days of raw water supply. This project is estimated to cost around $200M.

Figure 6. Water main break and repair

A second plant capable of producing 100 to 120 MGD would provide enough redundancy to provide water throughout the county during an emergency situation. An example of this approach is being used in the City of Atlanta with Bellwood Quarry (Figure 5) being converted to a water supply reservoir. This would protect public health and the economic interests of the county should there be a catastrophic failure of a critical component at the SCWTP. Important considerations would be to carefully control finished water chemistry to prevent corrosion of pipes within the distribution system.

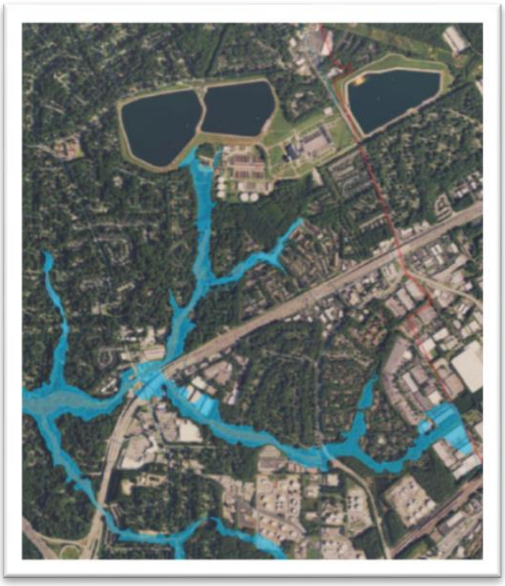
Another real threat to the resiliency of DeKalb County’s water supply is aging infrastructure. Recently, DeKalb County had a 48 inch transmission main break (Figure 6) in the northern part of the county. Because of old valves that had not been exercised regularly, it took over seven hours to isolate the break. An estimated water loss of 60 MG occurred with the reservoirs having a visible impact as the loss of water pressure shut down the raw water intake pumps due to low seal pressure (a vulnerability now being addressed). More than one-half of the county was out of water including hospitals, schools, and senior centers. A boil water advisory was issued countywide due to low pressures and schools were shut down for 2 days and businesses in the affected areas closed. This impact was widespread. Three years earlier a 30 inch transmission main broke with similar results.

Weekly, a water main breaks within the county due to ageing pipes. The Master Plan has identified old pipes and ranked replacement based on criticality of failure, problematic areas with numerous breaks, age, and water quality issues. Initial estimates for replacement indicates $500M to address water mains over the next five to ten years.

2.3 Emergency Action Plans – Dam Safety

The three reservoirs and the Scott Candler WTP are considered high hazard dams. Should one or more of these dams breach there could be an immediate significant loss of life and property. Longer-term impacts include: loss of raw water reliability for the county and potential destruction of critical infrastructure (the three main transmission mains that feed the majority of the County) are just downgradient of Reservoirs 1 and 2. Once DWM realized the criticality of the potential impact should a catastrophic failure of the dam(s) occur, Emergency Action Plans (EAPs) were developed that detailed the potential impacts including flood inundation (Figure 7); affected infrastructure including roads, pipes, and other facilities; and defined affected property owners.

Figure 7. Example of flood inundation mapping



The EAP is a formal document that identifies potential emergency conditions at a dam and outlines procedures to follow to minimize damage and potential loss of life. The national average for dams with completed EAPs is 79%[17] with some States addressing the issue through new regulations requiring owners of high hazard dams to develop and submit plans. When DWM developed the required EAPs, the extent of predicted damage from a dam failure was identified as catastrophic with a high probability of a large loss of life. The lack of awareness and planning became one of the highest risks to continuity of operation, not only from the three (3) DWM owned dams, but the additional fourteen (14) high hazard dams in the County, nine (9) of which are privately owned. There are an additional ninety-nine (99) dams in the county that are listed as low hazard (no permanent continuously occupied structures in the inundation zone) and exempt (meeting specific criteria).

To alert the county and emergency services, DWM conducted a table top exercise (TTX) on a dam breach. This TTX brought about a new awareness of the vulnerability of the water system and the need to add redundancy. From this, DWM has learned lessons from identification of this risk and is better prepared to move forward with a redundant storage reservoir and treatment plant. Changes that are still needed include the design and installation of a reverse pumping capability to lower reservoir levels in an emergency at a safe rate, a survey to look for settling in the dam conducted at regular intervals, obtaining a reverse 911 system to alert residents and businesses in the event of a failure, and review of potential

[17] "National Inventory of Dams" CorpsMap: The National Inventory of Dams (NID). N.p., n.d. Web. 08 February 2017.

individual private dam impacts on critical water infrastructure. However, there is a core knowledge of the risks and a clear mission at the facility and with engineering and regulatory compliance to ensure the response system is never needed.

3.0 PATH FORWARD

DWM has recognized that the water system within DeKalb County has several vulnerabilities. Once recognized, DWM began developing plans and projects to address each identified issue. Moving forward, DWM must educate County leadership on the criticality of these projects. Once done, developing a more reliable system with redundancies will ensure the welfare of the citizens of the county and provide a reliable basis for economic development.

NEED TO SPEED UP REHABILITATION RATE OF WATER AND WASTEWATER SYSTEMS

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Keywords: aging infrastructure, rehabilitation, vulnerability, green economy

In Finland as well as in most other developed nations one of the greatest future challenges is aging water infrastructure. In particular the invisible part of the systems, the underground networks, are deteriorating far faster than the pace of renovation. This problem is slowly being acknowledged but so far only limited actions have taken place to alter the development path. It is possible to solve the challenges of aging infrastructure and networks, but it will require appropriate institutional arrangements from various stakeholders. Without additional efforts on rehabilitation, the backlog in maintenance and repair will persist and vulnerability will continue to increase.

Water is fundamental to the green economy because it is interwoven with so many sustainable development issues, such as health, food security, and poverty. In developing countries, access to water and sanitation services is a fundamental precondition for poverty reduction and economic progress. The official figures on the coverage of water and sanitation services in developing countries give a far too positive picture of the situation. These figures typically cover the number of people living within the reach of the built systems. Unfortunately, often these systems are totally out of order, or function only some hours per day. Maintenance has been neglected as it is more attractive for politicians and decision makers to advertise expansion of the networks than spending on the maintenance of existing infrastructure.

The multiple benefits of providing access to water and sanitation in terms of health, life expectancy, and the freeing of time for education and economic activities, are well known. Water is arguably more fundamental than any other resource – to life itself, supporting a huge array of ecosystem services, and to every economy and society. Water contributes directly and indirectly to virtually all other ecosystem services but the area of water supply and sanitation also comprises an economic sector in itself.

Direct benefits to society can be expected to flow both from increased investment in the water supply and sanitation sector, including investment in the conservation of ecosystems critical for water. Research shows that by investing in green sectors, including the water sector, more jobs and greater prosperity can be created. These opportunities are likely strongest in areas where people still do not have access to clean water and adequate sanitation services. Early investment in the provision of these services appears to be a precondition for progress. Once these investments are made, the rate of progress will be faster and more sustainable, thus making transition to a green economy possible. The costs of achieving a transition will be much less if the increased investment is accompanied by improvements in governance arrangements, the reform of water policies and the development of partnerships with the private sector. The opportunity to improve governance arrangements is one of the biggest opportunities to speed transition to a greener economy.

The investments in the rehabilitation of water and sanitation services infrastructure have also recognized positive impacts on the job creation and economic performance of the businesses. For example, if in the US the estimated investment gap were closed, it would result in over USD 220 billion in total annual economic activity to the country. These investments would generate and sustain approximately 1.3 million jobs over the 10-year period. Furthermore, the value of safe provision, delivery, and treatment of water to customers results in significant avoided costs for businesses that would otherwise have to provide their own water supplies. These investments would save US businesses approximately USD 94 billion a year in sales in the next 10 years and as much as USD 402 billion a year from 2027 to 2040.

Measures of Road and Sewerage Bureau for the Sinkhole Accident in front of Hakata Station

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Road & Sewerage Bureau, Fukuoka City

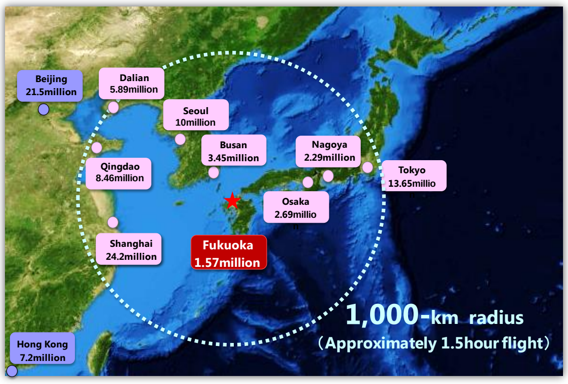
SUMMARY

At around 5:15 AM on November 8, 2016, a massive sinkhole (27 meters wide, 30 meters long, and 15 meters deep) occurred at the Hakata-eki 2-chome intersection in Hakata Ward in Fukuoka City. The sinkhole was caused by construction work that was underway on the extension of the Nanakuma Line of the Fukuoka City subway system. Although this accident had a significant impact on the lives of the residents and economic activity, the road reopened at 5AM on November 15, just seven days after the accident occurred. This paper describes the emergency responses taken by the Sewerage Department in the Road and Sewerage Bureau after the accident occurred and provides an outline of the recovery of the sewerage services affected by this accident.

Keywords: Sinkhole accident, emergency response, prompt action

1 Fukuoka City

Fukuoka City is located at the western part of the Japanese archipelago within 1,000 km of Tokyo, as well as Seoul, Korea and Shanghai, China. It is the largest city in Japan closest to East Asia. Fukuoka has developed through interaction and exchange with Asia for over 2,000 years. Today, it has a population of 1.57 million, the fifth largest in terms of population scale among the 20 designated ordinance cities in Japan. Urban functions are compactly concentrated in the city center of Fukuoka City, within a radius of 2.5 km of JR Hakata Station, a major stop for the city’s international airport, international port, and bullet train. With 420,000 passengers arriving and departing each day, Hakata Station is a leading terminal in Kyushu and Fukuoka with a number of commercial facilities and office buildings located in the vicinity of the station. Figure 1 shows the location of Fukuoka City. Figure 2 shows the compact concentration of urban functions.



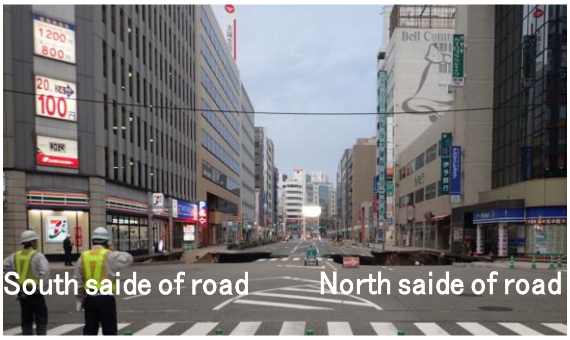
【Fig. 1. Location of Fukuoka City】

【Fig. 2. Compact city functions】

2 Overview of Sinkhole Accident

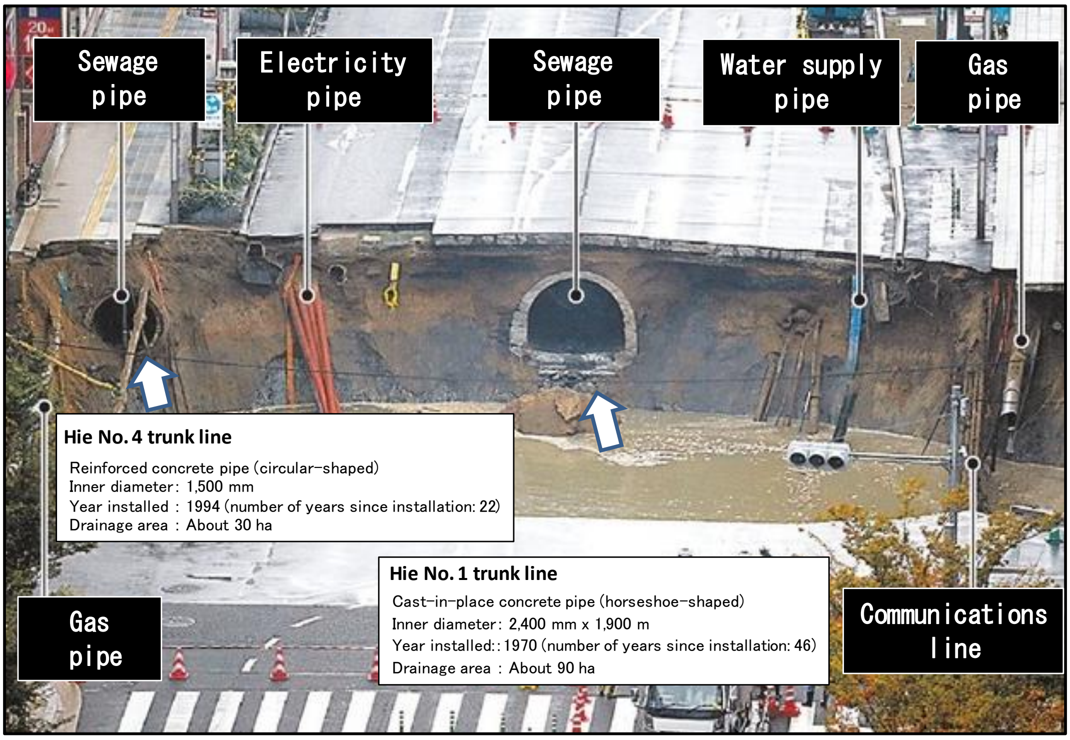
At around 5:15AM on November 8, 2016, a sinkhole occurred on a section of the road near the Hakata-eki 2-chome intersection, which is about 300 meters from JR Hakata Station. The massive collapse occurred around 5:20 AM on the southern section of the road and around 5:30 AM on the northern section of the road, with the central section of the road collapsing at around 7:20 AM, creating a sinkhole that was 27 meters wide, 30 meters long, and 15 meters deep. Photo 1 shows the location of the sinkhole. Photo 2 shows the sinkhole as seen from JR Hakata Station. Photo 3 is a photo of the sinkhole.

【Photo 1. Location of sinkhole】



【Photo 2. Sinkhole seen from JR Hakata Station】

The sinkhole was caused by a massive inflow of groundwater and soil into the tunnel, due to the collapse of the upper working face during construction of the tunnel using the NATM (New Austrian Tunneling Method) to extend the Nanakuma Line on the Fukuoka subway system. However, as a result of the quick evacuation of workers and measures to prevent vehicles traveling above ground from passing through the area, thankfully no life-threatening injuries were reported, even with the massive scale of the sinkhole. However, since lifelines, such as water supply, including the sewerage system, electricity, gas, and communications, were cut and functions temporarily stopped, there was no major impact on the lives of the city's residents and economic activity. Photo 4 shows the damaged lifelines.



【Photo 4. Stricken lifelines】

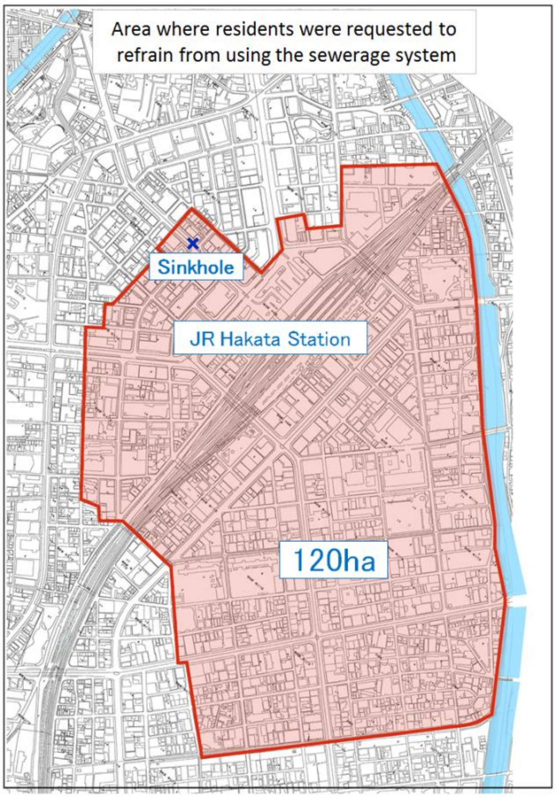
In order to reopen the road as quickly as possible, "fluidized treated soil" that solidifies even in water, was placed in the sinkhole on the day of the accident as backfilling material to stabilize the sinkhole and prevent a secondary collapse. In addition, in order to restore lifelines as quickly as possible, a "Lifeline Coordination Committee" was created that assembled together managers for traffic, roads, and underground structures, as well as subway construction companies and contractors. At the meeting of the committee the next day, the members indicated a policy to restore all the lifelines, including the collapsed road, so that they could be used by November 14. The combined sewerage trunk lines Hie No. 1 and No. 4 were extensively damaged and affected the recovery process significantly. However, as a result of the 24-hour efforts by the unified "All Fukuoka" team consisting of the public and private sector that worked to restore the area, the road reopened at 5 AM on November 15, seven days after the accident occurred.

3 Emergency Response by Sewerage Department

Since sewage flowed into the sinkhole immediately after the accident, the Sewerage Department implemented emergency measures, including requesting people to refrain from using the sewerage service, implementing bypass works, and injecting disinfectants. An overview of the responses taken is shown below.

3.1 Emergency Response: Requests to residents to refrain from using the sewerage service (November 8, 11:30-November 9, 20:00)

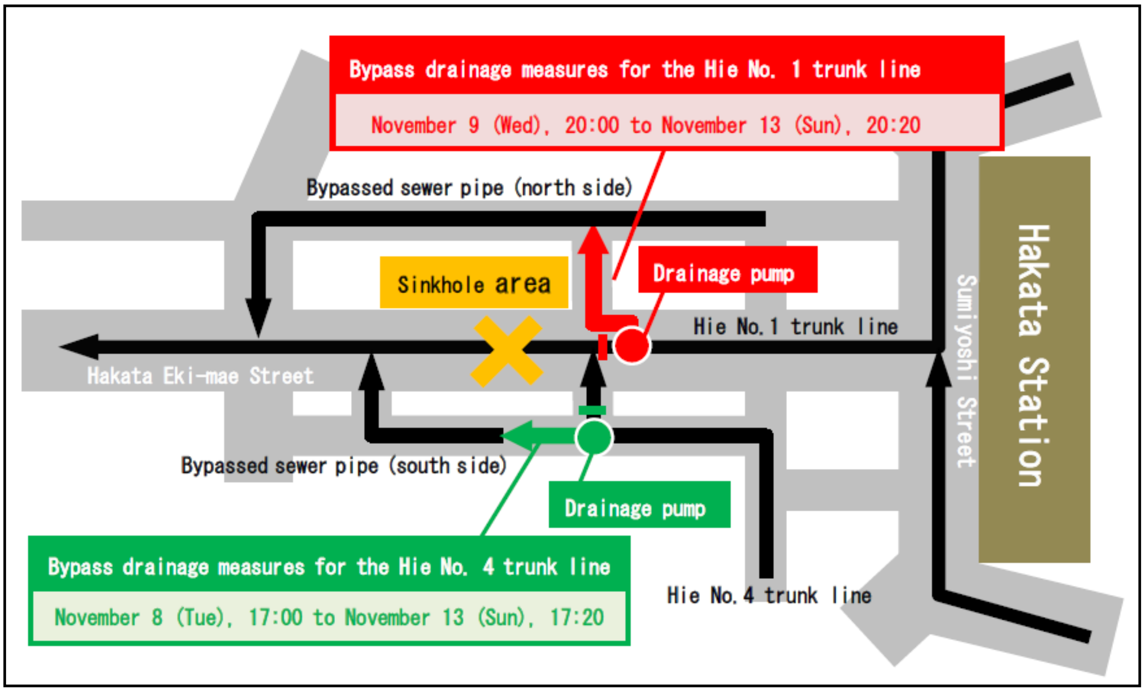
As an emergency response to control the inflow of sewage into the sinkhole, Fukuoka City requested residents to refrain from using the sewerage service covering an area of about 120 ha (about 1,000 buildings) around Hakata Station where sewage was flowing into the sinkhole. In addition to providing information to the press, Fukuoka City also made these requests using PR vehicles and on the city's website. There were about 50 inquiries from residents, including questions asking, "Is my house in the restricted area?" and "Please give me more details about how I should refrain from using the sewerage service." However, there were no complaints about the request. When the city received such inquiries, they asked for the cooperation of residents to wash dishes with stored water and frequently turn off the water or to use the remaining water from baths when doing laundry. As a result of the prompt actions taken with bypass works after the accident, the restriction period on the use of the sewerage system lasted only about 30 hours. Figure 3 shows the scope of the request to refrain from using the sewerage system.



【Fig.3. Scope of requests to residents to voluntarily refrain from using sewerage system】

3.2 Emergency Response 2: Bypass works (November 8, 17:00 - November 13, 20:20)

Although the critical Hie No. 1 and No. 4 trunk lines were damaged and the city put out a request for residents to voluntarily refrain from using the sewerage service, it was necessary to allow sewage to be discharged without flowing into the sinkhole in order to minimize the period in which residents voluntarily refrained from using the sewerage service and to avoid obstructing recovery work if sewage flowed into the sinkhole. For this reason, temporary drainage pumps were installed in manholes located upstream of the sinkhole area on the Hie No. 1 and No. 4 trunk lines and sewage was pumped quickly through hoses to sewage pipes in other systems. As a result of this action, it was possible to stop the inflow of sewage into the sinkhole and lift the voluntary restrictions on the use of the sewerage system at 20:00 the next day. Bypass works were carried out for six days until November 13 until a temporary pipe could be installed at the site of the sinkhole. Figure 4 shows a schematic diagram of the bypass works system. Table 1 shows facilities related to the bypass works. Photo 5 shows the state of bypass works on the Hie No. 1 trunk line.



【Fig. 4 . Bypass drainage measures (schematic drawing)】

【Table1.Facilities and equipment related to bypass works

	Cavity of existing facilities	Cut-off wall		Temporary pipe	Pipe materials
		Installation height	Opening height		
Hie No. 1 trunk line	2400㎜×1900㎜	900㎜	1000㎜	6 inches x 3 pumps Volume discharged: 0.04 m3/s x 3 pipes = 0.12 m3/s	Φ150㎜ Horseshoe-shaped section: Suction hose Hume concrete sewer: Sunny hose
Hie No. 4 trunk line	Φ1500㎜	900㎜	600㎜	6 inches x 2 pipes Volume discharged: 0.04 m3/s x 2 pipes = 0.08 m3/s	Φ150㎜ Suction hose

3.3 Emergency Response 3: Injection of disinfectants (November 8, 17:20 – November 11, 15:00)

In considering sanitation in the surrounding environment, Fukuoka City injected a chlorine disinfectant (solid and liquid form) for four days from November 8 to 11 in three places: the sinkhole site and the Hie No. 1 and No. 4 trunk lines located upstream from the sinkhole. A total amount of 70 kg of solid chlorine and two liters of sodium hypochlorite were injected. Photo 6 shows how the disinfectant was injected.

【Photo 6. Injecting disinfectants】

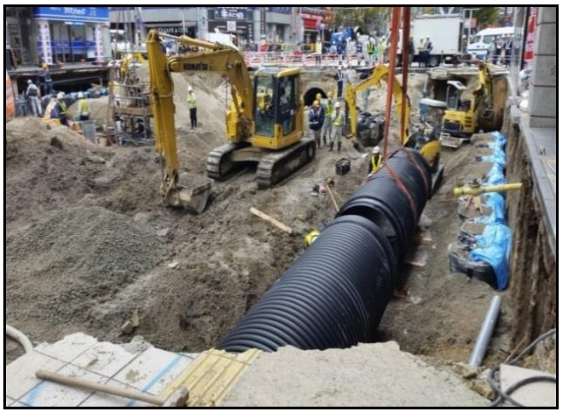
4 Temporary Restoration of Damaged Sewerage Facilities

Although restoring sewerage facilities was the principle idea behind the recovery effort, the existing Hie No. 1 trunk line was a horseshoe-shaped sewer and the Hie No. 4 trunk line was a Hume concrete sewer, both of which require concrete foundations. Recovery work on the Hie No. 1 trunk line, in particular, was expected to take longer to restore since it would require a considerable number of days. In this situation, the government and subway contractors worked together, and as a result of a review on the selection of pipes, construction machinery, and materials with a draining capacity equivalent to those of existing facilities that could be procured as soon as possible, they decided that it would be possible to use “polyethylene rib pressure pipes”, which are lightweight and strong, and which could be installed as temporary pipes to speed up the recovery period, which allowed them to complete the temporary recovery work of the Hie No. 1 and No. 4 trunk lines in two days. Table 2 shows a comparison of polyethylene rib pressure pipes with box culverts. Photo 7 shows the state of recovery work on the Hie No. 1 trunk line. Photo 8 shows the state of recovery work on the Hie No. 4 trunk line.

【Table2.Comparison with conventional materials(box culvert)

Item	Polyethylene rib pressure pipe	Box culvert
Construction period	About 2 days	About 5 days
Foundation	Crushed stone foundation (no need for covering)	Concrete foundation (requires covering)
Construction machinery	70-t crane	175-t crane

【Photo7. Status of recovery of Hie No. 1 trunk line】



【Photo 8 . Status of recovery of Hie No. 4 trunk line】

5 Leadership Key Decisions

Fukuoka City’s Mayor Takashima rushed to the site himself after the collapse and make two extremely important decisions immediately after the accident amid concerns that the sinkhole may expand further. The first was the decision to “prioritize recovery” rather than “investigate causes” in order to prevent secondary damage from occurring. The second was to carry out recovery in two stages by first implementing temporary recovery measures and then continuing with recovery work in order to quickly restore the functions of daily life where residents could feel safe, rather than full recovery work for damaged lifelines, which would have required a longer period of time. At the “Lifeline Coordination Committee” meeting the day after the sinkhole occurred, the mayor elicited a policy directly from the managers of underground facilities in their own words that all lifelines, including those in the collapsed road, would be temporarily restored by November 14 and strongly appealed for the cooperation of “All Fukuoka” to ensure that this would happen quickly. We shared this policy with everyone and believe that the quick recovery from this accident was achieved as a result of all parties working together.

Our Sewerage Department took the position that it was important that sewage did not flood the city area and to prioritize preserving sanitation in the city. Fortunately, since the sewage pipes were not blocked, sewage flowed downstream even when it remained in the sinkhole area, so there were no concerns of it overflowing aboveground. However, when sewage flowed into the sinkhole area, it interfered with recovery work. For this reason, we decided to implement emergency responses, including requests for residents to refrain from using the sewerage system and switching trunk lines with bypass works. Through the emergency responses by the Sewage Department for this accident, I feel that it is important for accurate decisions to be made at the head office and onsite, even in difficult situations where the situation is constantly changing. I once again recognize the need to develop human resources who are capable of understanding the entire sewerage system (sewers, pumping stations, treatment plants), including planning and maintenance, to secure urban functions in Fukuoka City.

6 Conclusion

Recovery work by the “All Fukuoka” team made up of the public and private sector was in place in 24 hours. With the cooperation of 110 companies from various industries, such as manufacturers of fluidized treated soil used as filling material at the sinkhole, mixer companies responsible for transportation, contractors engaged in temporary recovery work for facilities underground, including the sewerage system, water supply, gas, and electricity, and security companies, as well as over 1,000 workers, we were able to reopen the road at 5 AM on November 15, seven days after the accident.

We are currently in discussions with stakeholders about the specific time period and method we will use to restore sewerage facilities in the future. Photo 9 shows a line of mixer trucks. Photo 10 shows the state of recovery of each underground facility, and Photo 11 shows the situation just before the road was reopened.

【Photo 9. Line of mixer trucks】

【Photo 10. Underground facilitie

【Photo 11. Road just before it reopened】

A new sustainable river management Approach for improved asset resilience in a water utilities company

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Matthew Buckley, Environmental Planner, United Utilities

1. Resilience in the water sector

"Resilience is the ability of assets, networks and systems to anticipate, absorb, adapt to and / or rapidly recover from a disruptive event", UK Government definition[18].

Building resilience is one of the UK government's top priorities for the water sector and this is driven from the following five challenges: population growth, ageing infrastructure, environmental degradation, climate change and affordability[19]. The Water Act 2014 (England and Wales) introduced a new duty to Ofwat (the economic regulator of the water sector in England and Wales) to implement long term planning and investment to manage water networks sustainably and to increase efficiency[20]. Specifically, the UK Governments' guidance on natural hazards and infrastructure, suggests that resilience measures should fall into the following four categories, the 'four R's[1]:

1. **Resistance:** providing protection against future hazards
2. **Reliability:** enabling an asset to operate under a range of conditions
3. **Redundancy:** concerning a network or system and the availability or spare capacity of back up assets
4. **Response and Recovery:** enabling an asset to have a fast and effective response to disruption.

The 'four Rs' set out the key principles of resilience and recommend that authorities use an approach combining measures to address all four principles.

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[18] Cabinet office (2011) Keeping the country running: Natural Hazards and Infrastructure, Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/61342/natural-hazards-infrastructure.pdf

19 Arcadis and United Utilities (2017) Measuring resilience in the water sector, Available from: https://www.unitedutilities.com/globalassets/z_corporate-site/about-us-pdfs/looking-to-the-future/measuring-resilience-in-the-water-industry_final.pdf

20 Ofwat (2018) Resilience, Available from: https://www.ofwat.gov.uk/regulated-companies/resilience-2/

This paper particularly focuses on how United Utilities have changed their 'Resistance' approach for assets that have become vulnerable to risks of fluvial erosion and deposition. This is compatible with a wider United Utilities resilience strategy incorporating all 'four Rs'. Some of the case studies presented in this paper overlap into the other 'Rs'.

The two scientific disciplines of fluvial geomorphology and resilience have many similarities/ parallels. Both recognise the interlinkages between natural processes, ecosystems, economies and societies. However, those involved in resilience planning for riverine assets often have limited awareness of core geomorphological principles and themes (such as systems and scale, equilibrium, thresholds and stability, spatial differentiation and responses to historical events) suggesting that opportunities to apply knowledge and lessons learned from studying holistic geomorphic systems have often been missed when planning for resilience[21]. Until this new sustainable river management approach (encompassing a geomorphological assessment of erosion and deposition risks) was adopted in United Utilities, it was apparent that whilst UU have always strived for resilient assets, opportunities were being missed to optimise resilience measures.

2. About United Utilities

United Utilities (UU) is the largest private and only FTSE100 listed water utilities company in the UK. It provides water and wastewater services across the North West of England to Cumbria, Cheshire, Greater Manchester, Lancashire and Merseyside. It serves a combined population of nearly 7 million people.

A large proportion of UU's water resources are captured, stored and transported from the Lake District National Park and other parts of Cumbria via thousands of kilometres of pipes, aqueducts and associated river network. Much of this infrastructure dates back to late Victorian times and the early 20th century, where the system was designed to be gravity driven as far as possible. Consequently, many of the assets and associated infrastructure share the valley floor with rivers. Compared to water resource zones of the other water companies around the UK, the North west of England is generally steep and mountainous making many rivers flashy, powerful and very active geomorphologically, with consequences for those assets located adjacent to rivers.

[21] Thoms M.C., Piegay H. and Parsons M. (2017) What do you mean, 'resilient geomorphic systems'?, *Geomorphology*, **305**:8-19

A number of flood events in recent years (2007, 2009 and 2015) have caused major damage and disruption to infrastructure throughout Cumbria, including UU assets. There is public perception in some areas that key stakeholders, such as United Utilities, have contributed to or exacerbated the damage through the effects of reservoirs and water infrastructure throughout the catchment. It is key to United Utilities reputation to be seen to be managing assets in the catchment appropriately and also that where they are the landowner with accompanying assets, they are providing suitable resiliency measures to avoid future major disruption.

3. Factors influencing river channel changes in the North West England

Fluvial (river) geomorphology is the study of rivers, their channel shape and processes. River channel activity, such as erosion, deposition, is influenced by a number of factors including: how sensitive a river may be to change, prevailing flow conditions, channel gradient, channel shape, sediment supply and the available stream energy (stream power). The fluvial geomorphology within the North West of England is largely governed by steep topography, which has been shaped by glaciation during the late Pleistocene and Holocene periods. Like many rivers in the mountainous, glaciated areas of Europe, the rivers in North West England rivers can be characterised by high stream powers, flashy flow regimes and plentiful sediment supply (from hillslope processes and glaciation features), resulting in high rates of activity.

3.1 Gradual natural channel changes

As in many parts of Europe, the North West of England has been subjected to different climatic conditions giving rise to periods of glaciation and deglaciation, and consequent natural deforestation and afforestation. In the past, these natural changes in the environment would have altered hillslope flow pathways, hillslope erosion, and rates of sediment transport. Today the legacy of these past processes has determined rates of channel activity, together with human impact. Given the size of some river catchments, there could be considerable lag time before the effects of changes to climatic conditions become reflected in a river channel response. Additionally, the catchment response to a large storm event is often present in the landscape for many years after the event. Adjustment can be a slow process.

3.2 Rapid channel changes

Under normal circumstances in Cumbria, where the climate is humid and temperate (with stability being provided by vegetation), rapid river channel is relatively rare. Most accelerated erosion problems are where there have been anthropogenic modifications or after a high magnitude flood event. In the North West of England, a 1:1300-year event (Storm Desmond) broke the UK record for rainfall with 341mm across a 24-hour period which caused widespread erosion and deposition across the whole of the Cumbria region. The storm caused significant damage to infrastructure belonging to United Utilities as well as other responsible authorities in the region, with catastrophic erosion of the A591, a major transport route between Windermere and Keswick. Assistance from the army was required the short term to clear the mounds of deposited sediment (thousands of tonnes) piled across roads from rivers that had come out of bank. This event highlighted the widespread vulnerability of assets and infrastructure in the region which impacted a wide range of stakeholders.

3.3 Human influenced channel changes

Much of the river activity observed in the North West of England is directly influenced by human induced changes to land use, flow, sediment supply or channel morphology that have taken place historically. Like many rivers across Europe, rivers in the North West of England were utilised for their power (e.g. mills), water supply (e.g. reservoirs and intakes) and transport (e.g. Manchester Ship Canal). There is widespread evidence of channel realignment and river impoundments (weirs) dating back to the earliest available detailed maps (early 1800s) and records of channel dredging and other maintenance operations being undertaken regularly since at least the 1950s. When reservoir dams were constructed, many of them dating back to the late 1800s, these significantly altered flow regimes and could subject rivers to long periods of no flow or short sharp periods of high flows. This resulted in a disruption to natural river regimes and introduced and element of instability into river systems, particularly downstream.

Natural river regimes generally operate around an average state of equilibrium whereby channels will adjust their channel size and shape according to the average prevailing environmental conditions. If a channel has been artificially modified (e.g. widened straightened, impounded or subjected to an artificial flow regime) the following can happen:

- the river can become unstable making future river activity difficult to predict
- over time a river may recover towards a more natural state (provided no further modifications take place)
- as adjustment takes place, assets adjacent to rivers can be put at risk of erosion or deposition affecting them structurally and/or operationally.

Over the next few decades, river catchment responses to human-induced climate change are likely to further change the patterns and processes observed in active rivers across upland areas of the UK and Europe. As such, it is essential that utilities assets (and all other infrastructure adjacent to river channels) are protected in an appropriate way to increase their resilience to such changes, and that sustainable protection measures are implemented. Such measures need to provide environmental improvements where possible and also to be cost-effective in the long term.

4. Key legislation

Key legislation that has driven United Utilities new approach to sustainable river management is shown in Table 1. The European legislations must be considered during any river management works undertaken in member states of the European Union.

Table 1: Key legislation driving the new approach to sustainable river management

Legislation	Description	Driver for new approach
Water Act 2014 (England and Wales)	Places a new duty on Ofwat to ensure that water companies incorporate long term resilience measures into their price reviews and strategies.	New approach helps to demonstrate commitment to the '4 Rs', in particularly to the 'Resistance' of assets.
Water Framework Directive (WFD)	Takes a holistic approach to river catchment management and brings together key stakeholders within river catchments to reach a common goal of river protection and improvement. Under the WFD, it is mandatory that all surface water bodies, of which rivers are included, must achieve at least 'Good Status' by 2027 and in the meantime, their current status must not deteriorate. Where a water body is considered to be a 'Heavily Modified Water Body' or 'HMWB', the requirement is for that HMWB to achieve 'Good Potential'. For HMWBs, there is a set of mitigation measures that need to be implemented to achieve this Potential. River Basin Management Plans outline the key actions and stakeholders that must come together to achieve at least Good Status.	New approach is in line with the objectives of the WFD and provides the necessary assessment to demonstrate compliance with the WFD and mitigation measures for where there is risk of non-compliance.
Floods	Complements the WFD, and promotes	New approach promotes

Directive	catchment wide sustainable flood risk management.	working with natural processes and where possible relocating assets away from rivers, thus where possible improving flood risk and at the minimum having a neutral impact on flood risk.
Habitats Directive	Aims to conserve animal and plant species are classed as 'protected' because they are either rare, threatened or endemic. Characteristic habitat types are also named and protected under this directive. Many of the sites especially within Cumbria in the North West of England are classed as 'Designated Sites' - Special Areas of Conservation (SAC) or Special Protection Areas (SPA) because they contain protected species or habitat types. This can range from Fish such as Bullhead and Salmon to species such as White Clawed Crayfish or Freshwater Mussels to plant species and macrophytes within the river corridors.	New approach brings in all relevant environmental specialists early on in the project so that an appropriate solution is developed from many viewpoints and constraints and impacts of design and construction are mitigated as far as possible. The approach also encourages environmental betterment where there are protected species.

5. Asset resilience at the river reach scale

Figure 1: Example of poorly situated outfall with bank protection washed out and eroded because river previously meandered across this field before being straightened and recent high flow events instigated channel change towards a historical planform

Using the Water Act 2014, WFD, FD and HD, Jacobs geomorphologists and UU environment and sustainability team have promoted more sustainable methods of protection of utilities assets. Traditionally hard engineering techniques (e.g. concrete bank protection, river realignment, rock armour, gabion baskets and pipe bridges) have been employed to address geomorphological issues at utilities assets. If a river channel had laterally migrated and exposed an asset such as a water mains or wash out chamber, a common engineering response would be to modify the river channel (e.g. realign it), re-instate the eroded bank and protect with hard engineering techniques such as concrete, rock armour or gabion baskets with the aim of preventing the lateral migration of the river. These types of measures which keep the asset in place and work against natural river processes often end up being only relatively temporary fixes in the short to medium term as river channel will have a natural tendency (under gravity) to adjust. For example, without careful design, bank protection placed to prevent the natural lateral (sideways) movement of a channel can result in increased erosion elsewhere (particularly downstream) and ongoing maintenance issues. Preventing erosion where it would have occurred naturally often results in the transference of stream energy elsewhere, either to the next available unprotected point of the bank, or into the river bed (downcutting). Both of these processes can result in the undermining and failing of the bank protection, thus increasing the risk to the asset and requiring continued maintenance, which is unsustainable (Figure 1).

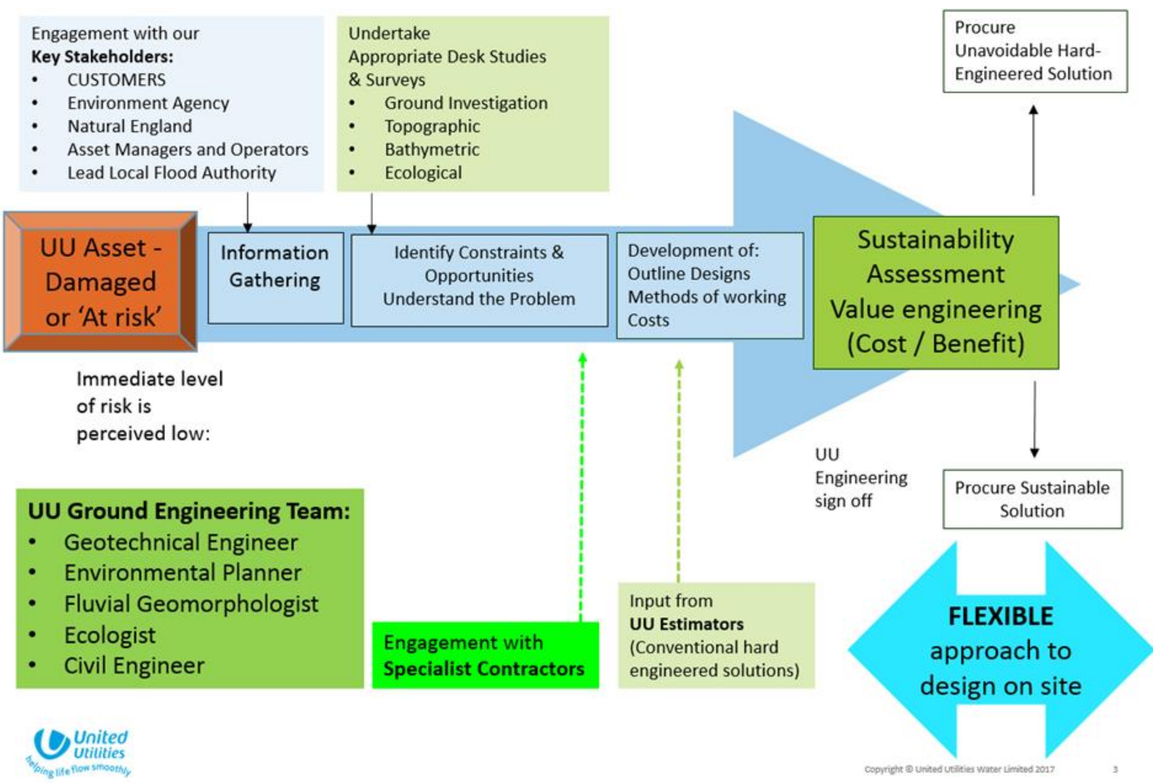
To implement the most sustainable, resilient solution for an asset, it is imperative that an adequate assessment is undertaken of the existing channel geomorphology (baseline) and what problems have arisen or are likely to arise with/ without intervention. This assessment can then inform a sustainable course of action to protect an asset. In some instances, hard engineering will be the preferred solution as engineering feasibility needs to be considered. Table 1 shows the risk matrix used in a geomorphological assessment to determine the level of risk to the asset and possible course of action. In cases where a river is not an active gravel bed river, it may be that no bank protection is required at all.

Table 2: Geomorphological risk matrix

Likely magnitude of impact	Significant	**Risk Level 7** Considerable Management Required	**Risk Level 8** Necessary management and monitor risks	**Risk Level 9** Extensive management essential
	Moderate	**Risk Level 4** Risks may be worth accepting, with monitoring	**Risk Level 5** Management intervention worthwhile	**Risk Level 6** Management intervention required
	Minor	**Risk Level 1** Accept risks	**Risk Level 2** Accept, but monitor risks	**Risk Level 3** Manage and monitor risks
		Low	Medium	High
		Likelihood of adverse outcome		

Within United Utilities, since 2014, there has been a marked move away from the use of hard engineering as the preferred option to provide increased resilience of assets towards the use of soft engineering. Previously the design for any asset protection / resilience projects was led by Civil Engineers (structural/ geotechnical) leading to hard engineered structures, often at significant cost. Now such projects within UU have as standard a multidisciplinary team including Geotechnical and Civil Engineers, Geomorphologists and Environmental Specialists. This has led to a collaborative, robust sustainable options assessment process which now sits within the UU Project Delivery System (See Figure 2).

Figure 2: UU Risk based sustainable options assessment process



By adopting and following this process more resilient and sustainable (cost and environmental) solutions have been available for selection. Generally, these are solutions proven to work with natural processes rather than against them.

This sustainable options assessment approach has seen major progress in United Utilities in the way that reach-scale river problems are approached and managed. However, whilst the benefits of cost savings and reduced environmental risk have been generally understood, the uptake on sustainable river solutions has been challenged by engineers fearing that soft engineering options may not be as robust as hard engineering solution. Therefore, the environmental and sustainability team and geomorphologists within United Utilities have used a number of tools, to publish the benefits of the approach across the whole Asset Maintenance division of the business. Of these tools, the development of the risk based options selections process (Figure 2) has been fundamental to uptake of a new approach. By using this assessment at the start of projects, it has meant that the right people are involved early on in the assessment of the problem and the development of the solution. It has enabled open dialogue between engineers with understanding of the how assets and networks operate and the Environment and Sustainability specialists who have the understanding of environmental processes.

Other aspects that have played a key role in the uptake of the sustainable options assessment approach include:

- knowing the key drivers for the sustainable approach (Water Act 2014, Water Framework Directive, Floods Directive and Habitats Directive) and being able to explain their relevance to engineers.
- working with key regulators such as the Environment Agency, Lead Local Flood Authorities and Natural England to get their support and encouragement for this approach
- regulator enforcement of key legislation during the consenting process
- successful project delivery and development of a portfolio of case studies to demonstrate sustainable techniques
- education of design and construction teams on the sustainable approach
- landowner liaison and stakeholder engagement

Demonstrating how far this process has come, United Utilities is in the process of tendering for a specialist river engineering contract which will be for the design and build of bioengineering sustainable solutions. By having the specialist contractors on a framework it will ensure that UU can involve them early on in the process so they can shape and create innovative solutions for river management at assets within the constraints of the operations of the asset.

Whilst the process has come a long way, there is still room for improvement. Some of the key areas for improvement are outlined below:

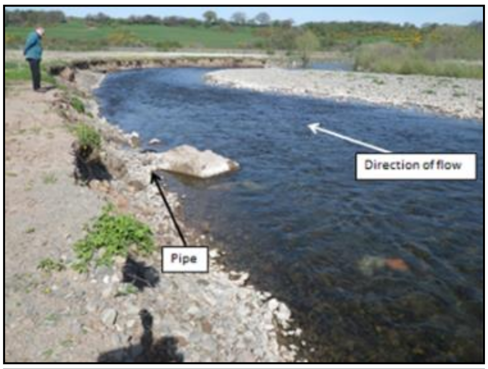
Use of UU risk based sustainable options assessment early on in the project: There are still cases where the UU environment and sustainability team and geomorphologists are being involved late in the scheme rather than at the beginning. This can sometimes mean that an inappropriate river design can become quite advanced, before the team is involved. Then additional time is required to modify the design putting delivery of the scheme at risk due to the restricted windows when riverine works can be undertaken.

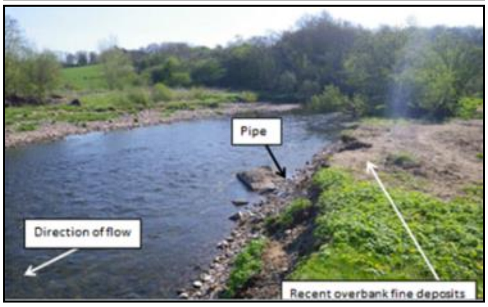
Environmental understanding of risk by insurance companies: Following Storm Desmond and Eva, a large number of assets were damaged and required repair or replacement. Insurance companies would only pay out for repairs, provided the asset was repaired or replaced ‘like for like’ with what had been there previously or the works undertaken were of an equivalent or lesser costs. This meant that the scope for providing a more sustainable and resilient design was greatly reduced. There were a number of sites where the sustainable options assessment demonstrated that a ‘like for like’ replacement scheme would not be suitable and that the more resilient solution would be to approach the works at a reach scale. Therefore, in some cases, the business had to find money quickly from other areas of the business to support this.

On site supervision by environmental specialist: When it has come to constructing a sustainable river design, there have been occasions where the design has not been implemented as planned by the environmental specialists, sometime due to site constraints or misinterpretation of requirements stated by the environmental specialist. It is recommended to have an environmental specialist on site during construction to ensure that the sustainable design is implemented to 100% satisfaction.

The following case study portfolio gives some examples of the work that has been subject to the risk based sustainable options assessment process outlined in Figure 2.

Case Study 1: Erosion of water mains pipe at River Caldew, Cummersdale





In May 2014, this was the first project of its kind where the Environment and Sustainability team collaborated with geomorphologists to determine a sustainable solution.

The problem: A water mains pipe became exposed and was being undermined by the river. This caused the pipe to crack and emergency repair works to be undertaken. A longer term solution was required to protect the pipe from future failure.

Diagnosis: *Human influenced Channel Change.* A geomorphological study looked at historical maps back to the mid-1800s and found that the river previously been aligned differently and had been fixed by an embankment. Over time, historical maps showed the tendency of the river to move towards the current alignment, presumably under more natural conditions. The maps also showed that a weir downstream of the site had become outflanked and made completely redundant over time. This evidence suggested that the river was recovering from previous modifications that pre-dated historical maps and that it was uncertain for how much longer this activity would occur for.

Initial engineering solution: A new pipe bridge to carry the pipe across the river, build back the river bank and protect with gabion baskets/ rock armour.

The sustainable solution: Due to the high risk of future river activity at this location, the original solution of a pipe bridge was deemed unsuitable. Instead the option selected was to bury the water mains below the river bed. The location for the drive and reception shafts of the water main are set significantly back from the edge of the watercourse (approximately 40m which was the assessed active river corridor) and at least 3-5m below the bed of the watercourse along a length of the directionally drilled tunnel. Whilst expensive up front, this solution ensured that going forward United Utilities should not need to undertake any future works to ensure the ongoing protection of the water main. Any future erosion works will need to be undertaken by Cumbria County Council to protect the path and Network Rail to protect the railway before the water main is at risk.

Costs/Savings: Though the costs of the works to replace the water main were greater then £500k these are justified by the design being future proofed and that there will be no need to go back in and undertake works to protect the bank in the future. Any bank protection works would need to be completed over a significant length of bank (>1km) as otherwise it would leave other sections of the bank at risk of being washed away. The costs of this bank protection is likely to be approximately £1M but this option was never assessed as part of this scheme due to prohibitive costs.

Case Study 2: Dalston Wastewater Treatment Works Outfall Replacement, River Caldew, Cumbria

The problem: In 2014, concerns were raised that the channel into which the Dalston Wastewater Treatment Works (WwTW) outfall was discharging appeared stagnant and was not providing enough flow to dilute the final effluent. Water quality tests confirmed that pollutants were accumulating within the channel and were potentially going to cause environmental and compliance issues. When the outfall was originally constructed, it would have discharged into the main river channel. Following the formation of a mid-channel bar, the area of river the outfall discharged into had become an aggrading secondary channel. It appeared that the outfall location was on the inside of a new meander bend, which is typically where deposition can be found.

Outfall as it discharged into what had become a stagnant channel, originally part of the main river channel.

Diagnosis: *Human influenced channel change.* The River Caldew in this location appeared to be responding to a number of historical modifications including: regrading by dredging, gravel abstraction, meander removal, weir construction, bank protection and channel realignment. A reduction of these pressures over the past two decades had likely resulted in the natural geomorphological recovery of the river and could have caused the mid-channel island and the consequent redundancy of the original channel.

Initial engineering solution: Extend the outfall across the redundant channel and mid channel bar and relocate the headwall on the edge of the bar in the main channel flow.

The sustainable solution: An options appraisal selected a site upstream of the mid-channel island for outfall relocation. This was identified as the area within the hydraulic limits with the least geomorphological activity and therefore least risk. The original solution was discarded as the likelihood of future channel activity in the area was deemed high risk. The design and build contractor constructed an outfall, set back into the river bank and works were completed during summer 2017 and pipework connected in October 2017.

The final result – an outfall located in a less active section of channel, designed by contractor to be set back from main channel and have natural banks as far as possible.

Costs/Savings: Although the scheme cost in region of £200k to deliver, it provided savings by not having to undertake any ongoing maintenance of the channel at potential costs of circa £50k p/a. The outfall relocation also helps to ensure ongoing environmental compliance.

Case Study 3: Hugbridge washout chamber, River Dane

The problem: A washout chamber that had originally been constructed within the river bank had become exposed and had become outflanked by the channel. The landowner was also concerned that the asset had exacerbated erosion and caused land loss.

Washout chamber in centre of channel

Diagnosis: *Gradual natural and human induced channel change.* The River Dane is a naturally active river and there is widespread channel change along its length. It is likely that the activity leading to the exposure of the washout chamber was down to natural channel movement, perhaps exacerbated by livestock come to the river to drink and eroding the banks. When the chamber became exposed, it appears that the structure further exacerbated erosion around it in the immediate vicinity.

Initial engineering solution: Remove asset and build river bank back to where it had been previously and protect with gabion baskets.

The sustainable solution: Remove asset, reprofile banks and leave to naturally recover (i.e. no hard bank protection). The risk of future channel change was assessed to be high, as the whole river was naturally adjusting. Therefore installing gabion baskets and back filling the river bank was assessed to be unsustainable, requiring ongoing maintenance and would likely exacerbate erosion further through bed downcutting or upstream and downstream scour behind the gabion baskets.

Washout chamber removed and bank reinstated

Costs/Savings: The sustainable solution resulted in approximately £300k of savings compared with the initial engineering solution.

Case Study 4: Raise Beck flood erosion, Thirlmere catchment


Major Erosion of A591, a major Lake District transport route

The problem: Raise Beck, a watercourse on UU land, caused major erosion along a section of the A591, a major transport route in the eastern Lake District, following a rare storm event. The road had to be closed whilst repairs were made which caused major disruption for several months. The Local Authority was concerned about erosion risk at other sections of Raise Beck and the potential for future disruption and costs.

Diagnosis: *Rapid natural and anthropogenic channel change.* In 2015, a major storm event (Storm Desmond) occurred with a return period of around 1:1300 years causing widespread damage throughout Cumbria. However previous river modifications probably exacerbated the problem. In the early 20th century, Raise Beck flowed into a different catchment. It was then engineered to flow north and join a small natural river to supply Thirlmere Reservoir. A much larger volume of water than natural was delivered along the watercourse during Storm Desmond. This and the cessation of a natural meander during A591 construction probably exacerbated the erosion.

Initial engineering solution: Initial discussions were steered towards providing a hydraulic modelling exercise and gabion basket solution to patches of erosion along Raise Beck.


Before (left) and After (right) pictures

Sustainable solution: The solution includes the use of site won boulders, gravels and stone to reinforce existing banks and deflect flow from the road, with tree planting to stabilise and provide extra protection to the land between the river and the road. The use of this natural material significantly reduces the volume of material that will be imported and has been fully supported by our regulators. Due for completion in summer 2018, some protection has already been delivered to a short section of bank. UU collaborated with Cumbria County Council to implement soft engineering bank protection techniques including a log and toe revetment, willow planting and coir matting as shown in the before and after photographs below. This also provides potential for habitat improvement.

Costs/ Savings: The cost to complete the short section pictured was in the region of £30k compared with typical hard engineered solution which would have been in the region of £100-£150k. Minimal maintenance should be required for the sustainable solution compared to the gabion basket solution.

Case Study 5: Mill Gill Thirlmere Estate office erosion, St Johns Beck catchment


Significant erosion adjacent to UU's Catchment and Woodland office

The problem: During Storm Desmond in late 2015, Mill Gill, a steep mountain stream caused significant scour of the bed and banks where the United Utilities Catchment and Woodland Office was located adjacently. This put the office at high risk of structural failure.

Diagnosis: *Rapid natural channel change.* In this case, the cause of the channel change was obvious and attributed to the extremely high stream power resulting from the rare storm event, together with the sudden mobilisation of sediment from the hillslopes. In this case, had been kept relatively free from modifications and it was assessed that the situation had been unavoidable.

Initial engineering solution: A number of options were considered to repair the bank and support the estate office. These included a concrete retaining wall, rock armour or stone wall however all these would have required additional working areas and would have likely meant that UU would need to demolish the office to undertake the works.


Finished result, bank protection using pre-cast Redi-Rocks

Sustainable solution: Whilst the storm event had been rare and the likelihood of occurring again was low, a hard engineering solution was deemed necessary to protect the office from collapsing into Mill Gill. A multi-disciplinary project team including civil engineers, geomorphologists, geotechnical engineers and environmental specialists collaborated to devise the most sustainable hard engineering solution which for the use of pre cast redi-rocks was selected. This option did not require the office to be demolished, minimised the works required on site, thus reducing the environmental risk.

Costs/savings: The use of the redi-rock was significantly more cost effective compared to the other hard engineering solutions. The main saving made using this option was due to the avoidance of the office demolition and the reduced environmental risk through this avoidance. The cost for a solution involving office demolition would have been over £400k compared to the completed works using Redi-rocks which came in at just over £144k.

6. Building resilience for the future on a catchment scale

With the increasing threat of climate change, there will be changes to rainfall and river flow patterns across upland Europe over the next few decades. Where there are active gravel bed rivers, asset resilience in terms of risk of river erosion and deposition also needs to be considered on a catchment scale. This is because river activity is often governed by catchment wide processes, and catchment wide measures could result in the greatest increase in asset resilience.

Some examples of catchment wide measures taken by United Utilities are shown in Table 3.

Table 3: Catchment wide measure being implemented by UU

Catchment wide measure	Description
Catchment managers	United Utilities recognises that river processes and habitats operate on a catchment scale and as such catchment managers are employed to take high level overview of assets and operations on that scale.
Sustainable Catchment	This programme works with landowners and other catchment stakeholders to undertake work such as moorland restoration,

Management Programme (SCaMP)[22]	woodland management, watercourse protection and farm improvements, with the aim of improving water within reservoirs. This sustainable scheme has resulted in habitat improvements to make them more resilient to climate change and increase carbon capture, potentially reduce the pressure on water treatment works and helps to meet environmental legislation targets. Whilst these measures do not directly alter erosion and deposition rates within the catchment, some of them are natural flood management measures and they will likely have some impacts by slowing down the flow and increasing the storage capacity of rainfall within the catchments so that storm events are not so flashy.
Catchment sediment management plans	Under the WFD and HD, United Utilities have commissioned several sediment management plans, approved by the regulators which stipulate when assets, which act as barriers to sediment transport, should be periodically inspected and sediment from them removed and replaced downstream. The benefits of these plans are two-fold; improved asset operation and resilience from the sediment removal at intakes and improved downstream habitats as sediment is placed and replenished in downstream reaches. Placing sediment in downstream reaches where there is sediment starvation can often have the impact of reducing erosion rates.
Reservoir discontinuance	In terms of anthropogenic modifications, impounding reservoirs probably cause the most significant geomorphological impacts to rivers; they obstruct sediment movement (essential for natural river processes and habitats) and the artificial flow regimes they impose can result in unnatural channel morphology and habitat types a long way downstream. Over the years, United Utilities has commissioned a number of studies on reservoir discontinuance and has implemented some schemes. Where possible, reservoirs are discontinued to naturalise river systems for improved geomorphology and habitats (particularly in SAC areas, where there are protected species), remove barriers to fish passage, increase

[22] Sustainable Catchment Management Programme (SCaMP) https://www.unitedutilities.com/corporate/responsibility/environment/catchment-management/

	catchment resilience to climate change and reduce maintenance costs and liability to the company.

7. Conclusions and recommendations for further work

Sustainable river management solutions for asset resilience can be implemented at many scales, from the river reach scale to the river catchment scale. In UU up until 2014, the understanding and planning for resilience were very much considered at the catchment scale only and did not consider geomorphological risk in detail. Since the introduction of the risk based sustainable options assessment, including a specific geomorphological risk assessment for reach scale problems in 2014, United Utilities’ approach to asset resilience has focused on providing sustainable reactive solutions to river problems. At this scale it has been demonstrated that sustainable and resilient designs are often more cost effective as well as providing environmental benefits, like many of the catchment initiatives, albeit at a different scale.

To consolidate the reach scale and catchment scale approaches to resilience a next step for UU could be to utilise Geographical Information Systems (GIS) to create a tool that strategically maps out potential geomorphological risk against key assets, so that these assets can be proactively managed. Similar exercises have been undertaken by Jacobs for other organisations within the UK and Ireland. Key assets that could be mapped are: pipelines along river valleys, water treatment works and wastewater treatment works (which often serve large populations) and water abstraction intakes.

There are many different river types in the North West of England and Europe. Having an understanding of these river types, is important in defining the risk to assets and the sustainable solution. Often in rivers which are not active, the most sustainable solution could be to have no bank protection.

Of the case studies presented, all rivers are active gravel bed rivers. Whilst river catchments in the North West England will be relatively small in comparison to catchments in Europe, the principles of many of the solutions outlined in this paper for active gravel bed rivers could be implemented on a larger scale. The Water Framework Directive, Floods Directive and Habitats Directive can all be used as drivers for changing the way that utilities companies plan and manage for resilience in areas where there are active rivers and where there are human pressures and modifications.

RESTORATION OF SENDAI SEWERAGE SERVICE FROM THE GREAT EAST JAPAN EARSQUAKE AND DISASTER-PREVENTION MEASURES FOR THE FUTURE

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1 INTRODUCTION

Sendai is a city with a population of over one million, and is the political and economic center of Japan's Tohoku (north-east) Region. Although Sendai is a large city, it is known throughout Japan as a modern city in harmony with nature. The city possesses beautiful scenery, such as Hirose River running through central Sendai and the lush zelkova trees that line its streets. Greenery is especially abundant in the center of the city, which has tree-lined streets and parks. As a result, Sendai is called the "City of Trees."

On the other hand, Sendai city is well known as one of the areas where earthquakes occur frequently, and a large-scale earthquake occurs approximately once every 40 years. In June 1978, an earthquake of M7.4 occurred off the Pacific coast of Sendai, and in March 2011, sewer facilities in coastal areas were severely damaged again by the Great East Japan Earthquake and following tsunami.

During this quarter century, Japan has experienced many big earthquakes, such as the Great Hanshin-Awaji Earthquake in January 1995, the Niigata Prefecture Chuetsu Earthquake in October 2004, the Great East Japan Earthquake in March 2011 and the Kumamoto Earthquake in April 2016. Every time a large-scale earthquake occurred, the necessity of earthquake-proof measures of sewerage facilities was re-recognized, and so far earthquake resistance of facilities has been promoted under the national government policy. In addition to improve earthquake resistance of facilities, many municipalities which are responsible for sewerage service have made mutual support agreements among them at the time of disaster. These agreements have greatly contributed to early recovery from disasters.

This paper will describe the recovery project of sewerage facilities in Sendai from the Great East Japan Earthquake (GEJE), and also especially introduce the immediate response and the permanent restoration policy for the future, of the Minami-Gamo Wastewater Treatment Plant (MGWWTP).

2 THE HISTORY OF THE SENDAI WASTEWATER UTILITY

Sewerage system in Sendai takes its origin from Yotsuya artificial ditch that was constructed by Masamune Date, the first feudal lord of Sendai Domain in the seventeenth century. The ditch supplied the clean water from Hirose River running through central Sendai to an urban area and carried away wastewater out of the area.

Sendai was the first city that was allowed to construct a modern sewerage system by the Japanese Government. In 1891, Sendai City started a precise survey which was necessary to make a sewerage works plan. After that, the Sendai Wastewater Utility (SWU) began the construction of its sewerage system in 1899 following Tokyo and Osaka. In 1957, the 20-year sewerage works plan covering 3,900 hectares of the municipal area was made including the construction of the MGWWTP. The wastewater has been collected and treated at MGWWTP since 1964.

The previous plan was revised to cover an area of 8,419 hectares in 1972. Due to subsequent annexation with neighboring municipalities, the sewerage service expanded to the current area of 19,097 hectares. An activated sludge process was introduced into the MGWWTP in 1979. In 2011, the MGWWTP treated the wastewater about 300,000m3/day on average. The plant has been treating wastewater about 70 percent of 1,080,000 people living in Sendai.

3 DAMAGE TO SEWERAGE FACILITIES AND INITIAL RESPONSE

3.1 Information about the Great East Japan Earthquake

Information about the Great East Japan Earthquake is shown in Tab. 3.1. The earthquake that occurred off the Sanriku Coast on March 11th, 2011 at a magnitude of 9.0 was the largest earthquake in Japan's recorded history and the fourth largest in the recorded history of the world. In Sendai, a maximum seismic intensity of upper 6 on the Japanese intensity scale was recorded (Picture 3.1). This caused an enormous damage including landslides in the hilly areas, the collapse of roads and buildings, and the disruption of vital utilities. And after the largest aftershock occurred on April 7th, in some areas, we had to investigate the sewer pipe damaged by it again.

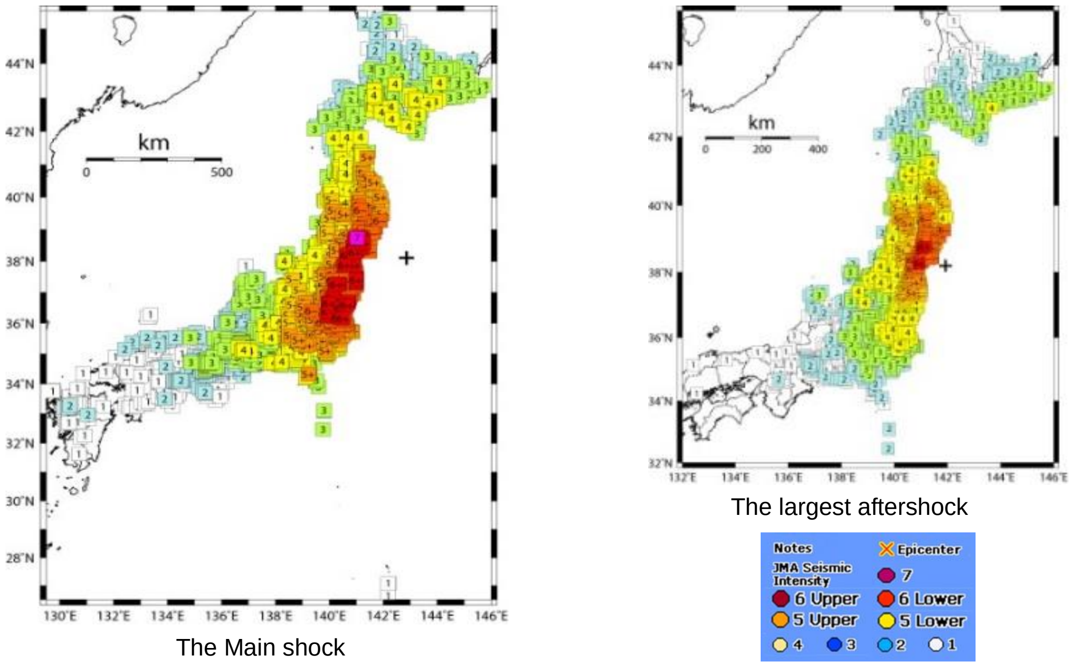
Tab. 3.1: Outline of the Great East Japan Earthquake

Official name of the earthquake by JMA	The 2011 off the Pacific Coast of Tohoku Earthquake	
	Main shock	Largest aftershock
Date and Time of Occurrence	At 2:46 p.m. March 11th, 2011	At 11:32 p.m. April 7th, 2011
Epicenter	Off the Sanriku Coast (N38 06.2’, E142 51.6’, depth 24km)	Off the Miyagi Coast (N38 12.2’, E141 55.2’, depth 66km)
Magnitude	9.0	7.2

3.2 Occurrence of the Great East Japan Earthquake

The GEJE and Tsunami caused unprecedented damage to the region, especially on the Pacific coast. In Sendai City, the lifeline such as water, gas, and electricity stopped supplying in many areas, and the traffic such as roads, railways and buses became gridlocked. In addition, it also had a serious impact on the daily life of citizens including the lack of a daily commodity such as foods, gasoline and so on.

As for Sendai sewerage facilities, there were serious damages in the whole of area. Especially the MGWWTP which has been treating wastewater for 70% people living in Sendai was attacked by the great tsunami of more than 10 meters high, and the facility was devastated. Due to the damage of sewerage facilities, it was worried that the sewer might overflow in the urban and residential areas. However, there was no overflow because sewer was collected by vacuum cars, temporary sewer pipe and pumps were set, and so on. And the most important fact was that there was no sewer pipe damage where it did not flow at all.



Picture 3.1: The epicenter and JMA seismic intensity of the Great East Japan Earthquake (Main shock and largest aftershock)
Source reference [1]

Therefore, sewage did not overflow in the area, and the sanitary condition was maintained. Moreover, the MGWWTP did not regulate the use of sewerage facilities to the citizen because the plant had a structure that could discharge the sewage to the sea by gravity flow even in case of power failure.

On the other hand, there was an area where the water supply service resumed after the temporary piping of the sewer pipe restored in the hilly area where the landslide occurred due to the earthquake. However, due to the damage of the drainage facility, the sewage leaking from the broken sewer pipe might lead to further landslide.

During about the six months from the GEJE, SWU asked the users to cooperate in saving water use to reduce the influent into the MGWWTP in order to minimize the environmental effect of the GEJE. In addition, we asked the users to dispose of toilet paper as garbage not to flush it to the sewage to reduce the discharge of the suspended solid to the environment.

3.2.1 Amount of damages

Although the earthquake-proof measures of sewerage facilities before the GEJE were based on the tremor of earthquakes, the damage of facilities was caused mainly by the giant tsunami. The total damage in sewerage facilities in Sendai amounted to approximately 650 million dollars, including approximately 590 million of the MGWWTP. Such a situation had not been observed in past earthquake disasters. In particular, many sewerage treatment facilities and pumping stations with buildings in the coastal area suffered inundation and wave pressure of tsunami, resulting in functional failure.

3.2.2 Damage to pipeline infrastructure

Thanks to the support from 12 municipalities, including Tokyo, over one month, SWU was able to complete the survey of damaged pipeline infrastructure in seriously affected areas (Picture 3.2). Then, although SWU managed to continue sewer service, it took nine months of further investigation to get a full picture of the damages.

Picture 3.2: The damage of pipeline facilities and inclined pumping building

Sewer pipelines of 102km out of 4,758km were also affected by the tremor of earthquake (Tab. 3.2). The pipes and manholes in landfill and soft ground areas were floated up due to the liquefaction. The backfill soil of pipes caused road collapses. However, the pipes which had been taken the earthquake resistant measures such as pipe lining had no damage.

Tab. 3.2: Outline of sewer pipeline

Pipeline type	Total pipelines (km)	Surveyed pipelines (km)			Damaged pipelines (km)*
		Primary survey (visual inspection)	Second survey (manholes)	CCTV inspections	
Combined	590.0	590.0	38.5	35.1	30.1
Separate sewer	2,946.0	2,904.7	163.6	79.9	63
Separate rainwater	1,042.0	1,030.3	28.6	10.9	9
Total	4,578.0	4,525.0	230.7	125.9	102.1
*Length of damaged pipelines is the full length of the spans that contain damaged portions.					

3.2.3 Damage to pumping stations and wastewater treatment facilities

The major damage caused by tremor was not severe at a relatively small-scale pumping station building, though a part of the large-scale one for stormwater inclined (Picture 3.2). However, in the manhole pump installed in the lower land zone, there was an area where urgent correspondence was necessary by the damage of the dropout of pump and the manhole structure.

On the other hand, the damage caused by tsunami was severe, and all facilities located near the coastal area were all washed away and the equipment stopped its function in most of the facilities (Tab. 3.3). Especially the MGWWTP lost all function by the over 10 meters tsunami.

The recovery project of the MGWWTP will be described in the next chapter.

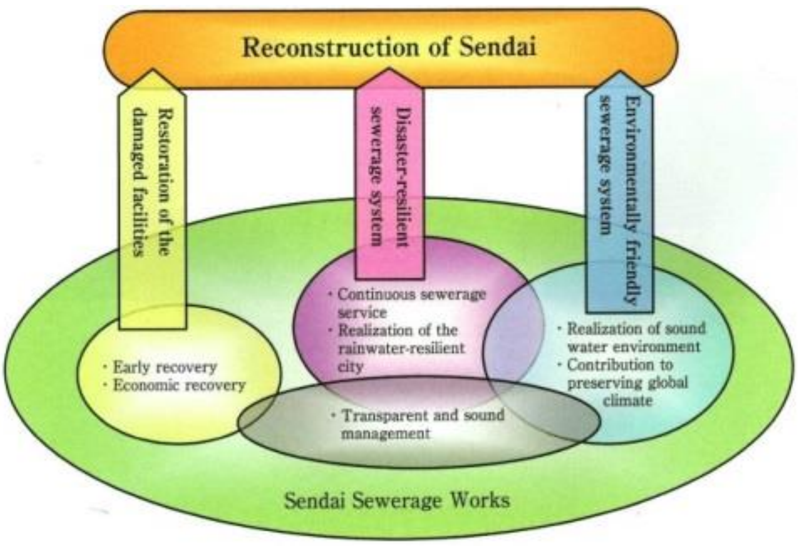
Tab. 3.3: Outline of sewerage facilities

Facility type	Number of facilities	Damaged facilities		
		Damaged by tremor	Damaged by tsunami	Total
Wastewater treatment plants	23	6	9	15
Pumping stations, etc.	307	43	41	83
Subtotal	330	49	50	98
Septic tanks (publicly-owned)	1,153	126	2	128
Grand total	1,483	175	52	226

3.3 The initial response and Sendai Wastewater Utility Reconstruction Plan

Right after the GEJE, SWU immediately decided on three strategies for immediate response in order to resume a normal life for citizens as soon as possible. The first priority was "Securing toilet use of citizens", the second one was “Maintaining sanitary condition in the urban area by ensuring the gravity flow of sewage to avoid its overflows", and the third one was "Preventing water pollution in the environment".

After immediate response ended, SWU made the “Sendai Wastewater Utility Reconstruction



Picture 3.3: The concept of Sendai Wastewater Utility

Plan” and worked on the mid-and-long term disaster restoration projects on purpose of quick recovery from the GEJE, in March 2012. The first policy was “Restoration of the damaged facilities”, the second one was “Disaster-resilient sewerage system”, and the third one was “Environmentally friendly sewerage system”.

This plan, in addition to the restoration of the damaged sewerage facilities including the MGWWTP, suggested taking storm water measures because of the recent heavy rain before the GEJE and ground subsidence by the earthquake.

The period of this plan was from 2012 to 2015. Although SWU has almost achieved full recovery from the GEJE, SWU is still going on the storm water measures.

3.4 Build Back Better measures for sewerage pipeline networks

Most of pipelines restorations had completed in three years after the earthquake. However, the most important trunk sewers have not been inspected and rehabilitated because they are always full of wastewater. Furthermore, Ground subsidence occurred in the eastern low-land area and inundation risks have increased. Therefore SWU decided to build a new back-up trunk sewer to rehabilitate existed trunk sewers, and construct new stormwater trunk sewers and pumping facilities to prevent inundation. These measures are being conducted by using subsidies from the national government, and will contribute to achieve the policy of Sendai City called ‘Disaster-resilient and Environmentally-friendly City’ (Picture 3.3).

4 THE RECOVERY PROJECT OF THE MINAMI-GAMO WASTEWATER TREATMENT PLANT

4.1 The specification

The MGWWTP, which handles the sewage of about 70% of Sendai’s 1,080,000 citizens, is the most important facility for the sewage service in Sendai city municipal area. The specification of this plant is as follows (Tab. 4.1):

Tab. 4.1: New wastewater treatment facility outline of MGWWTP

Treatment process	Conventional activated sludge method
Design flow	400,000 m3/day (Maximum daily flow)
Design influent BOD and SS*1	BOD 205 mg/l and SS 205 mg/l
Design effluent BOD and SS*2	BOD 5 mg/l and SS 8 mg/l

*1 Design inflow quality is value incorporating returnflow load.

*2 Approved treated water quality is BOD 15 mg/l, SS 30 mg/l

4.2 Situation of damage

The earthquake and tsunami also destroyed the MGWWTP. Its foundation and primary sedimentation tank were heavily damaged (Picture 4.1). Final sedimentation and aeration tanks became tilted. The wall of the pumping station building was curved by a 10-metre-high tsunami (Picture 4.2). Most of the mechanical and electrical equipment were flooded with seawater and swept away. The MGWWTP completely lost its wastewater treatment functions. Since that moment, we have had the mission to recover the MGWWTP as soon as possible.

Fortunately, at the time of the earthquake and tsunami, 101 staff members and workers at the MGWWTP were all safe because they evacuated onto the rooftop of the administration building according to the business continuity plan (BCP) (Picture 4.3). The next morning, the 101 people were rescued by helicopter after opening the emergency discharge gate so that the sewage continued to be accepted and did not overflow in the urban area. And it took five days from rescued to come back to the MGWWTP for being blocked by seawater and sludge which the tsunami carried.

4.3 The initial responses

The MGWWTP was originally designed so that municipal wastewater could be treated and discharged by taking advantage of the landform height difference between the city area and the plant. And it has been able to receive wastewater from the municipal area without consuming a lot of energy and treat it by sedimentation and disinfection. In order to discharge the water, we had to open an emergency discharge gate. However, the gate was designed to be operated by electricity. So, we manually opened the gate at 10 cm interval. Due to this, we could fortunately discharge the collected wastewater. Later we had to break the gate in order to discharge increasing influent wastewater out of recovering water supply service (Picture 4.4). This behavior enabled to completely prevent the wastewater overflow in urban and residential areas. This action was contributed to continuing the sewage service and preserved the public sanitation in Sendai.

As the damage by the tsunami came to be known, we recognized that it was impossible to restore the structure and facility to its former state and that it was a difficult situation to make the prospect of the recovery of the mechanical and electrical equipment.

Then, SWU decided to set up the restoration policy committee for the MGWWTP to study the basic restoration policy. As the result of the study, the wastewater treatment plant facilities were rebuilt, and sludge handling facilities were repaired. The detail of the committee will be introduced later.

Finally, the new wastewater treatment plant facility was completed in April 2017, and the sludge handling facilities were recovered in April 2015.

4.4 The restoration policy

In June 2011 after three months from the GEJE and Tsunami, the restoration policy committee for the MGWWTP was established to discuss the basic policies for the recovery

Picture 4.1: The damaged primary sedimentation tank.

Picture 4.2: The pumping building’s wall bent by the tsunami.

Picture 4.3: Employees evacuated to the roof of the building.

Picture 4.4: Breaking the emergency discharge gate of MGWWTP.

project with

"Build Back Better". In order to formulate restoration policies, the committee considered whether the plant could be rebuilt as a new plant or not, the expense for the restoration project, the introduction of tsunami countermeasures, the method of wastewater treatment during the restoration of the new plant and so on. The committee proposed the following restoration policies on September 15th:

a) The height difference between the urban area and the coastal area is critical to operate the MGWWTP. This is extremely beneficial from a crisis management standpoint in case of a disaster to maintain public sanitation, and thus we suggested preserving these characteristics during the rebuilding process.

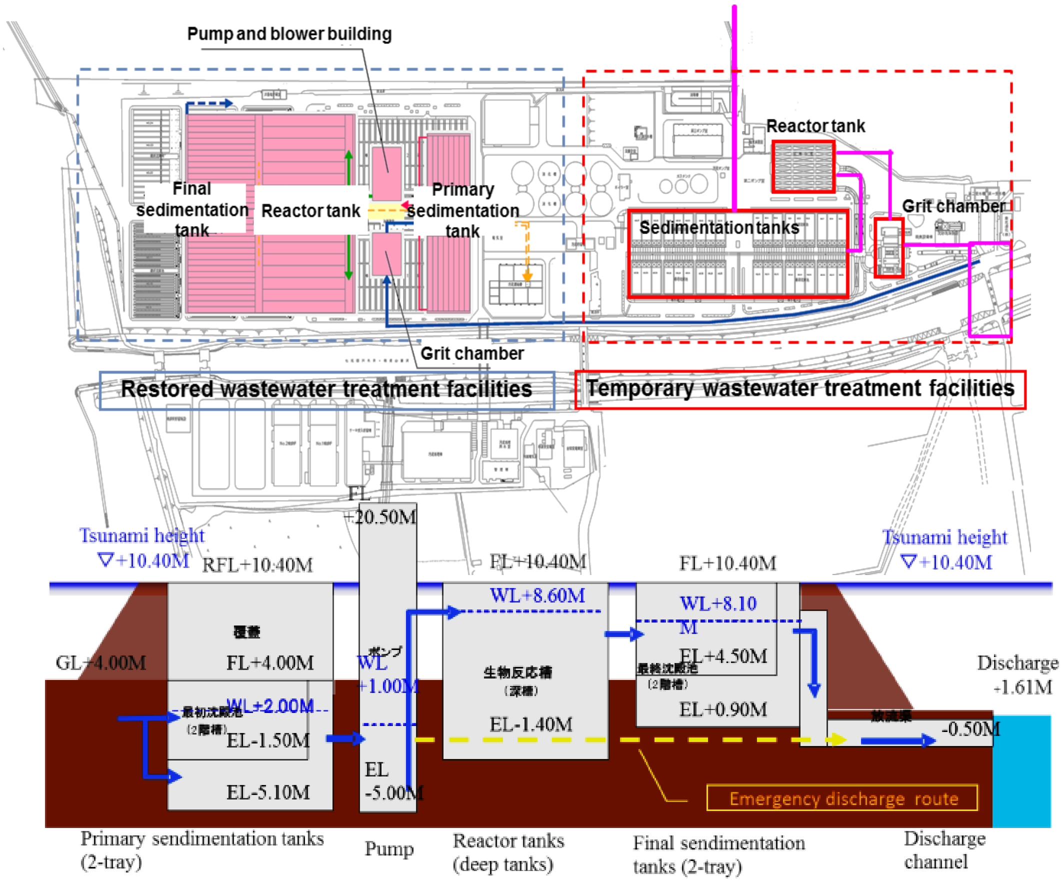
b) Rebuilding the wastewater treatment facilities will take at least five years. During this period of constructing the new plant, the MGWWTP will treat municipal wastewater with temporary facilities. The quality of treated water should be improved in stages during the period of temporary treatment. Considering the cost of maintenance and management, we decided to adopt the contact oxidation process as the temporary treatment method.

c) Considering the ability to preserve primary treatment functions through the gravity flow of wastewater, the location of the sludge handling facility, the amount of time needed for restoration, and the cost of this project, we recommend that rather than relocating or decentralizing the wastewater treatment facility, it be more rational and economical to restore the facility on its current site or in the vicinity.

d) In order to prevent structural damage by a tsunami and to design it in such a way to preserve functioning equipment, it is necessary to adopt tsunami countermeasures, such as building a facility based on the recorded height of the tsunami caused by the GEJE. Additionally, measures should be taken to protect workers from tsunami by building suitable evacuation areas.

e) After considering tsunami countermeasures, construction time, project cost, and maintenance and management, we concluded that the wastewater treatment facility should be restored on its current site.

f) In order to secure electric power in a time of disaster and reduce the burden on the environment, we recommend introducing energy-saving equipment and solar and small hydroelectric power generators. Furthermore, new technologies for the re-cycling of resources at the sewerage works, energy saving, energy generation, and reducing the burden on the environment should be introduced in the mid- to long-term after analyzing the cost-benefit



Picture 4.5: Scheme of the restored (blue dash line) and temporary (red dash line) wastewater treatment facilities. A back ground drawn in black line is the scheme of MGWTTP facilities before the Great East Japan

effects on business.

After reviewing the committee's proposals, the SWU judged that the MGWWTP could not be rebuilt to its original form and decided to rebuild it as a new wastewater treatment plant (Picture 4.5). The features of the new facility are as follows:

a) Like the previous facility, the structure allows for primary treatment functions (sedimentation, disinfection, and discharge) through the gravity flow of wastewater, even when we suffer from power failure in a time of disaster.

b) While preserving the previous function, the primary and final sedimentation tanks are double-layered. The reactor tank is deepened to increase its height in order to make the facility resilient to tsunami.

c) We reduce the burden on the environment by introducing solar and small hydroelectric power generators. These are also used as a part of emergency power sources in a time of disaster.

4.5 Temporary wastewater treatment by the contact oxidation process

Based on the proposal of the restoration policy committee for the MGWWTP, several treatment processes were investigated, which would meet the upper limit of the temporary effluent standard of the Biochemical Oxygen Demand (BOD) of 60 mg/l as proposed by the National Sewerage Disaster Countermeasures Committee of the Ministry of Land, Infrastructure, Transport and Tourism (MLIT). This was because it took five years to rebuild the new MGWWTP. This process was settled in pre-aeration and primary sedimentation tanks after the GEJE. Subsequently, as a measure to gradually improve the quality of effluent at the MGWWTP, we implemented mid-level treatment through contact oxidation with string media (Table 4.2). The MGWWTP was the largest WWTP in Japan to adopt this method.

The process had been operated since April 2012. The effluent BOD successfully decreased (Picture. 4.6). However, effluent BOD had exceeded the temporary effluent standard during peak hours. In order to keep the effluent BOD stably below 60 mg/l (which was the temporary effluent standard), we introduced a coagulation-sedimentation method in December 2013.

As a result, it was possible to stably treat municipal wastewater effluent quality in the temporary wastewater treatment. The effluent quality before starting operation of the new MGWWTP facility was below BOD50 mg/l.

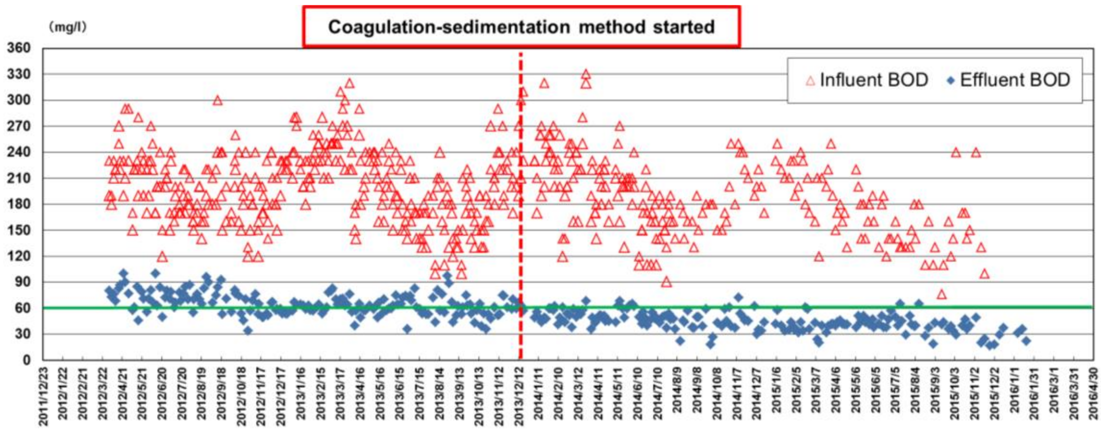
Tab. 4.2: Facility outline of the contact oxidation.

Treatment process	Biological contact oxidation using a biofilm method with string media (68 units/tank)
Design flow	300,000 m3/day
Design influent and effluent BOD (temporary standard)	177 mg/l and 60 mg/l
Hydraulic retention time	50 min
BOD volumetric loading	5.2 kg-BOD/m3/day
Ventilation equipment	GM blower (260 Nm3 × 400 kW × 2units)
Reactor tank	4 channels × 2 pools (Volume: 102,000 m3)

4.6 Managing construction for disaster recovery

The former facility of the MGWWTP had been started to be constructed in 1959 and completely finished in 1994. It took about 35 years. While it commonly takes 10 years to build a wastewater plant with processing capacity of 433,000 m3/ day, we were required to fully rebuild the plant in only five years. Therefore, we needed to have a superior organization to execute this plan. In fact, it took a year to make the plan and design, and it took another year to demolish the existing facilities, and the new facilities were built in the remaining three years.

For example, the construction field was divided into five areas and the manager was assigned to each area. In November 2014, mechanical and electrical equipment for the building began to be installed, along with construction. To avoid delay in the construction schedule, the



Picture 4.6: The influent and Effluent BOD of the temporary wastewater

coordination council meeting was held every week.

A safety managerial division was established to ensure the safety of a total of (at the highest number) 1,300 people, including staff members and service contractors. Safety checks and patrols were conducted every day.

An alarm system, which automatically gave warnings by five audio speakers in the plant in the event of an earthquake, was set up. Emergency tsunami drills were conducted every six months.

4.7 Start of operation and its acclimation

During the recovery of the MGWWTP facilities, SWU used the temporary wastewater treatment facilities, and starting to operate some parts of the facilities to be finished construction as aiming to operate the new facility as soon as possible.

As the result, in November 2015 when it was after four years and half, a half of facilities was started to operate. These facilities could treat wastewater 200,000 m3 every day. Due to the huge scale of facilities, the acclimation started without the seed of sludge. On the other hand, because of the hydrologic parameter of an each tank was different, so we had been needed a trial-and-error to adjust. Finally, an activated sludge grew from organic matters in inflow wastewater. And the quality of treated water achieved BOD 15 mg/l after a standard level after two months.

Five years after disaster, in March 2016, all reconstructed wastewater treatment facilities were completed (Tab. 4.3).

In addition, amount of damage is approximately 590 million dollars, and almost 95% of the cost required is using the subsidies from national government.

Tab. 4.3: Chronology of the recovery project

	2011	2012	2013	2014	2015	2016
Occurrence of the GEJE and Tsunami	●					
Operating the temporary treatment by the contact oxidation process		●	—	—	—	●
Plan and design of the new facilities	●	●				
Demolishing the existed facilities		●	●			
Construction of the new facilities			●	—	—	●
Start operating the part of facilities to be able to use					●	
Start operating the all facilities to finish construction						●

5 Lessons learned

5.1 The Minami-Gamo Wastewater Treatment Plant recovery project

The MGWWTP was situated in the coastal area and started to operate of primary treatment from 1964. At the same time, trunk sewer that named Minami-Gamo Trunk Sewer 1 which keeps the gravity flow from urban area was constructed. It was considering that the deference of the landform height between the urban area and the location of the MGWWTP to be made of Hirose River terrace. The fact was very useful at when the GEJE happened. The electric power outage due to the GEJE and Tsunami, it was thought that it was extremely difficult for the MGWWTP and other sewage works facilities in SWU to continue normal operations. However, due to gravity flow of wastewater downslope from urban area to the treatment plant and the layout in the primary treatment facilities to be able to discharge using gravity flow, the MGWWTP was able to continue collecting sewer from users and discharging into the ocean from there. As a result, it is worth noting that there were no major overflows in Sendai, and it was not necessary to take measures to restrict the use of the sewage system.

This fact is very important point to recover the sewerage facilities from the GEJE. At the MGWWTP recovery project, based on this fact, the restoration of the MGWWTP has been restored to be able to discharge the wastewater with gravity flow. Furthermore, if the electric power will be completely lost, the solar power generation facility is equipped with an electric capacity that can be used primary treatment facilities as a minimum process.

5.2 The contribution of asset management system for restoration from the Great East Japan Earthquake

In Sendai, it has been taking the asset management project since 2008. The purpose of this project is to improve the GIS, including how to collect the information about the condition of sewerage facilities, and to build the system about risk assessment. As the result, in 2014, Sendai required the first certification of ISO55001 in Japan.

When a disaster occurs, Japanese wastewater utilities support a damage survey for pipe each other based on the agreement of mutual aids. For example, the damage survey of Sendai's pipe network was conducted by over 100 staff members from other cities and service providers. So procedures, criteria and IT systems had to be simple to input survey results. Therefore, SWU decided to install the new GIS and database improved through the implementation of AM tentatively.

SWU received damages from the GEJE during developing the asset management system, and realized that asset management and conducted earthquake resistant measures were very effective to reduce disaster risk and accelerate restoration and establishes the system to focus on promoting disaster resistant measures. Disaster restoration has to be completed as soon as possible, but to build 'Disaster-resilient and Environmentally Friendly City' never ends in a short term. It is necessary to incorporate a concept of disaster risk reduction into a management system.

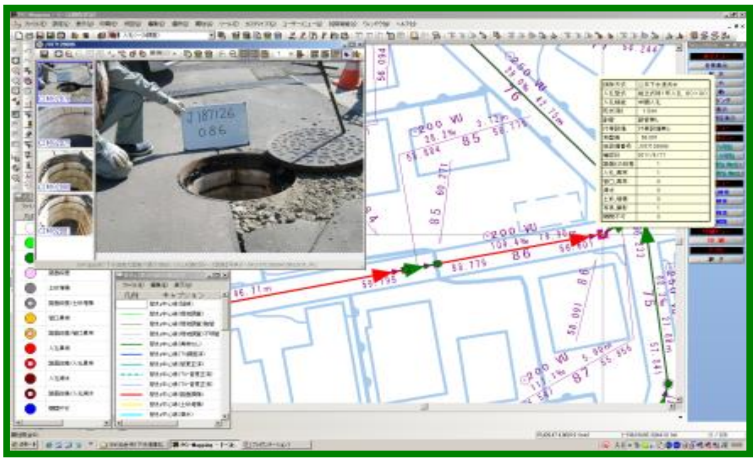
5.2.1 Benefits of asset management in the Great East Japan Earthquake

The utility of asset management has focused on increasing disaster risks such as earthquakes before the GEJE because big earthquakes hit our city every 30-40 years. Therefore objectives for improving earthquake resistance and earthquake risk criteria were incorporated into our asset management system from the beginning. SWU’s asset management development had been conducted from 2009 to 2013, but it was intermitted by the GEJE in 2011 for a half year. As a result, some parts of our asset management have effects to disaster restoration as follows:

a) Benefit of GIS improved

In asset management, a lot of data are used to evaluate asset conditions and performances. Therefore the GIS had been improved in asset management development to facilitate to browse, input and output data (Picture 5.1). In fact, a lot of data have to be input and output in a short time in the GEJE. In addition, procedures and rule to use them should be simple and easy because many support members from other cities and service providers are not familiar with them. So the utility decided to install the new GIS and database into the damage survey of sewer pipeline. After developed and arranged data formats and procedures with IT consultants, it finally improved efficiency of damage survey drastically. For example, the times to summarize survey results and determine next day’s survey areas could be shorten from 5 to 1 hour. It contributed to improve health of staff members and reduce costs.

b) Benefits of disaster preparation



Picture 5.1: The improved new GIS

In addition, benefits of earthquake resistant measures before the GEJE appeared. The utility had constructed earthquake resistant pipes by using pipe lining methods which was approved by the MLIT. The MLIT also defined the earthquake resistant design standard based on experiences of previous earthquakes such as Kobe, and established a subsidy system for earthquake resistant measures to support utilities. In fact, 72km lined pipes in Sendai didn’t have damages at all according to the survey results after the GEJE. It proved that the method had earthquake resistance.

5.2.2 Application of experiences in the Great East Japan Earthquake into our asset management system

The GEJE occurred during asset management development. Therefore experiences in the GEJE were reflected to following parts of SWU’s asset management system:

a) Increase budgets for earthquake resistant measures based on the revise of earthquake risk criteria

Earthquake risks of SWU’s assets are evaluated by using the design standard of earthquake resistant measures. As pipelines under designated emergency routes and to collect wastewater from hospitals are classified to critical pipes in the revision of the design standard based on experiences of disaster, consequence of failures due to earthquakes became evaluated higher. In addition, the national ministry supports utilities to meet the new design standard by providing subsidies for earthquake resistant measures. According to these changes, SWU budgets for rehabilitation including earthquake resistant measures twice than before the GEJE in the mid-term business plan drafted based on the asset management process.

b) Disaster drill

SWU has conducted damage survey drills once a year with staff members from other cities and service providers. The procedures, criteria and GIS used in the drills are almost same as used in disaster. The participants in the drills actually go to survey to high risk area for earthquakes and pipeline deterioration, and survey results are used as asset management data to CCTV camera survey, risk assessment, cleaning and repair. These procedures are compiled in the manuals and improved based on survey results every year. This improvement is incorporated into our asset management system as one of the asset management objectives. These procedures were used in the Kumamoto Earthquake occurred in 2016 as `Sendai method’.

5.3 BCP and its contribution to disaster

In 2006 SWU planed the sewage disaster control manual that showed the immediate initial survey when disaster happened, and in 2010, the utility started formulate the business continuity plan (BCP) which was included the time oriented initial response. As the result, the initiative to make the BCP contributed to the initial response at the GEJE. Therefore, it contributed greatly to the initial response by the BCP that was being developed because of all staff members understood the plan well.

In case of the MGWWTP, when the staff members were required to review the BCP responding to the damage Miyagi prefecture suffered from the Tsunami caused by Chile Earthquake in 2010, during the discussion about its BCP, the GEJE happened. Therefore it was able to respond rapidly because contents of the BCP were practical and the staff understood the contents well. On the other hand, the staff members opened the emergency gate based on the BCP in the next morning of the GEJE. Usually we had assumed that the gate should be opened by electric power, but it was very heavy by hand and barely to be opened only 10 cm. When disaster happens, we should image power outage and many important facilities to be broken, and always recognize the importance to manual operation and so on. And since the GEJE we have realized that it is important to always check the contents of the BCP among staff members. Through the GEJE, the most important matter we learned was to save the human life. Therefore, it has been written in the BCP that the most important thing is to think of the top priority behavior to evacuate for protecting one's life rather than to correspond to specified role for maintenance and so on. And it is well known among the staff members working at the MGWWTP after the GEJE.

When a disaster happens, a lot of damages that the BCP does not anticipate may occur. Therefore, it requires not only the behavior written by the BCP but also the appropriate response. In this case, it is important for every staff members of SWU to understand well its contents including the roles and steps written in the BCP. Therefore, it has been recognized that we must always check and revise the BCP by following the "plan do check action (PDCA) cycle" of the asset management system.

As the result, after the GEJE, SWU revised the BCP in 2013. This was clearly written that the contents of the BCP had to be checked once a year.

5.4 The importance of a disaster agreement with related organizations

Up until now, when a large-scale disaster has occurred, the major cities in Japan have supported each other and undertaken restoration work. Based on the mutual aid agreement between large cities in times of disaster, four days after the disaster, we undertook the first pipeline survey (visual inspection) with staff from other cities. About a month after the disaster, we had received the support of 1,630 people from 12 cities, and were able to quickly carry out the damage survey of pipelines. After that, we also received the support of staff from other cities in the disaster assessments and recovery construction work.

Generally speaking, the staffs who work at the municipal government are basically personnel who required for routine works and do not always have amount of staffs for responding to a huge-scale disaster. Therefore, it is most important in the future that the system to cooperate each other to secure temporary personnel in the case of a disaster.

As a disaster response of sewage facilities, before the GEJE, the SWU concluded a pact with mutual support agreements with the large cities including Tokyo in Japan, and the Japan Sewer Collection System Maintenance Association, and the Japan Sewerage Treatment Plant Operation and Maintenance Association. When the GEJE happened, disaster recovery project for the sewerage facilities in SWU had been done based on this agreement. Also SWU has cooperated to hold regular disaster drills every year before and after the GEJE. Due to these efforts, we were able to swiftly carry out the emergency response after the GEJE.

Furthermore, when the sewerage facilities of SWU had been recovering from the GEJE, we recognized that we needed more organizations to support each other. For that reason, for example, the SWU has been pact with the Association of Water and Sewage works Consultants Japan who could planning and designed of disaster recovery methods and so on.

6 THE 2015 SENDAI SYMPOSIUM ON SEWERAGE WORKS DISASTER RISK REDUCTION

The Third United Nations (UN) World Conference on Disaster Risk Reduction was held in Sendai from March 14th to 18th 2015, drawing 6,500 delegates from 187 nations. The conference included discussions about a disaster risk reduction and reconstruction.

In this conference, the concept of "build back better" was shown as a basic policy, and the "Sendai Framework for Disaster Risk Reduction 2015–2030", the successor of the "Hyogo Action Framework", became a new international disaster prevention guideline. In addition, the "Sendai Declaration of Sewerage Works Disaster Risk Reduction" was adopted that political commitment of each country to disaster prevention were shown. The framework and declaration included the importance of investing in disaster reduction and an implementation guide with a multi-stakeholder approach.

In terms of the sewerage works, the "2015 Sendai Symposium on Sewerage Works Disaster Risk Reduction" was co-hosted as a public forum by the Ministry of Land, Infrastructure, Transport and Tourism, Miyagi Prefecture, Japan Sewage Works Association, and Sendai

Picture 6.1: A panel discussion in the 2015 Sendai Symposium on Sewerage Works Disaster Risk

City. The following events were held at the symposium: a discussion regarding the reconstruction of the MGWWTP, introduction of domestic and international disasters, and a panel discussion with delegates from New Zealand, Peru and Turkey (Picture 6.1).

Through these events, the “Sendai Declaration of Sewerage Works Disaster Risk Reduction” has been shared with the world. The declaration affirms actions toward disaster risk reduction in sewage works in order to mitigate the human, social, economic, and environmental losses that are caused by disasters, thereby agreeing with the concept of “build back better” and the “Sendai Framework for Disaster Risk Reduction 2015–2030”. Sendai will internationally contribute and cooperate towards the realization of a sustainable society.

When sewerage professionals assembled in Sendai City on March 17th and 18th, 2015, Sendai was in the midst of recovery from the GEJE and Tsunami of March 11th, 2011. In the conference, we expressed our deepest sympathies to many victims of the earthquake and tsunami, and our gratitude for the great outpouring of support from around the world to the affected areas.

Until now Sendai has been conducting various disaster risk reduction measures. Actually it is impossible to fully prevent damage in the event of such unprecedented disasters such as the GEJE and Tsunami. But we have confirmed that it is possible to considerably mitigate impacts not only by taking preliminary “hard” (structural) measures, but also by implementing “soft” (non-structural) measures. The former “hard” measures are the earthquake proofing of sewerage facilities, securing equipment, materials and fuel for use in emergencies, and so on. The “soft” measures are formulating BCP, providing mutual assistance when a disaster occurs, and training citizens. In view of the growing global risks posed by large-scale disasters, it is necessary to further strengthen and enhance structural and non-structural countermeasures.

Furthermore, from the restoration and reconstruction following the GEJE, we have learned the importance of returning valuable resources such as energy and biomass from sewers to the local community and contributing to global environmental conservation and sustainable society through implementing energy-saving measures and utilizing renewable energy.

By widely sharing various examples, experiences, and lessons of post-disaster restoration and reconstruction at the symposium, we hoped to further the cause of disaster risk reduction and mitigation. For this reason, from now on, we need to actively share information and cooperate internationally. At the same time, we must actively implement sewerage initiatives geared toward mitigating the human, social, economic, and environmental losses that are caused by disasters.

From this viewpoint, we formulated the following declarations to the world concerning the reduction of disaster risks in sewerage systems.

a) Declaration concerning the importance of "hard" structural disaster countermeasures

We will contribute to the construction of a robust society through continuing to promote "hard" measures for sewerage networks and facilities such as earthquake proofing and tsunami proofing in light of the lessons of the GEJE and Tsunami.

b) Declaration concerning the importance of "soft" non-structural disaster countermeasures

We will strive to secure, develop, and maintain human resources in the sewerage sector and mitigate the impacts of large-scale disasters through mutual aid.

c) Declaration concerning the importance of restoring facilities in the short-term to medium-term

We will quickly restore sewerage functions at times of disaster and provide the valuable resources of sewerage systems for supporting the regeneration and reconstruction of communities and industries.

d) Declaration concerning the importance of facilities restoration and the approach to sewerage systems in the long-term term

In conducting restoration and reconstruction, we will contribute to the realization of sustainable society through promoting energy saving initiatives and the utilization of renewable energy.

e) Declaration concerning the importance of information sharing and international cooperation

We will contribute to the realization of safe and congenial societies in the world through broadly sharing and providing our experiences and lessons of sewerage damage, restoration and reconstruction, and actively involved international cooperation concerning technology and know-how for reduction of disaster risks.

7 CONCLUSIONS

Until now, we have conducted various disaster risk reduction measures. However, it was impossible to fully prevent damage in the event of unprecedented disasters such as the GEJE and Tsunami. And we learned a lot of things through disaster.

In the meanwhile, Japanese disaster-prevention measures have been upgraded step by step to alleviate the damage of large-scale earthquakes, but our comprehensive countermeasures against tsunami conducted in Sendai are the first case in Japan. The experience of the GEJE and Tsunami will be a reference for future disasters around the world from immediate response, temporary recovery, to permanent recovery with the concept of "build back better".

First, in the temporary treatment during the restoration period, a combination of the contact oxidation process, addition of coagulant, and settling method was adopted by using existing grit chamber, pre-aeration tank, and primary sedimentation tank. The temporary treatment finally achieved the effluent quality of less than 50 mg/l in BOD as designed.

Second, the new wastewater treatment plant was designed to be small footprint in consideration of countermeasures against tsunami, construction period until restoration, economic efficiency, maintainability, and provisional processing until restoration, as well as to withstand the next tsunami. In addition, in order to build an eco-friendly system, energy-efficient equipment, solar power generation, and small hydropower generation were installed. The solar system has a capacity that enables primary treatment even in the complete power outage.

Third, during recovery project from the GEJE, SWU have learned that it is important not only disaster-prevention measures but also non-structure like the asset management, BCP, the cooperation of other organization and so on. These facts are revealed to be able to speed up recovering from disaster. For that reason, we recognize that these items should be thoroughly examined on a routine basis and preparations should be advanced.

Although we have learned many other things, the most important thing was to evacuate to the safety places as soon as possible for protecting our lives as written in the chapter about BCP.

We strongly hope that our experience during the seven years after the GEJE described in this paper will contribute to the prevention and restoration of disaster and damage, which may be caused by an unexpected huge disaster like the GEJE. Lastly, we will continue to internationally disseminate the “Sendai Declaration of Sewerage Works Disaster Risk Reduction” adopted in the “2015 Sendai Symposium on Sewerage Works Disaster”.

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Building and Utilizing the Wastewater Treatment Plant Network in Kobe City

Hidenobu Wakimoto

1. Introduction

The biggest Wastewater Treatment Plant (WWTP) in Kobe city lost its function by the Great Hanshin-Awaji Earthquake occurred in 1995. Kobe city unavoidably treated wastewater by primary treatment about 100 days. Having this experience, Kobe city has created the “sewerage network system” and started its operation since 2011. The “sewerage network system” is a system that connects several WWTPs with deeply buried trunk sewers and enables to compensate the capacity loss in an emergency. This paper reports what could be achieved by using this network system and issues found after the start of the operation.

2. Sewage Works in Kobe City

Kobe city is located about 500 km to the west from Tokyo. Its population is around 1.5 million and it is the sixth biggest population in Japan.

Kobe city started its sewage works in 1951. After starting the business, Kobe city actively expanded its treatment area and almost all the sanitary sewers were completed in 2005. Today, Kobe city is working on inundation control, introduction of advanced wastewater treatment, effective use of the sewerage resources, and reconstruction of aging facilities. Table 1 shows the overview of the sewage works in Kobe city.

Table 1 Status of development

Population	1 530 858
City area (km^2)	557.02
Total pipe length of sanitary sewer (km)	4 080
Total pipe length of storm sewer (km)	655
Treatment plant capacity (m^3/day)	700 200
Average daily wastewater treatment volume (m^3/day)	496 256

3. Damages caused by the Great Hanshin-Awaji Earthquake

The Great Hanshin-Awaji Earthquake occurred in Jan.17, 1995. It measured 7.2 on the magnitude scale. Kobe city suffered disastrous damages. Table 2 summarizes the damages of Kobe city.

Table 2 Damages of Kobe city

Loss of life	4 569
Missing	2
Injured	14 679
Completely destroyed houses	67 421
Evacuees (at peak)	236 899

As shown in the table 3, the sewerage facilities also suffered serious damages. Three WWTPs out of seven declined their treatment capacity. Above all the Higashinada WWTP, which is the biggest in the city, completely lost its ability to treat wastewater and took 100 days to restore. Fortunately, the pumping station in the treatment plant did not suffered. We pumped wastewater out to the canal next to the WWTP by using the pumping station. And then, we made the temporary sedimentation tank by closing the canal. During the restoration, we treated wastewater by primary treatment such as sedimentation and disinfection.

Table 3 Damages of Sewerage facilities

Sewers

Total pipe length of damaged sanitary sewer (km)	65.4
Total pipe length of damaged storm sewer (km)	9.5

Treatment plants

Plant name	Capacity (m^3/day)	Damage / Capacity loss
Higashinada	225 000	Completely lost in function (capacity 0 %)
Port island	20 300	No loss
Chubu	77 900	Capacity down to 50%
Suzurandai	43 825	No loss

Seibu	161 500	Capacity down to 20%
Tarumi	133 890	No loss
Tamatsu	75 000	No loss

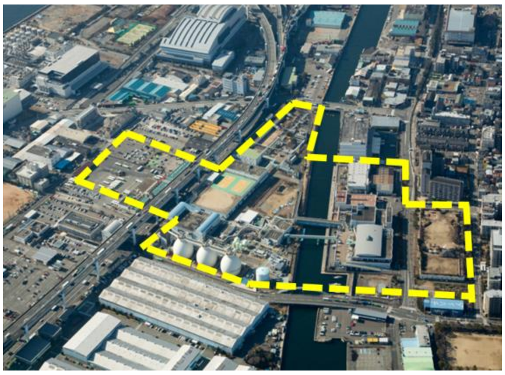


Fig.1Higashinada WWTP

Fig.2 Temporary sedimentation tank using canal

4. Overview of sewerage network system and its structure

Having experiences that WWTP lost its ability by the earthquake, Kobe city selected the policy of “construction of a disaster resistant sewerage system” and started networking the wastewater treatment plants. This is aiming to interconnect the several WWTPs with large bore sewage pipes installed deep underground and to make it possible to distribute the wastewater among the plants. In this paper, the entire system that connects several WWTPs and integrated operation of them is called “sewerage network system”. The trunk sewers that connect WWTPs are called “network trunk sewers”. By interconnecting the WWTPs, even when one of the WWTPs is stopped its function due to a disaster, the remaining WWTPs can receive the wastewater of the stopped plant. The sewerage network system improves the resilience of the entire sewerage system.

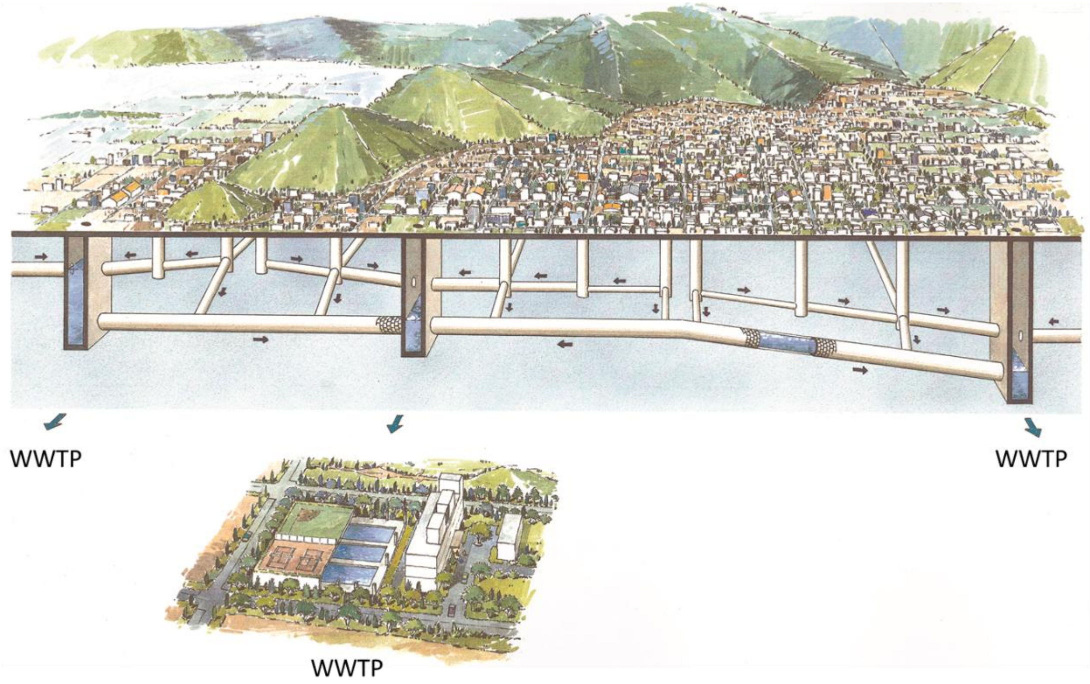


Fig.3 Concept diagram of the sewerage network system

The network trunk sewers can be used in following operations at normal times in addition to its backup functions at emergency.

a. Solving capacity shortage of existing trunk sewers

Populated area generates more wastewater than originally planned and it might exceed the capacity of the existing trunk sewer. This issue can be solved by partially connecting trunk sewers in the area directly to the network trunk sewers.

b. Solving unbalancing issue between the generated wastewater volume and the WWTP capacity

With the same reason mentioned above, the volume of wastewater can exceed WWTP capacity in the area. In such a case, the network trunk sewers can rebalance the wastewater volume sending the overflowed wastewater to other WWTPs that are well within the capacity.

c. Enabling a smooth reconstruction of a WWTP

Some old WWTPs, which need to be reconstructed, do not have enough space to reconstruct efficiently. In such a case, the wastewater of the plant can be transported to another WWTP through the network trunk sewers and treated there. By doing so, the old

WWTP can be decommissioned. Or, if the WWTP is reconstructed, the reconstructing WWTP can be stopped its operation once and perform a large-scale plant reconstruction.

d. Reducing time variation of wastewater volume by pipe storage

By performing pipe storage in the network trunk sewers, the time variation of wastewater volume can be reduced.

Each WWTP has its own flow equalization tank, but its capacity is not enough to receive the wastewater from other plants through the network trunk sewers. Pipe storage in the network trunk sewers make possible smooth wastewater treatment even when receiving the wastewater from other WWTPs.

Kobe city has already constructed deeply buried trunk sewers for other purposes as follows: improving the combined sewer system, improving the combined operation of two different WWTPs, and solving capacity shortage of the existing trunk sewers. We constructed new sanitary trunk sewers that connect those existing trunk sewers. Thus, we structured network trunk sewers. The shield tunneling method was adopted for the construction of almost all the new sanitary sewers. The network trunk sewers that connect five WWTPs were completed in March 2011. The total length of the network trunk sewers is 33.3 km (including the 15.1 km long existing trunk sewers, which were originally constructed for some other purposes) . Construction cost for them was 31.1 billion Japanese Yen.

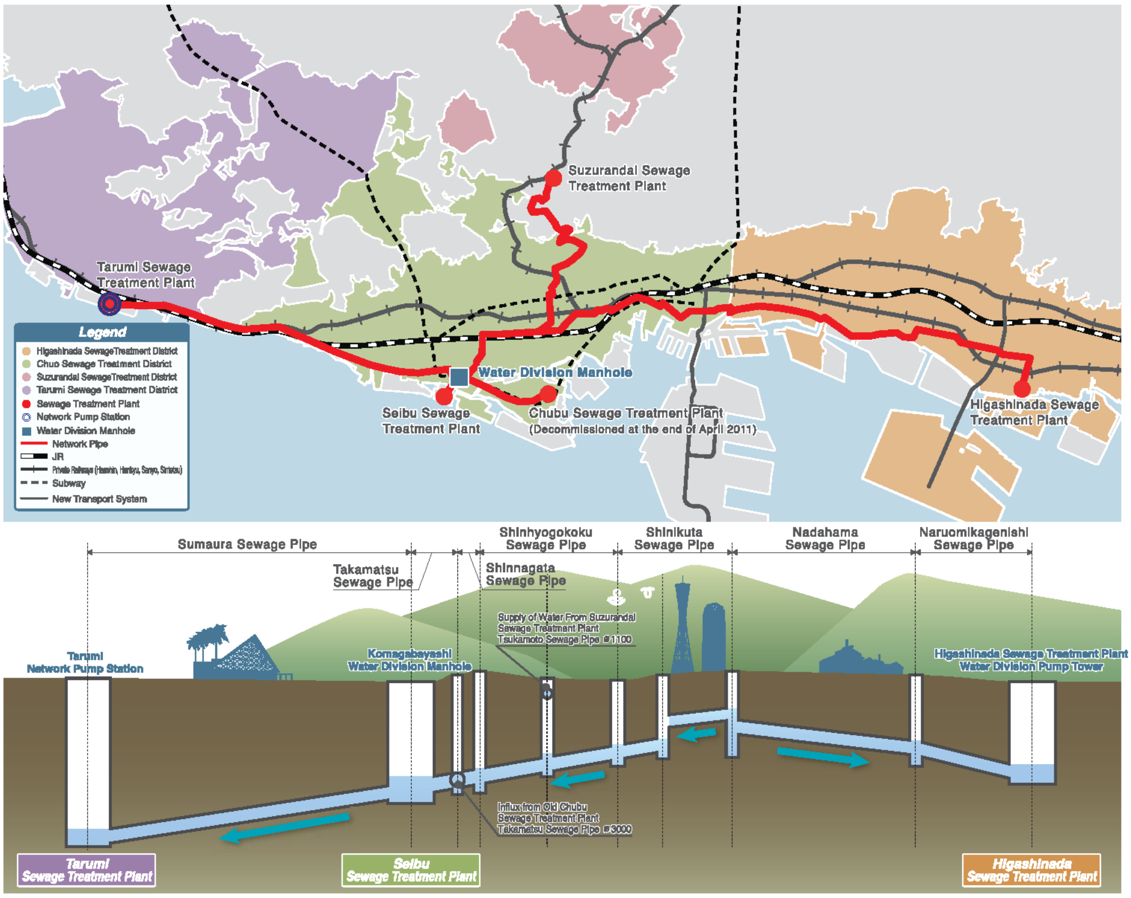


Fig.4 Route map of the network trunk sewers and its cross-section view

The network trunk sewers must function in case of disaster and need to be maintenance free as much as possible during the normal times. Therefore, the network trunk sewers require quake resistance and corrosion resistance. Kobe city adopted the Fiber Reinforced Plastic Mortar (FRPM) pipe insertion method as a standard method for the secondary lining work of the shield tunneling method. This method is to insert the FRPM pipe inside the primary lining work and to fill the gap between the pipe and the primary lining with aerated-mortar. When the ground is displaced due to an earthquake, the displacement in the pipe axis direction is absorbed with the insertion and extraction movement of the rubber ring joint, and the displacement in the vertical direction to the pipe axis is absorbed with the plastic-deformation of the aerated-mortal layer. The FRPM pipe has high corrosion resistance, and the structure of network trunk sewer is flexible for the reason mentioned earlier.

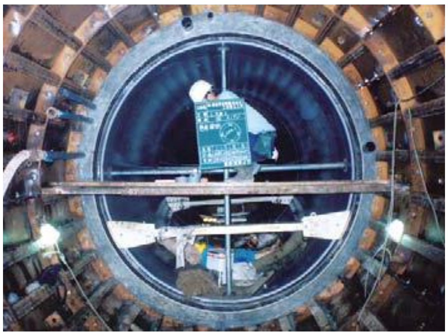


Fig.5 Secondary lining of the FRPM pipe insertion method (under construction)

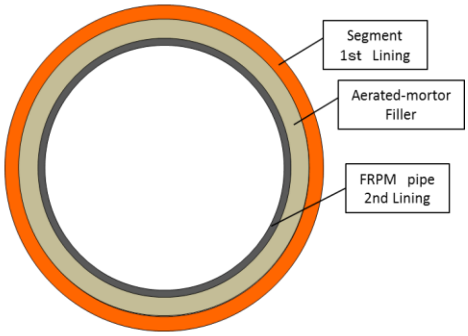


Fig.6 Structure of the secondary liner construction of FRPM pipe insertion method (schematic diagram)

5. Utilization example of the network trunk sewers

Here introduces examples of rationalization and a large-scale reconstruction of the WWTPs which became possible thanks to the network trunk sewers.

(1) Rationalizing of the WWTPs

By using the network trunk sewers, one WWTP, which was surrounded by a residential area and difficult to reconstruct, could be decommissioned. The Chubu WWTP, which started its operation in 1958, was an aging plant and needs to be reconstructed. However, the reconstruction at the current location was very difficult because of the following reasons;

a. The plant was surrounded by a residential area and it was difficult to secure spaces for reconstruction.
b. Advanced wastewater treatment should be introduced after the reconstruction to improve water quality of receiving water body.

Because of the reasons above, the Chubu WWTP was decided to be decommissioned and the wastewater of the Chubu WWTP is transported to the Tarumi WWTP through the network trunk sewers. Since the advanced wastewater treatment system and the network trunk sewers of the Tarumi WWTP, to which the wastewater of the Chub WWTP is sent, was completed in March 2011, the Chubu WWTP was decommissioned in April 2011.

Fig.7 Chubu WWTP

(2) Large-scale WWTP reconstruction

By transporting wastewater to other WWTP through the network trunk sewers, a large-scale reconstruction of an aging WWTP became possible. The Seibu WWTP has two treatment lines, which are called the 1^{st} line (capacity: 80,000 m^3/day) and the 2^{nd} line (capacity: 50,000 m^3/day). These lines will be reconstructed using the network trunk sewers, sequentially following the steps below.

a. Newly build a wastewater treatment line (capacity: 50,000 m^3/day, hereafter called Northline) on a land secured on the northeast of the Seibu plant.

b. Reinforce the wastewater treatment facilities’ capacity of the Tarumi WWTP, which is connected with the Seibu WWTP through the network trunk sewers, so that it can receive wastewater from the Seibu plant.

c. Decommission and demolish the 1^{st} line after the North line starts its operation and build a new line (capacity: 80,000 m^3/day, hereafter called South line) at the place where the 1^{st} line used to be located. During the construction of the South line, the capacity difference between the 1^{st} line and North line of 30,000 m^3/day worth wastewater will be sent to the Tarumi WWTP through the network trunk sewers.

d. After the South line started its operation, the transportation of wastewater to the Tarumi plant will be stopped and the 2^{nd} line will be decommissioned and demolished.

e. Expanded facilities in the Tarumi WWTP will be used as wastewater receiver when aged facilities of Tarumi plant will be decommissioned.

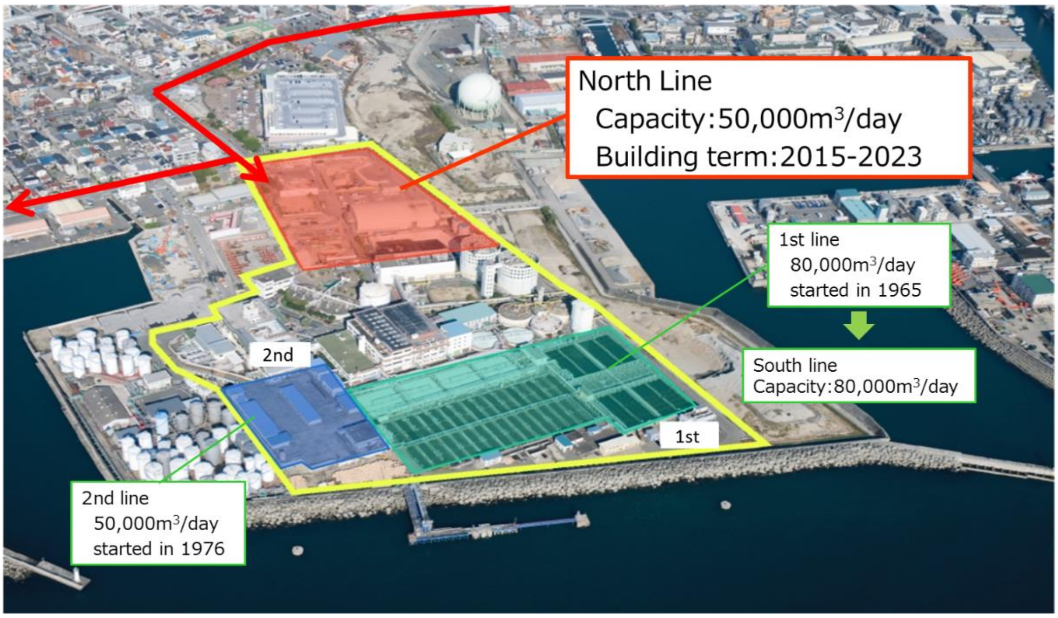


Fig.8 Reconstruction plan of the Seibu WWTP

Currently, the North line’s wastewater treatment facilities are under construction and the transportation of wastewater through the network trunk sewers is planned to start from 2024.

6. Issues found during the operation

It is seven years since the sewerage network system is in operation. Following issues have been found during the operation and we are working on each issue.

(1) Generation of hydrogen sulfide gas

At the pumping well in the Tarumi WWTP, which is the deepest point of the network trunk sewers, very high concentration (over 600 ppm) hydrogen sulfide gas was generated. The gas rusted some devices and shortened life of the activated carbon in deodorization equipment (activated carbon absorption tower). The investigation showed that we need to improve the operation of pipe storage in the network trunk sewers.

To storage wastewater in pipes for a long time causes putrefaction of wastewater and generation of hydrogen sulfide gas. When we store wastewater in pipes, we make the pipe empty once a day to prevent solids from settling inside pipes. At last minutes before the trunk sewer become empty, wastewater with high density of solids flows into the WWTP. The upper end of the network trunk sewer which flows into Tarumi WWTP links with the lower end of the network trunk sewer which flows into Seibu WWPT by Komagabayashi water division manhole. Thus, when we reduced the wastewater level of the network trunk sewer at Seibu WWTP, wastewater with high density of solids flows into the network trunk sewer connected with Tarumi WWTP. Because of that, wastewater putrefied, and hydrogen sulfide gas generated at Tarumi WWTP.

To solve this issue, we decided to close the valve at the Komagabayashi water division manhole while the Seibu WWTP reducing the water level of the trunk sewers so that wastewater with high density of solids will not flow into the Tarumi WWTP. As a result, the time duration that hydrogen sulfide gas concentration exceeds over 400 ppm became one third compared with the duration before the change (from about three hours to about one hour).

Chemical material (polyferric sulfate) was added to decrease the concentration of the hydrogen sulfide gas further. After two years test to decide an effective volume and a time zone to add chemicals, we installed chemical feeder in 2016. Currently, the concentration of the hydrogen sulfide gas is almost all the time 50 ppm or less. (140 ppm only at the peak time)

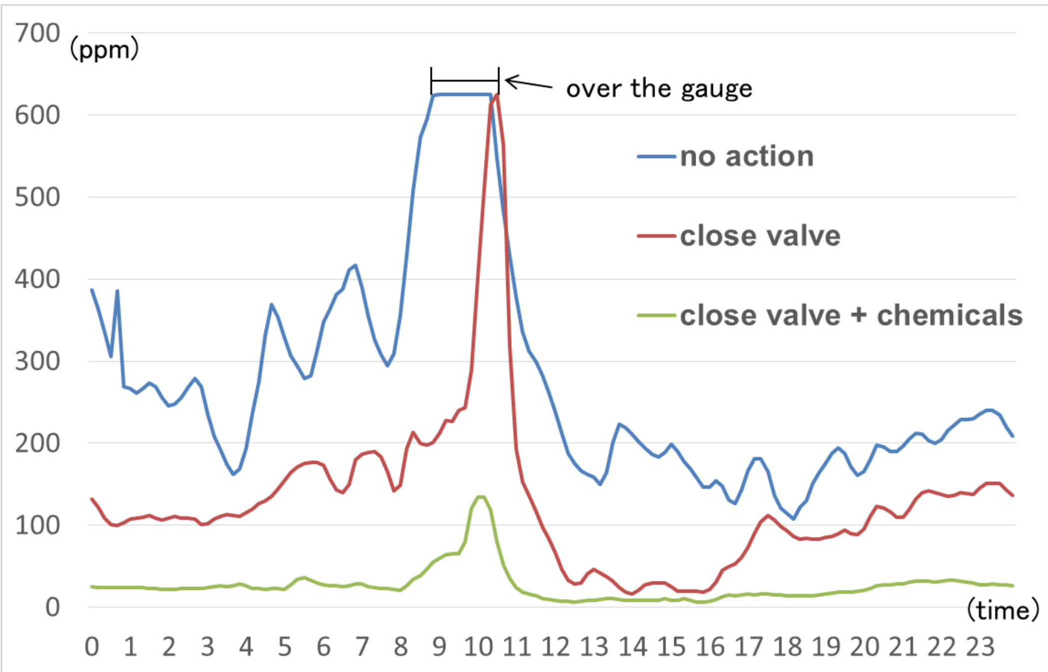


Fig.9 Hydrogen sulfide gas concentration at the pumping well of the Tarumi WWTP

(2) Rapid water level elevation due to the inflow of rain water

When it is raining, due to the inflow of the rain water, the water level inside the network trunk sewers increases rapidly and overflow might occur in the upstream. Kobe city adopts the separate sewer system for almost all the areas inside the city, but the volume of incoming rain water to the sanitary sewage when it rains has been increasing in recent years. The network trunk sewers are directly connected to the existing sanitary sewage line in some areas. Therefore, rapid water level elevation at the time of heavy rain occurs these days. Before, the assumption was that the water surface inside the network trunk sewers is flat. Water storage volume and possible water surface level of the network trunk sewers are decided based on the assumption. But, the fact is that when a rapid water volume change occurs, gradient of water level inside the trunk sewers occurs. This cause the possibility of the overflow in the upper stream when a WWTP in the downstream is reserving wastewater with high water level, in case of having heavy rain in the upstream area.

To solve this issue, we will set water level gauges inside the network trunk sewers to investigate the relationship between the rain fall volume and the water level inside the trunk sewers. Using that data, we are planning to decide the upper limit of the safe water storage level so that it could prevent overflow. The setting of the water level gauges is planned in 2018.

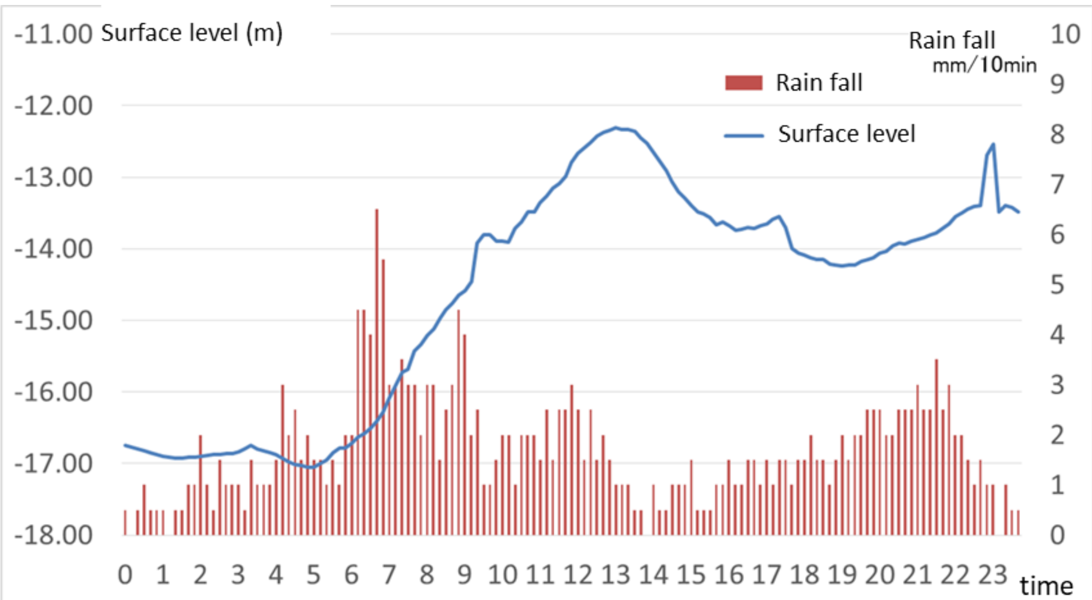


Fig.10 Water level of network trunk sewers and rainfall

7. Conclusions

As described in this paper, rationalization and a large-scale reconstruction of the WWTPs have been realized by using the sewerage network system. This sewerage network system functions as planned at normal times. We are planning to use this system for the reconstruction of the aging wastewater trunk sewers. Now, it has become indispensable system for Kobe city’s sewage works operation.

On the other hand, there are some issues that we did not expect to happen, such as the inflow of rainwater issue.

Cooperation of pipe section and plant section is essential to operate the sewerage network system. Thus, we organized a cross-sectional meeting gathering various section members to discuss issues of this system. Through this activity, we are planning to use this system more effectively.

Floods and Storm Water Rainfall: Are you prepared? DWA Audit to reduce the risks of floods caused by inundations and heavy rainfalls.

Dr. Friedrich Hetzel
German Association for Water, Wastewater and Waste, Germany

DWA, Who are we:

One of the biggest associations in the water in Europe. 14.000 members support our work and are convinced that water and environment need a strong voice in order to achieve a sustainable way of life.

A huge network of experts is an excellent precondition to solve the complex and challenging problems in the water sector and beyond. We bring the experts together and elaborate in over 320 committees standards and guidelines for technicians which they use in their daily work. In order to make sure that those standards and guidelines are implied in the right kind of manner we ran every year more than over 350 trainings and workshops.

Special short papers are produced to inform politicians and decision makers about our point of view to specific topics in the water sector and beyond. Because there are strong linkages between the water and other sectors, we are closely working together with experts from other divisions. Since already some decades, we have a department for international cooperation. Water flows beyond borders and Groundwater aquifers a shared between several countries; therefore, it is obvious that we exchange our ideas and our experiences. And this not only happens with our neighboring countries. Trainings are conducted all over the world, quite often due to the fact, that other countries would like to know, how we developed the German Water Sector. That we all have to cooperate is tangible due to climate change, weather extremes occur more frequently with severe damages and even loss of lives. To combat our unstainable way of live, the destructive and ruthless exploitation, the heads of states formulated in September 2015 the SDG. Target 13 is dealing with Climate and SDG 6 with water, all the 17 goals are interlinked and have to be dealt with in an integrated kind of manner.

Since water is the key to climate change adaptation, a lot can be done to reduce the damages caused by floodings.

The DWA Audit is a prefect tool to evaluate the current situation of flood protection in a municipality and to present measures how to improve the precautions.

As already mentioned, the DWA Audit tool takes inundations caused by rivers and caused by heavy rainfalls (flash floods) into consideration, since the impact of both is very similar.

Unfortunately the awareness to be prepared and to improve resilience against inundations shortly after a flood event is buried in oblivion. Even though, the best time to deal with the risks of inundations is during a dry season.

The time of “preparedness”

The framework and requirements of sustainable precautionary flood prevention measures have to be discussed with the decision makers and authorities of the municipality however, the civil society has to be and should be involved from the beginning on. This is appreciated by the “European directive on the assessment and management of flood risks” (“Floods directive”), which requires that communities discuss flood risks in public. “DWA Flood-Audit” is a tool, which helps to raise local awareness regarding the risks and helps to systematically improve knowledge about different aspects of risk management in a confidential atmosphere. It’s not about to examine people performance, it’s about giving advice.

How does the “Flood-Audit” work?

A “Flood-Audit” starts with a request from a community at the DWA-headquarter. Out of an expert pool two specialists are selected knowing the region and therefore the hydrological circumstances.

The experts get in touch with the focal point of the municipality, explain the procedure and required documents needed for the Audit. By the way they give useful hints, which will help that the community is well prepared for the visit.

Such an on-site visit usually takes two days. In a cooperative manner, the DWA Experts work together with representative members of the community to answer the questions of the survey and to check the level of "preparedness" (due to the DWA- guideline M 551). The result of the audit is a classification of the state of "preparedness" for river floods and for flash floods.

In a comprehensive report, all findings are noted and the classifications are documented. Flood precautionary projects already in place are highlighted and evaluated. Furthermore, the report comes up with a bunch of implementations possibilities making the community more flood resilient. It is the municipality which has to select the appropriates measures due to the circumstances and constrains the municipality has to face and to take into consideration. The audit does not impose any measurements, it is the community, which is in the driver's seat and has to select the best-suited recommendations for actions and to define priorities agreed by all stakeholders. This approach has been proved as the most successful way to increase flood precautionary.

Beside and an extensive documentation of the Audit process the community receives a certificate indicating that the municipality carried out successfully a DWA Flood Audit. After six years, a follow-up audit should take place, allowing checking the impact of the implemented measures and to look for further options to improve the flood resilience of the settlement.

Content of Audit

The "Flood-Audit" focusses on the knowledge of participants about risks and possible actions to increase flood resilience. Mainly the information status of the concerned employees in the municipality about possible risks is assessed.

It has to be kept in mind, that the reference area of the audit is the total municipal area, irrespective of the mandate of the decision makers of an authority. Therefore, it is from utmost importance, that from the very beginning, a stakeholder analyses is conducted. The audit focuses on :

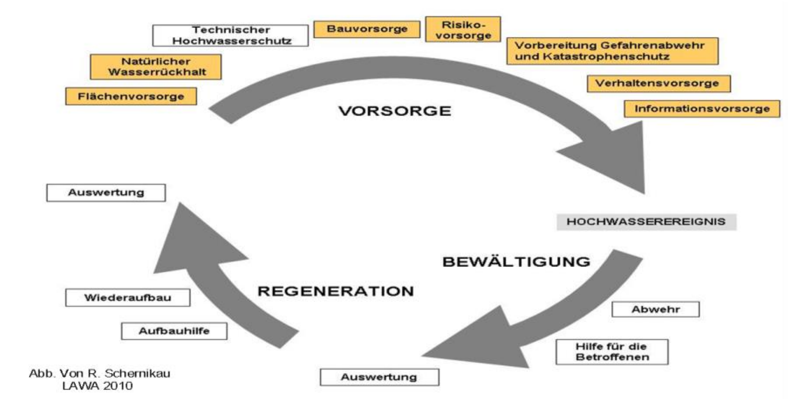
Land-related precautions

Building precautions

Behavioral precautions

Risk prevention

and not on technical flood protection (e.g. dikes, dams, levees…). When implementing the "floods directive" the principle of the 7 fields of action for non-structural flood protection has to be followed. Those 7 are taken in consideration when conducting a DWA Audit. Furthermore, three scenarios (defined by the European Union) are assessed: a frequent flood, a flood with average probability and an extreme flood.



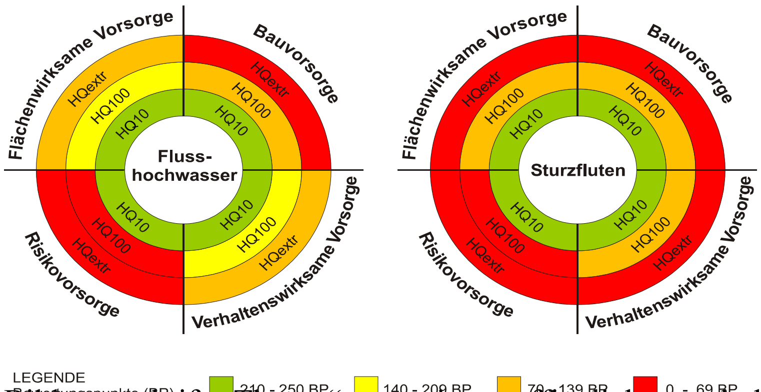
Bildunterschrift: The basis of "Flood Audit" are the fields of action for non-structural flood-protection defined by the European "flood-directive" (yellow)

Assessment

The assessment is based on 35 indicators, divided into seven fields of action for "flood preparedness". The ranges of action have to be assessed separately for the three flood scenarios frequent flood (HQ10), flood with average probability (HQ100), extreme flood (HQextr) and for the two types of floods (river floods and flash floods).

To gain an overview, the indicators are summarized and visualized with colors in two "precaution traffic light symbols", one for river floods and one for flash floods. Each symbol shows four assessment sectors: land-related precautions, building precautions, behavioral precautions, risk prevention.

By that means, the strengths and weaknesses of "flood preparedness" of a municipality are easily captured and understood by all stakeholder including the civil society - a perfect tool to select the existing measures for flood precaution.



Bildunterschrift: These “precaution traffic light symbols” allow the decision makers to identify the demand for action regarding “flood preparedness” in the municipality on first glimpse.

HOW CAN WE BUILD RELIABLE AND RESILIENT SURFACE WATER FLOOD MANAGEMENT?

James Webber, Guangtao Fu and David Butler (University of Exeter)

1. ABSTRACT

Traditional surface water management has focused on building interventions to maintain reliability to design standard flood events. Contemporary academic and legislative guidance now recognises the need to move beyond design standards and implement resilient strategies to manage the duration and magnitude of consequences caused by extreme events. Many assessment methodologies to apply resilience into the water sector are available. However, application is frequently limited by a lack of operationally focused approaches. Where resilience has been operationalised, this is typically achieved through qualitative and high level frameworks which do not provide a quantifiable evidential basis for decision makers.

This research builds on work undertaken by the ‘Safe & SuRe’ project to define and apply resilience in water management by assessing the relationship between reliability and resilience of surface water flood management interventions. The study analyses reliability and resilience using a novel fast intervention assessment framework to simulate intervention responses to many flood events in an urban catchment, including design standard and extreme scenarios. Analysis of flood consequences is made relative to flood damage costs calculated using industry standard assumptions and represented using intervention performance curves which visualise the consequences of flooding. Results indicate that intervention performance during design standard events is not an indicator of a strategies response to extreme scenarios. It is recommended that decision makers include resilience assessment when designing surface water management strategies.

2. INTRODUCTION

Surface water flooding is a major hazard affecting communities in the UK and globally. There is an emerging realisation of the importance of managing surface water, which has historically been overshadowed relative to fluvial and coastal flooding counterparts [1]. Recent reports highlight surface water flooding accounts for 50% of the properties at risk in the UK [2]. Damage from surface water flooding is significant, with current annual damages estimated between 0.25 and 0.5 billion GBP in the UK alone [2,3]. This is predicted to rise to between

0.5 and 1 billion GBP over the next 50 years [4]. Some studies estimate current damage costs from surface water to constitute up to 40% of UK annual flood losses [5,6].

Future hazards are likely to be exacerbated by several emerging drivers. The recent UK Climate Change Risk Assessment highlights that urgent action is required in order to respond to an increasing future risk associated with surface water flooding [3]. Predictions indicate that winters will be wetter and that there will be an increase in the frequency and magnitude of extreme events at all times of the year. Increasing precipitation intensity and variability is a key challenge for the global water industry to manage [7]. Changes in patterns of extreme weather events attributed to climate change will require management of extremes, beyond contemporary design standards [8].

Compounding the effects of a changing climate is the increase in urban sprawl, fuelled by population growth, urbanisation and social changes [9]. Urbanisation both concentrates vulnerability (therefore increasing the consequences of failure) and increases impermeable area within the catchment (thus increasing runoff).

Historic action to protect populations, cities and critical infrastructure from flooding has relied on prediction and action to reliably manage disruption. However, future action must also incorporate resilience to manage the increased likelihood and magnitude of extreme and unprecedented events. This paper discusses the application of reliability and resilience to achieve this balance. The aim of this work is to examine differences between reliable and resilient design in theory and practice. Similar theoretical discussions are found in many studies, however literature recognises a gap regarding practical and measurable application of knowledge [10]. The study aims to take steps towards operationalising understanding through application of theory to a case study, where a recent methodology has been applied to visualise the relationship between reliability and resilience in surface water management.

3. TERMINOLOGY

3.1. Reliable surface water management

Contemporary management of hazards in the water industry has been underpinned by the concept of 'reliability', defined as "the degree to which the system minimizes level of service failure frequency over its design life when subject to standard loading" [9]. Simply put, systems are designed to minimize the likelihood of failure under a predicted stress. Stresses are typically defined by a probability specified as part of a legislated or agreed design standard.

Analysing the performance of reliable systems is referred to as risk management. Risk is a term used frequently within engineering and is a key consideration in planning within the water industry. Generally, the term refers to the exposure to danger, which in the case of the water industry can be regarded as both the vulnerability of assets to hazards and secondary risks conveyed due to assets failing.

In order to manage risks it is key to identify the vulnerabilities of a system and its components and quantify potential losses [11]. From this point risk is managed through 'hardening' the components of a system to reduce the probability of failure or altering the system design to reduce the consequence if a failure does occur [12].

The limitation of current risk management approaches is that the narrow focus on quantifying specific risks and standards does not consider uncertainty effectively, as in order to calculate the risk all probabilities and impacts need to be known and understood [13,14]. This unpredictability and lack of knowledge impedes risk management, and means not all risks can be accurately accounted for [11]. In practice this can be compensated for through the application of confidence grades for calculations and additional safety margins built into designs; however, this approach will still only account for known and understood risks. This demonstrates that future uncertainty is a key principle when assessing risk and that tools to manage this need to be developed [15]. Even when uncertainty is minimised, risk management is not intended to manage disruption beyond design standard events, therefore constituting a gap relative to a future increase in extreme events [8].

3.2. Resilient surface water management

Resilient management aims to add the benefit of assessing systems and strategy's beyond the scope of a defined risk assessment by assessing impacts of events beyond design conditions.

The term 'resilience' has been adopted by a wide range of disciplines, from business planning to social science, and is now subject to extensive contemporary academic debate [16]. Each discipline has adopted the term with slight variations from the original definition, resulting in a noted lack of consistency and confusion in the application of the term [17–21]. As with many other disciplines, there is ongoing debate within the field of engineering as to the definition of resilience and subsequently how this can be operationalised to form a useful, actionable and measurable outcome [10].

Many definitions of resilience (both within and outside of engineering) share the characteristic of 'bouncing back' from a disturbance as a distinguishing feature. This is evident within the field mechanical engineering which defines the term resilience as the "*power or ability of a body to return to original state after being altered due to potential energy that has been stored through modification from previous state*" [22]. This mechanical engineering definition is focused specifically on the properties of materials or a component to bounce back to the original state. Within civil or water engineering this idea can be extrapolated from a description of a material to the description of a system. When describing a system the concept of stored energy in modification (which could be described as the elasticity of a material) is removed, and replaced with the inherent ability of the system to bounce back. The ability to bouncing back from, or minimising the duration of, disruption can be enhanced by a series of interventions which facilitate adaption, mitigation, coping and learning [9].

Recovery of system components is also emphasised in other literature which states that the focus should be on adapting to and quickly recovering from broad categories of threats [11]. This is further expanded through emphasising system functionality over a wide range of possible states, therefore meaning that the system is likely to operate more effectively during a disturbance [23]. Resilience is contextualised as an alternative to traditional resistant systems, which are designed to recover quickly from a perturbation within a narrow band of tolerance, but cannot to operate under a wide range of conditions. This definition emphasises the need to assess many future scenarios when analysing resilience.

As well as rapid recovery or 'bouncing back' from a disturbance, a further common element within literature is that resilience to manage extreme or unexpected events [9,24]. This relationship is shown within Figure 1. Events can be unexpected due to either a high magnitude/ low probability falling outside of normal planning policy, or from a hazard not considered or deemed to be a significant threat during design.

The 'Safe and SuRe' (Safe, Sustainable & Resilient) framework provides a definition of resilience which includes the concept of managing exceptional conditions by defining resilience as "*The degree to which the system minimises level of service failure magnitude and duration over it's design life when subject to exceptional conditions*" [9].This encapsulates the concepts of managing extremes through reducing magnitude and bouncing back by minimising the duration of failures.

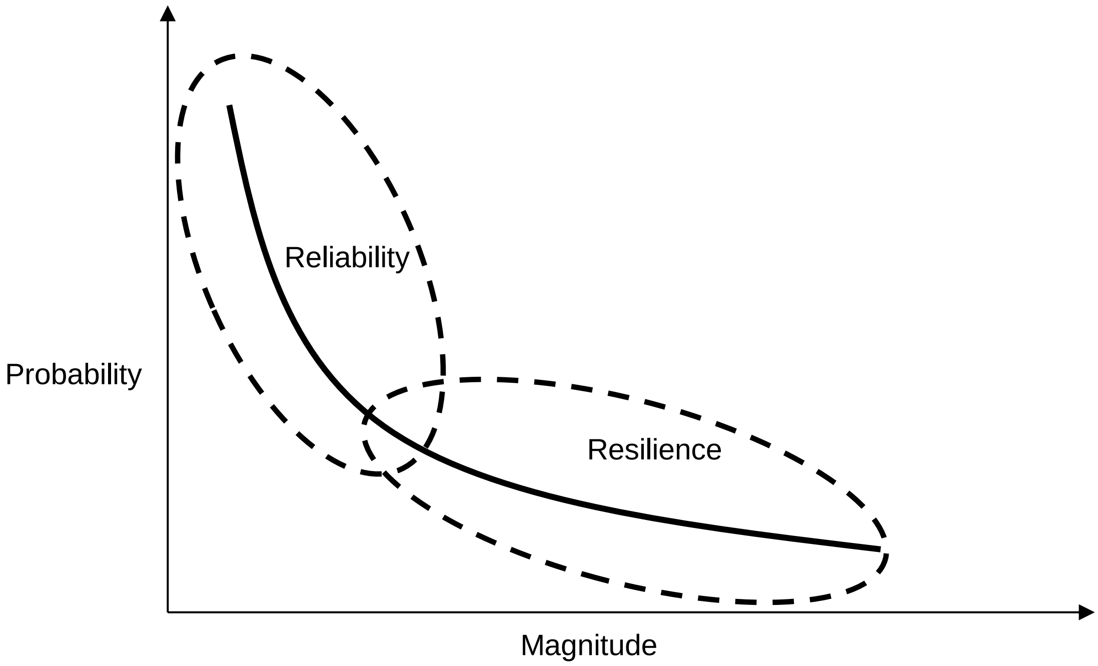


Figure 1: The relationship between reliability and resilience [9].

4. THEORETICAL APPLICATION

4.1.Measuring reliability

Reliability is typically measured in terms of performance to a specified standard. In the case of surface water standards are usually linked to the probability of a rainfall event overwhelming a system or causing damage and disruption. For example, by stating a measure should continue to be effective up to a 1 in X year event. In this research reliability is expressed as the probability or the cost of failure at each specified probability.

An example of reducing the probability of failure would be constructing a tank to capture all rainfall in a specific precipitation event. This would prevent flooding to the standard of the probability specified. The advantage of this approach affords a level of safety, however residual risks beyond tank capacity are not assessed or managed, so uncertainties and unknown impacts from low probability events need to be communicated to stakeholders.

4.2.Measuring resilience

A long-standing critique of resilience science has been a lack of operational and quantitative application of theories [10]. This is of particular note in complex systems, such as surface water management in cities.

The Safe & SuRe project at Exeter University [9,24] has proposed a definition for resilience which allows a quantification of resilience in a practical setting by measuring the failure magnitude and duration during extreme events. This model has been applied to a range of challenges, including: wastewater treatment [25,26], water distribution [27], urban drainage [28] and urban catchment management [29]. As of yet this research has not been applied to assessing surface water flooding interventions.

The Safe and SuRe project specifies resilience as 'general', the ability of a system to as limit failure duration to all threats, and 'specified', limiting failure to a particular threat based on an operational goal. Specified resilience is applied in this research to identify the resilience of cities to surface water flooding.

Resilience is measured as a function of the magnitude and duration of failure. This research applies short duration flood costs (depth-damage) which act as a single metric that combines magnitude depth and duration.

5. PRACTICAL APPLICATION

5.1.Intervention performance case study in an urban catchment

This study applies new analysis to previously published data to highlight the relationships between reliability and resilience in a practical setting [30]. Intervention reliability and resilience was investigated through analysis of performance across many rainfall events using a novel fast option assessment framework [31,32]. Assessment using a simplified framework facilitated analysis of many simulations to identify response to extreme events, not usually considered within the decision making process.

5.1.1. Setup

The rapid intervention assessment framework provides fast analysis of scenarios through a simplified representation of interventions in a cellular automata flood routing model, 'CADDIES' (Cellular Automata Dual DraInagE Simulation). CADDIES represents movement of runoff across a regular grid via application of weight based cell transition rules [33,34]. This simplified approach has been demonstrated to show comparable accuracy to industry standard hydrodynamic models with processing speeds five to twenty times faster [35].

The model controls movement of water between grid cells using input, output and movement parameters. Input values refer to the intensity of rainfall applied to the cell in each time-step and are specified in mm/ hour. Output parameters control the water removed from each cell at each time-step, representing the action of infiltration, evapotranspiration, storage and conveyance through the drainage system. The movement parameter controls the speed of transmission between cells, and is specified using a Manning's n roughness coefficient.

A test catchment was represented using a 1 m resolution elevation model, with land use parameters specified using infiltration rates and roughness coefficients from literature [36–38]. Buildings were represented using a threshold elevation and an artificially high roughness value to simulate water being held within a structure [39].

Interventions included surface drainage upgrades, installation of green roofs and rain water capture. These were represented through manipulation of input, output and cell transfer parameters using values from literature [30]. Interventions were placed across all suitable locations within the study sub-catchment.

Rainfall was represented using design storm hyetographs representing one hour duration storm intensity at 2, 5, 10, 20, 30, 50, 100, 200 and 1000 year return periods [40].

81 simulations were run to analyse the performance of each intervention strategy in every rainfall event. Each simulation output a peak depth file which represented the maximum depth in each cell across the simulation. Peak depths were converted to damage costs using flood depth-damage curves [41] and a GIS based flood damage estimation tool [42,43].

Reliability is assessed relative to damage costs at each specified probability. Resilience is assessed relative to the magnitude and duration of failure across multiple events. In this case failure is specified as any damage cost above zero. Surface water flood costs applied represent short duration (< six hour) flood damage.

5.1.2. Results

Results were used to develop a performance curve representing the damage cost response of intervention strategies in relation to a set of events, representing a range of rainfall intensites (**Fehler! Verweisquelle konnte nicht gefunden werden.**). Figure 2 maps the intensity of each one hour rainfall event (primary x axis) to a return period, expressed in terms of a '1 in X year' event (secondary x axis).

The damage cost resulting from each intervention strategy rises as the rainfall intensity increases. The highest flood damage costs during each event are consistently observed in the 'do nothing' baseline, where no interventions are applied.

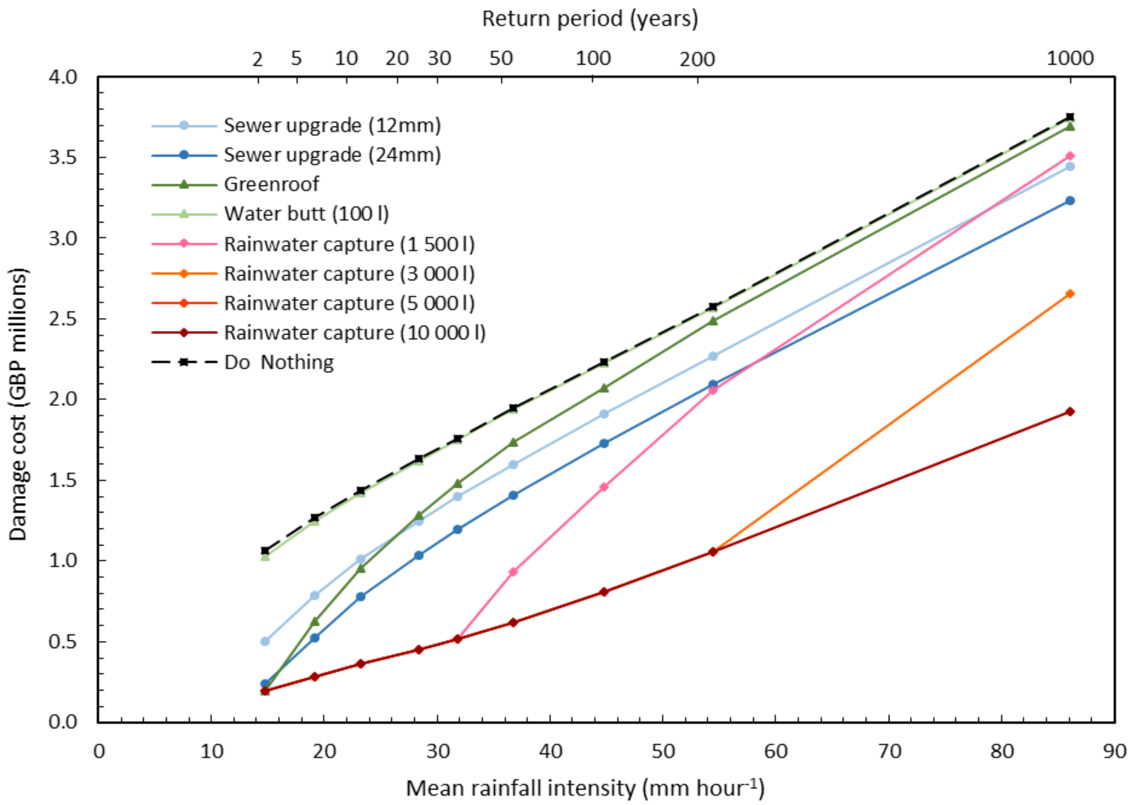


Figure 2: Intervention response to increasing stress (mean rainfall intensity) [30]

Intervention performance across return periods is inconsistent. Interventions which minimise damage during higher probability/ low intensity rainfall are not always observed to be the most effective interventions in lower probability/ higher intensity storms. This is expressed most clearly when considering how the ranking of interventions changes during each return period.

All rainwater capture tanks are the equal best ranking intervention during two to thirty year return period rainfall. Large (10 000 l) tanks remain the best ranking intervention for all events; however smaller tanks demonstrate inconsistent performance, with a large increase in flood damage costs and a consequent reduction in ranking during higher return periods. The increase in flood damage costs is observed with 1 500 l tank scenario from the fifty year return period onward. By the 200 year return period this intervention is only marginally better performing than the 24 mm/ hour sewer upgrade, although it is still the second ranked strategy. By the 1000 year return period the intervention is now ranked fifth and demonstrates considerably worse performance than interventions it outperformed well during the lower intensity events.

Sewer upgrades perform well at lower intensity storms, but demonstrate higher damage costs as storm intensity increases. Damage costs rise in a relatively consistent and incremental values in response to the increasing strain. This stable rise in cost results in the interventions improving their ranking during the higher return periods, despite initially ranking poorly. The strategies still demonstrate increasingly high costs relative to the best performing interventions in each events.

Green roofs rank equal first place during the two year return period but fall to sixth following the twenty year event. The cost increase steps are particularly large relative to other interventions between these two return periods.

Both small capacity water butts and the do nothing base case demonstrate the worst performance and are respectively ranked eighth and ninth at each return period. Damage cost increases in stable steps relative to increasing rainfall intensity.

6. DISCUSSION

Findings specific to the case study interventions indicate that that relative performance of interventions changes as the intensity of the rainfall increases. In this example, the proposed mechanisms controlling damage increase are the storage capacity and rate of runoff removal from each cell, parameterised for each intervention. Storing rainfall is an effective damage reduction technique when storage is able to contain all rainfall, however as rainfall exceeds intervention capacity the damage increases significantly at each additional increase in intensity. Removing rainfall at a set rate from a cell via infiltration or increasing the drainage capacity did not perform as effectively as capturing all of it, however a more consistent response to the increasing rainfall events was observed. The mechanisms presented here are simplified. In practice the output rate is controlled by a variety of physical processes including hydraulic limitations in the piped system and saturation in soils, therefore these findings can only be considered indicative of high level strategic implications of the actual strategies.

Generally, these findings indicate that intervention performance during a high probability event is not an indicator of performance during low probability events. This is of major significance when considering a planning environment focused on meeting specified design standards versus environmental hazards which are increasing in severity as a response to climate change, urbanization and aging infrastructure systems. Planning based solely on design standard events is not guaranteed to develop systems which are able to cope with extreme events. Future developments to planning methods should include analysis of a range of events and conditions so decision makers are able to better manage system shocks.

Application of simplified simulation approaches is one way of including extreme events within design. These approaches have the advantage of assessing many scenarios and expanding understanding of catchments, but encounter several drawbacks regarding the simplification of certain underlying physical processes. These approaches require understanding of hazard characteristics (ie rainfall intensities) in order to simulate surroundings. As such they are best applied at an initial strategic level of design, with findings advanced and corroborated by further more detailed analysis. Alternative approaches of including extreme events within planning include application of ‘middle state’ failure analysis or emergency planning [24]. Middle state analysis removes the need for understanding of hazards by systematically assessing how a system operates as more components fail. This has been applied with success to WDS where components can clearly be identified and changed. So far this approach has not been applied to surface water management. On the other hand, emergency planning approaches encourage planners to develop contingency plans for failure as part of an understanding that unprecedented and unknown events may take place, so advance communication strategies for managing failures gracefully becomes necessary.

On balance, a combination of these approaches is likely the best outcome for managing resilience, however the advantages of applying visualisation of resilience to decision support should not be understated. Particularly in light of potential for quick wins, where a selection of similarly costed strategies may all meet design standards but certain options may provide additional benefits beyond this.

7. CONCLUSIONS AND FUTURE WORK

This work identifies that performance of strategies during low magnitude events is not reflective of a strategies response to extreme events. A paradigm based on design standard planning therefore misses assessing resilient performance. A range of approaches can be used to assess resilience and it is important that these feature in future urban design in order to ensure preparedness for unexpected, unprecedented and extreme events. Visualisation of resilience curves using fast simulation approaches is one way of achieving this, however this needs to be developed further to encapsulate an easier to report metric.

This work was based on the assumption of short duration surface water flooding. Further future work should expand this methodology to assess how the duration, magnitude, rate of change and timing of hazards will influence the impacts of disruptions. General resilience [9] should include interventions response to all hazards, so the methodology should also be developed to respond to the wider remit of future threats.

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DEMONSTRATION STUDY OF USE OF STORMWATER MANAGEMENT TECHNOLOGY TO MITIGATE FLOOD DAMAGE FROM LOCALIZED HEAVY RAINFALL

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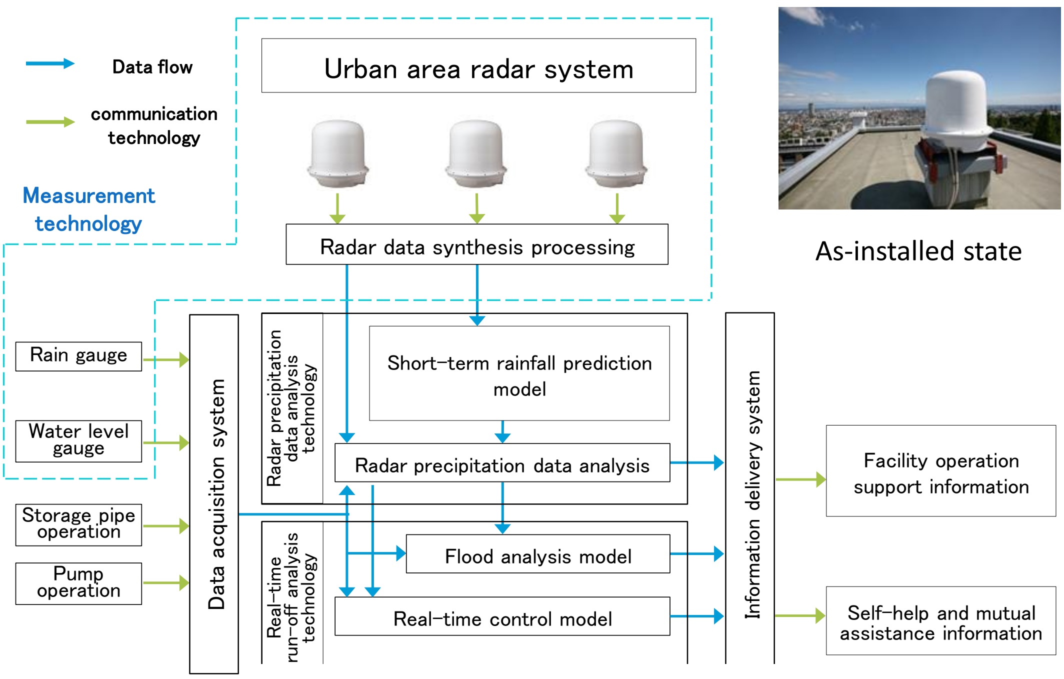
1 Introduction

In Japan, landside water inundation damage has occurred frequently in recent years due to localized heavy rain (over 100 mm/h) exceeding sewerage stormwater drainage capacity. To mitigate such damage, advanced stormwater management, including effective operation of existing flood control facilities, and delivery of information to promote self-help and mutual assistance among residents, are necessary.

The National Institute for Land Infrastructure Management, MLIT, formed a joint study team whose participants included Metawater Co., Ltd., New Nippon consultants, Co., Ltd., Nihon Suido Consultants, Co., Ltd., FURUNO ELECTRIC Co., Ltd., EMORI Infotech Co., Ltd., Kobe University, Fukui City, and Toyama City. The demonstration study was conducted using sewage drainage districts in Fukui City and Toyama City as



Picture 1.1: System

the fields. The objective was to evaluate the effects of flood damage mitigation obtained by securing capacity in stormwater storage pipes for subsequent rainfall events by operating drainage pumps for maximum utilization of receiving waters and by securing sufficient lead time for flood damage mitigation activities through residents’ self-help and mutual assistance. The technology evaluated in the study was a system (Picture 1.1) with combined use of a “short-term rainfall prediction model” and “real-time runoff analysis.” The former model incorporates small (radar dome diameter about 1 m) X-band dual polarization radar (“urban area radar system”), the first radar ever applied for sewerage stormwater management in Japan, and the ensemble prediction approach.

The latter model enables high-speed analysis.

2 Rainfall Observation Performance of the urban area radar system

2.1 Features of the urban area radar system

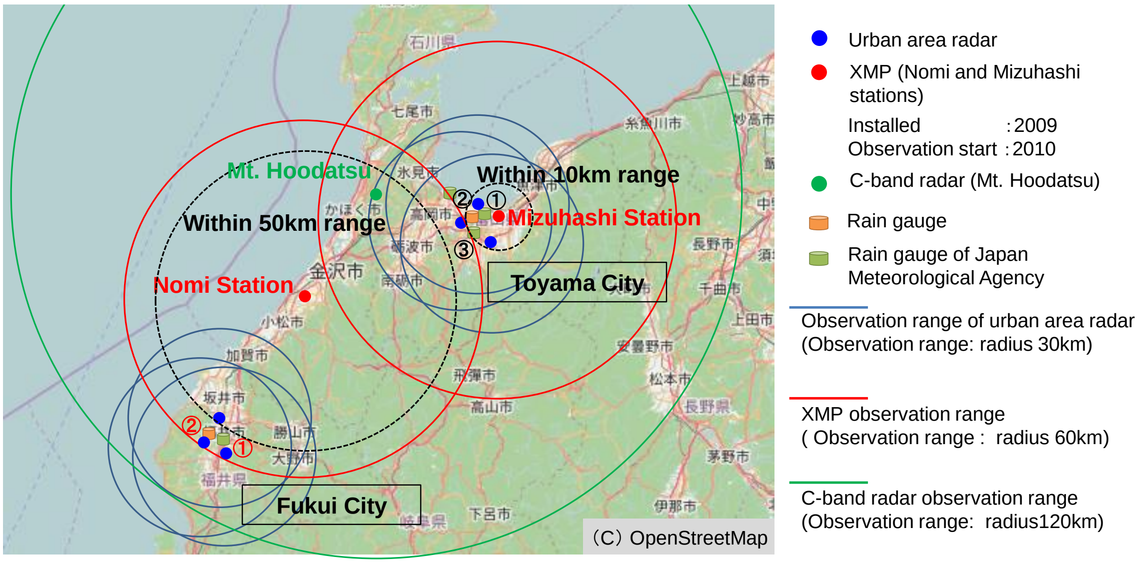
Urban area radar is a small X-band dual polarization Doppler weather radar used for monitoring of urban inundation, sediment disasters, and river floods. When installed outside the range of quantitative observation with X-band dual polarization Doppler weather radar (hereinafter XMP) under control of MLIT, the urban area radar system can perform interpolation observation of rainfall in low-level rainfall not covered by XMP.

The urban area radar has an observation range as small as 30 km, but its compactness and light weight (antenna diameter: 0.75 m, radar dome diameter: 1 m, and weight: 68 kg) ensure easy transport and carry-in, while enabling manual installation without using heavy machinery. Its ease of installation enables installation on a building roof with limited space. It is also inexpensive compared to conventional weather radars, which means multiple urban area radars can be installed. This in turn enables observation of rain existing behind extremely strong rainfall by another urban area radar. This reduces the areas where observation is missed due to radio wave dissipation.

2.2 Demonstration method

Picture 2.1 shows the rainfall observation system studied. The demonstration field was the sewage drainage districts in Fukui City and Toyama City. The Nomi and Mizuhashi XMP stations are located around the field. For the demonstration field of Toyama City with the XMP Mizuhashi Station located nearby, the rainfall observation accuracy of XMP and that of ground rain gauges were compared within a 10-km range from the center of three urban area radars. For the demonstration field of Fukui City, the rainfall observation accuracy was compared with rain gauges on the periphery (50 – 60 km) of the quantitative observation range of XMP Nomi Station.

The rainfall observation period for the urban area radar was from April 1 to November 30, 2016. During that period, the maximum hourly rainfall was 13.1 mm/h for Fukui City and 19.2 mm/h for Toyama City. The maximum 10-minute rainfall was 4.5 mm/10 min for Fukui City and 6.2 mm/10 min for Toyama City. It should be noted that rainfall causing inundation damage was not observed during this period.



[Rain gauge] ①Toyama ②Kureha sewage drainage district ③Akigashima
①Fukui ②Drainage district No.6

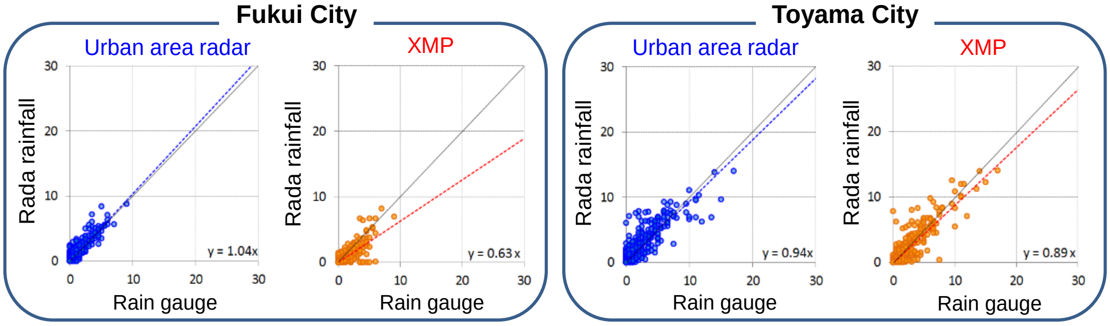
Picture 2.1: Rainfall observation system in the demonstration fields

2.3 Verification results

2.3.1 Rainfall observation accuracy

Picture 2.2 shows the resultant accuracy of rainfall observation. In Fukui City, the regression coefficient and the coefficient of correlation exceeded XMP, and RMSE was equivalent to that of XMP. In Toyama City, the regression coefficient, the coefficient of correlation, and RMSE were equivalent to those of XMP.

This suggests that urban area radar has rainfall observation accuracy equivalent to that of a larger XMP of the same type and that urban area radar can perform interpolation observation around and outside the observation of XMP.



Observation period Fukui : June 7,2017〜September 30,2017 Toyama : June 1,2017〜September 28,2017

		Fukui City		Toyama City	
		Urban area radar	XMP	Urban area radar	XMP
Data counts (*)		6336	6336	12528	12528
Evaluation indices	Regression coefficient	1.04	0.63	0.94	0.89
	Coefficient of correlation	0.89	0.79	0.88	0.90
	RMSE	0.27	0.32	0.32	0.27

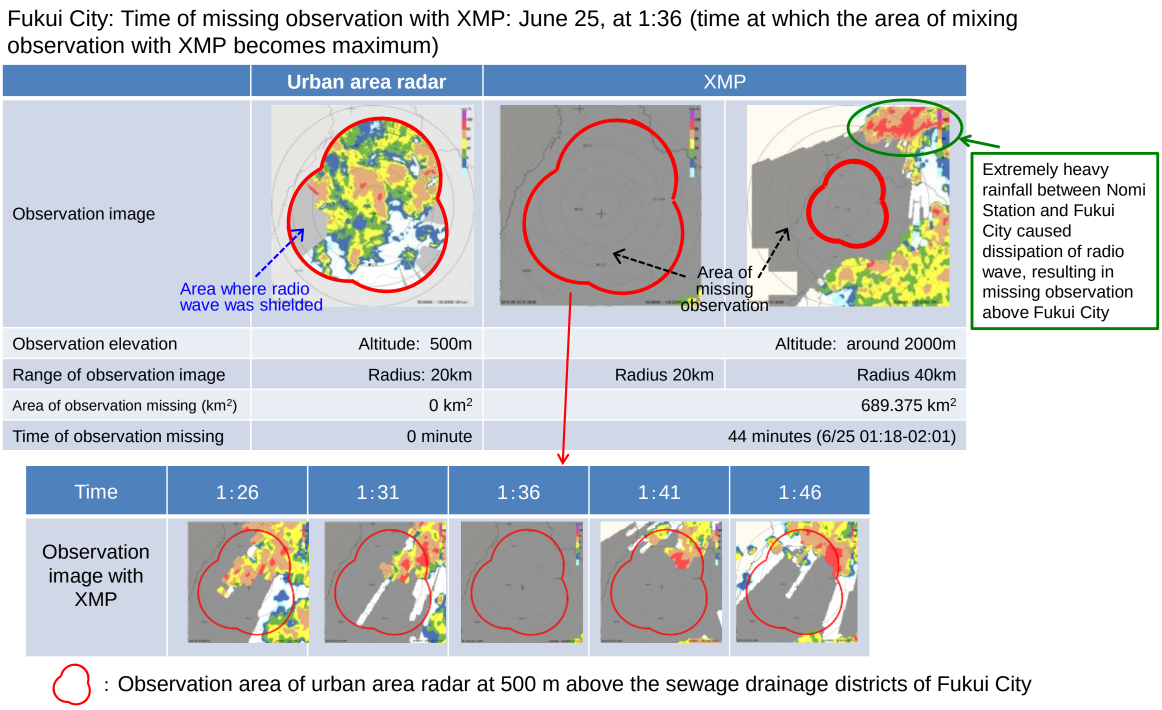
Rainfall unit: mm/10min

* The number of data in which the rainfall value exists in both the rain gauge and the radar rain gauge at a time when the 10 minute data is the same.

Picture 2.2: Rainfall observation accuracy

2.3.2 Area of missing observation due to signal decay

The missing observation ratio was zero in both Fukui and Toyama. The time of missing observation was 0 minute for the urban area radar and 1,001 minutes for XMP. Picture 2.3 shows the cases in which the urban area radar could perform interpolation observation when observation missing occurred with XMP. As shown in Picture 2.3, extremely heavy rainfall of 50 mm/h or more between Fukui City and Nomi Station caused signal decay, resulting in missing observation within the area covered by XMP. For the urban area radar, no heavy rainfall that would cause missing observation above the sewage drainage districts occurred, and three radars were arranged to surround these districts. Even when missing observation occurred with one of these urban area radars due to signal decay, the area could be covered by other urban area radars, resulting in elimination of missing observation.



Picture 2.3: Cases of observation missing with XMP

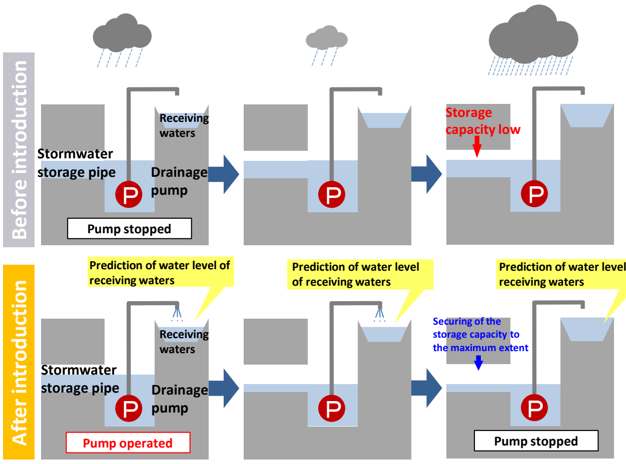
3 Mitigation effects of flood damage

3.1 Securing storage capacity with improved operation of stormwater storage pipe drainage pumps

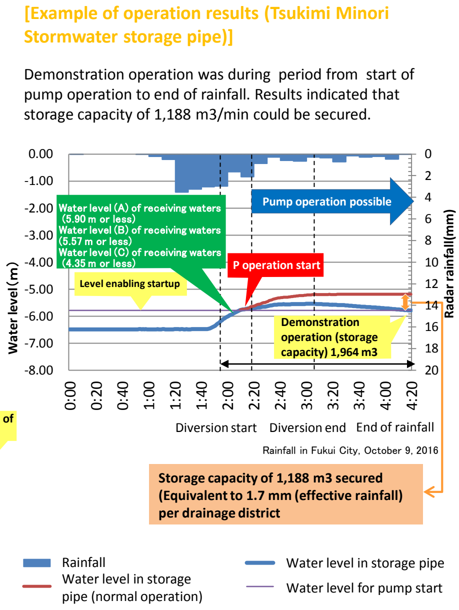
Before the demonstration technology was introduced, the limited capacity of receiving waters caused drainage pumps to be operated at a stage when the receiving water level dropped sufficiently after the rain stopped. This is illustrated in Picture 3.1. In this situation, storage of previous rainfall resulted in decreased storage capacity, often at the peak inflow stage. After the technology was introduced, the drainage pumps could be operated continuously within the capacity of the receiving water even during rainfall. This operation was based on predictions of water levels in the storm sewer where overflow occurs initially on the downstream side of the receiving waters. The results confirmed that, after introduction of the technology (before peak inflow), the storage amount was increased by about 10% from the level before introduction (secured storage capacity 1,118 m^3/storage amount 12,700 m^3).

(Tsukimi Minori Storage Pipe)

Drainage area	255 ha
Storage capacity	12,700 m3 (Φ3,750 mm L=1,150 m)
Design rainfall:	43.1 mm/hour (corresponding to the rainfall, once in five years)
Intake weir	8 (fixed weir)
Drainage pump	200 mm diameter, 4.5 m3/minute x 2 (total: 540 m3/hour



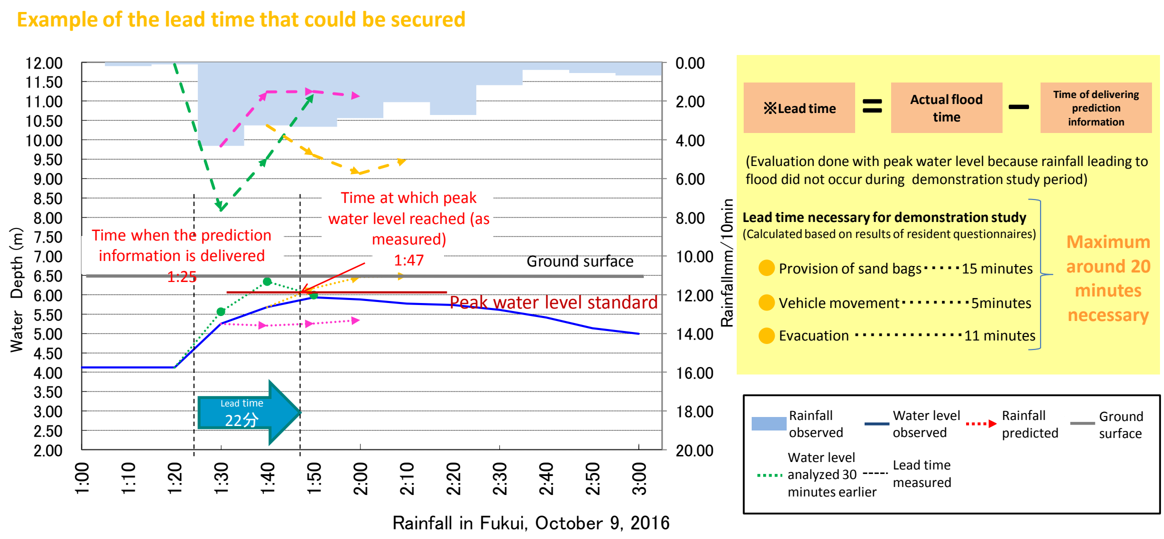
Based on predicted water level of receiving waters, pump operated continuously within a range not promoting flood at downstream side



Picture 3.1: Improvement and effects of stormwater storage pipe drainage pump

3.2 Securing time needed for flood damage mitigation activities by residents

In the demonstration test, the data compiled from the rainfall observed with the urban area radar was delivered to the residents in real time (renewed every five minutes). This included average rainfall of the area, short-term prediction of rainfall, pipe internal water level (measured and predicted) within the area, and landside inundation prediction map information. The flood damage mitigation activities by residents examined in this study were provision of sand bags in front of entrances of houses and movement of vehicles to high ground. Based on the results of a hearing with residents, the lead times necessary for damage mitigation activities were set to 15 minutes and 5 minutes. Accordingly, the aims set were delivery, 20 minutes or more in advance, of flood prediction information before inundation. As rainfall causing inundation did not occur during the demonstration period, evaluation was made for five rainfall events with high water-level rises, while referring to peak water levels. Basically, as shown in Picture 3.2, a lead time of about 20 minutes could be secured.



Picture 3.2: Verification of effects of self-help and mutual assistance

4 Conclusions

◆For the first time in Japan, an evaluation was conducted of the effects of damage mitigation activities of residents of areas vulnerable to flood, to which information on prediction of water inside the sewer and prediction of landside inundation was delivered by combining the use of urban area radar, short-term rainfall prediction, and real-time analysis in the sewage works.

◆Urban area radar can achieve observation accuracy equivalent to that of XMP. It was confirmed therefore that urban area radar has rainfall observation accuracy as interpolation observation of XMP.

◆It was confirmed that, for the observation range at an altitude of 500 m, no missing observation occurred with urban area radar. For Fukui City at the periphery of the quantitative observation area (radius: 60 km), urban area radar could perform interpolation observation even when missing observation occurred with XMP. Namely interpolation observation with the urban area radars was confirmed to be effective for the observation area with one XMP only and for the periphery of the quantitative observation range (radius: 60 km) of XMP.

◆Though rainfall with landside flooding did not occur during the demonstration study period, the proposed technology proved to be effective for improvement of the drainage pump operation of stormwater storage pipe and provision of sand bags and movement of vehicles to elevated spots by the residents in case of flood.

◆In the future, a Guideline for Introduction of Stormwater Management Technology will be issued by the National Institute for Land and Infrastructure Management, MLIT, for application and dissemination to local authorities across the country.

5 Acknowledgement

The content of this paper is based on the results of research contracted by the National Institute for Land and Infrastructure Management of MLIT for 2015 to 2016 in the Breakthrough by Dynamic Approach in Sewage High Technology Product (B-DASH Project) sponsored by the Sewerage and Wastewater Management Department, MLIT. We would like to express our thanks to the members of the joint study team, those concerned for cooperation extended in the course of summarization of study results.

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EVALUATING CITY RESILIENCE AND SERVICES CASCADE EFFECTS IN FLOODING SCENARIOS

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1 Introduction

City resilience reflects the overall capacity of a city (individuals, communities, institutions, businesses and systems) to survive, adapt and thrive no matter what kinds of chronic stresses or acute shocks they experience [1]. This capacity may be acquired through adopting structural and non-structural solutions and/or introducing knowledge and intelligence in the management of cities infrastructures.

In recent years, society has become increasingly aware of the risks that climate change poses to cities. Climate change is likely to result in sea level rise, irregularity in rainfall frequency and intensity, droughts and heat waves, which calls for a rapid but also informed, sustainable and cohesive response from several stakeholders. In fact, the growing diversity of hazards, increasing complexity of cities, and uncertainty associated with climate change, globalisation and rapid urbanisation have contributed to introduce urban resilience into a critical agenda [2] and reinforced and it is necessary to make cities and human settlements inclusive, safe, resilient and sustainable [3].

Furthermore, there is a need for models and tools that analyse urban resilience based on a multisectoral approach, considering service interdependences and cascading effects, in order to increase city’s sustainability and resilience, in particular to flooding [4].

This paper presents the work being carried out under RESCCUE Project - Resilience to Cope with Climate Change in Urban Areas (funded by EU’s Horizon 2020 Programme) regarding the assessment of the urban resilience in Lisbon, namely related to rainfall and flooding events.

The critical services and infrastructure and their interdependences and cascading effects were assessed in areas prone to flooding and sea level rise, namely in the downtown areas (drainage basins J and L). These basins have more than 600 ha, 140 km of combined sewers with limited capacity and serve almost 76 400 inhabitants [5].

2 Methodology

2.1 General description

The proposed methodology aims to evaluate urban resilience in result of extreme precipitation events leading to flooding, on a multisectoral approach, considering service interdependences and cascading effects, and is developed in the following steps:

1. Definition and characterization of the study area.
2. Application of dynamic 1D/2D models to determine flooded areas and the severity of the floods.
3. Identification of interdependencies, impacts and cascading effects, taking into account several multisectoral services.
4. Evaluation of urban resilience, trough simple quantifiable indicators and a resilience index.

These four steps are described in detail in the following paragraphs.

2.2 Definition and characterization of the study area

Since the main purpose of the study fs to evaluate urban resilience in flooding scenarios, the definition of the study area usually comprises the catchments more susceptible to those events.

The characterization of the study area constitutes the preassessment phase that aims to provide a base point from which the study is developed, defining the services to include in the process and the critical infrastructures to analyse, as well as the physical or human resources that can be activated in an emergency in order to restore the normal state of operation of the services as soon as possible. A special focus should be placed on the characterization of the drainage system so as to collect data used to build the 1D/2D dynamic models. In addition, the main services and critical infrastructures of the city should be identified and characterized, including their operating procedures, both under normal and extraordinary conditions. The number of infrastructures to be analysed should neither be excessive or too scarce, allowing a realistic analysis of the system without an increasing degree of complexity that might compromise the results.

2.3 Application of dynamic 1D/2D models

The application of hydraulic dynamic 1D/2D models allows to simulate the drainage system behaviour, estimating the impact of extreme rain events with different return periods. The models identify the surcharge nodes, quantify the runoff volumes and contribute to delimitate the flooded areas and the height of accumulated surface water, thus allowing a further analysis on the impacts of each event.

This goal is achieved by combining two existing simulation tools (SWMM, developed by EPA, and BASEMENT - Basic Simulation Environment, developed by the Laboratory of Hydraulics, Hydrology and Glaciology of the ETH Zürich). A Combined Model SWMM+BASEMENT (CMSB) was developed, that integrates the results of both models, and takes into account the efficiency of the rainfall interception devices (inlets). Therefore, a parameter was defined, the α parameter, that reflects the catchment average inlet efficiency and acts on the useful precipitation hyetograph, resulting in an attenuated precipitation hyetograph which is introduced on SWMM. The remaining useful precipitation hyetograph is converted to runoff and introduced on BASEMENT as a hydrograph [6], as well as the volumes that are discharged by each SWMM node where surcharge of the drainage system occurs. BASEMENT also considers the effect of inlet efficiencies, reducing the surface accumulated volumes and heights accordingly. The overall conceptualisation of this combined model is shown in Figure 1.

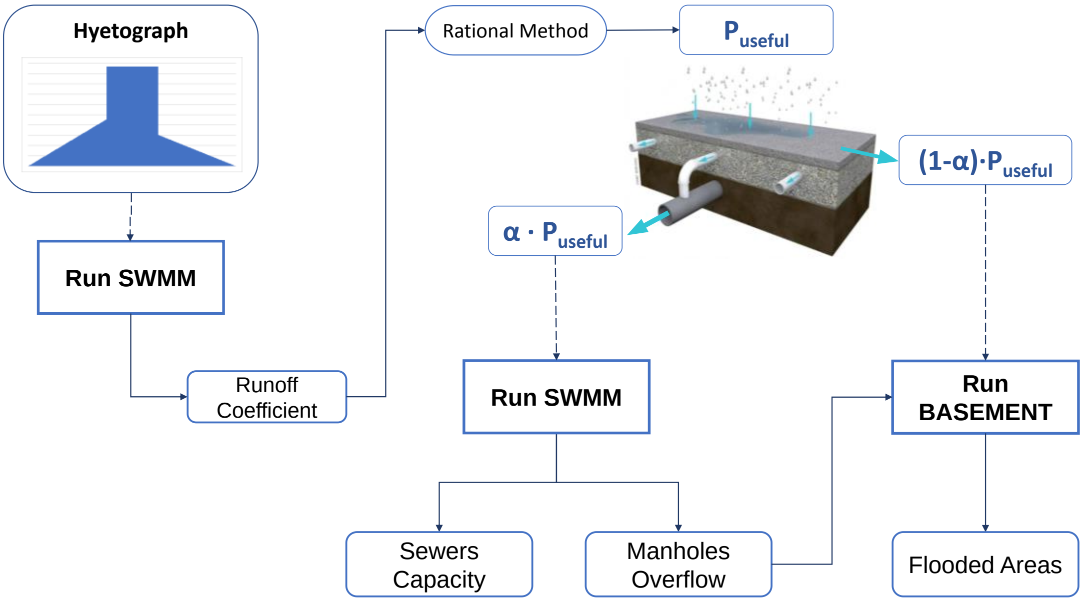

Figure 1. Conceptualisation and procedure of the application of the CMSB [6]**.**

2.4 Identification of interdependencies, impacts and cascading effects

Considering the selected services, critical infrastructures and responders, this assessment phase analyses interdependencies in service networks and evaluates impacts and cascading effects, taking into account systems redundancy. The process of assessing urban resilience is based on different qualitative methodologies applied in cross-functional workshops and individual interviews involving political and managerial senior administration officers and operators from different services. It is intended to define resilience objectives, interdependencies between services and infrastructures, redundancies between infrastructures and cascading effects, as well as the operational routines of response to a given disruptive event. In this phase the recovery time of the services after the occurrence of a given disruptive event should also be established.

The proposed cross-functional workshops also enables the identification of potential improvements and facilitates the definition of crisis management protocols. The main objective is to break down the barriers between the different actors responsible for urban metabolism (*e.g.* public or private companies, institutions) and arise critical issues, which ultimately should lead to a more sound management of urban water-cycle related hazards.

2.5 Urban resilience evaluation

The overall performance of the city to flooding may be reflected on the proposed indicators showed on Table 1 [6]. These simple indicators can be calculated considering the outputs of 1D/2D models, for events with different return periods.

Considering the weighted average of the presented five urban resilience indicators, an integrated urban resilience index (IURI) can be determined, allowing to evaluate the city resilience accordingly to the following criteria:

- For IURI higher than 90, the urban resilience is considered excellent.
- For IURI between 75 and 90, the urban resilience is considered good.
- For IURI between 50 and 75, the urban resilience is considered acceptable.
- For IURI between 30 and 50, the urban resilience is considered insufficient.
- For IURI lower than 30, the urban resilience is considered unacceptable.

Table 1. Proposed urban resilience indicators.

Indicator	**Description / Computation**
I1 - Percentage of volume overflowed by the drainage system (%)	It measures the degree of affectation of the drainage system and its contribution to the aggravation of the urban flood through the extravasation of the flow to the public highway. *I1 = Volume overflowed by drainage system / Volume entering the drainage system × 100*
I2 - Percentage of Flooded Area	It measures the extent (area) of public space that is affected by flood.

(%)	*I2 = Flooded area / Total area × 100*
I3 – Percentage of Flood Duration (%)	It measures the extent (time) of public space that is affected by flood. *I3 = Duration of flooding / Duration of precipitation event × 100*
I4 - Percentage of Buildings Affected (%)	Measures the extent of potentially affected buildings located in flooded areas. *I4 = Number of affected buildings / Number of total buildings × 100*
I5 - Percentage of Critical Services Affected (%)	Measures the extent of critical services potentially affected by flooding. *I5 = Number of services affected / Total number of services × 100*

3 Lisbon Downtown Case Study

3.1 The study area

The study area is defined by two main catchments, J (Avenida da Liberdade) and L (Avenida Almirante Reis), which drain high level zones of Lisbon to the lower riverside catchments, KJL (Baixa). These catchments were selected since they comprise areas (namely Regueirão dos Anjos, Av. Almirante Reis, Rossio, Terreiro do Paço and R. de Santa Marta) that register an average of 5 to 8 flooding events per decade [7]. The case study area (presented in Figure 2) represents nearly 7.5% of the total council area, concentrating about 14% of its inhabitants, 68% of the tourist accommodation, 30% of the buildings and monuments of public interest and 30% of the commercial activities [8].

The services and critical infrastructures to be analysed are located in the J, L and KLJ catchments or in the surrounding areas, as presented in Figure 3. Although most of the services affected by floods are located in the flooded areas, other services located nearby might be affected due to interdependence effects and therefore should be considered. An example of these are the services that require overland transports that might be partially compromised by the traffic interruptions related to floods.

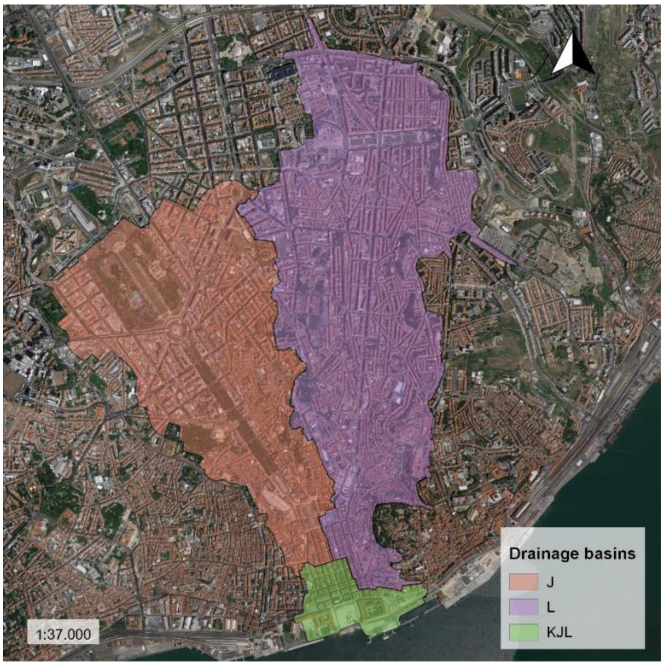

Figure 2. Lisbon study area.

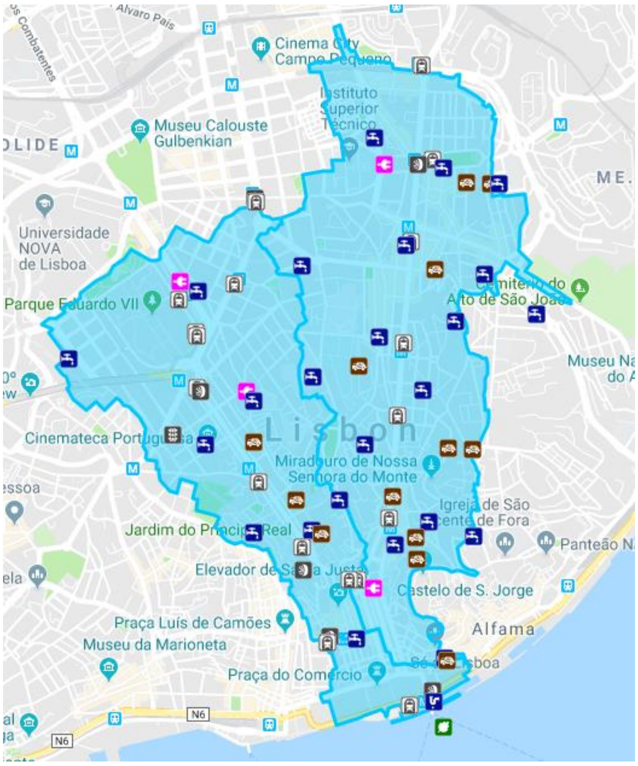

Figure 3. Georeferencing of the infrastructures considered inside the study area. Source: GIS Map - Hazur®, Lisbon RESCCUE project.

The list of services and infrastructures considered is presented in Table 2, comprising the water, power, mobility and waste sectors. The total number of analysed infrastructures is 130.

Table 2. Services and Infrastructures analysed with HAZUR® in Lisbon, located in the study area.

Sector	Service	Infrastructures	Nr
Water Sector	Water Distribution	District Metering Areas	37
	Urban Drainage	Wastewater Pumping Stations	1
		Overflows	3
Power Sector	Secondary Power Distribution	Power substation	31
Mobility Sector	Subway	Subway stations	15
		METRO Power Substation	2
		Control Room	1
	Public Transport Hubs	Hubs	6
	Bus	Bus Routes	19
	Traffic Management	Traffic Control Room	1
Waste Sector	Unselective Municipal Waste Collection	Routes	13
	Mobile Telecom *(analysed only as a service provider, “donor”, and no characterization will be provided.)*	-	-
	Receiver Waters	Tagus River	1

3.2 Combined Model SWMM+BASEMENT application

The CMSB was applied considering the Portuguese 4 hours design hyetograph [9], for a 10 year return period (T) rain event. The tide level considered, 1.95 m, corresponds to 6/7 of the highest high water level of 2.27 m (the simultaneous occurrence of an extreme precipitation and the highest high water tide is unlikely). An additional scenario corresponding to the long term effects of climate change was considered, including a rainfall intensity increase of 5% and a tidal level of 2.57 m [10].

The α parameter was established to reflect as faithfully as possible the real interception capacity of the drainage system's inlets (including curb, gutter and combination inlets). A set of α parameters was defined for each sub-catchment, throughout the duration of the rain event, considering the efficiency of the most frequent inlet type in the sub-catchment, and an uniform distribution of inlets. Figure 4 presents the different α parameter values for a 10 year return period, for all the sub-catchments analysed. As expected, the inlet capacity decreases when higher runoff is generated.

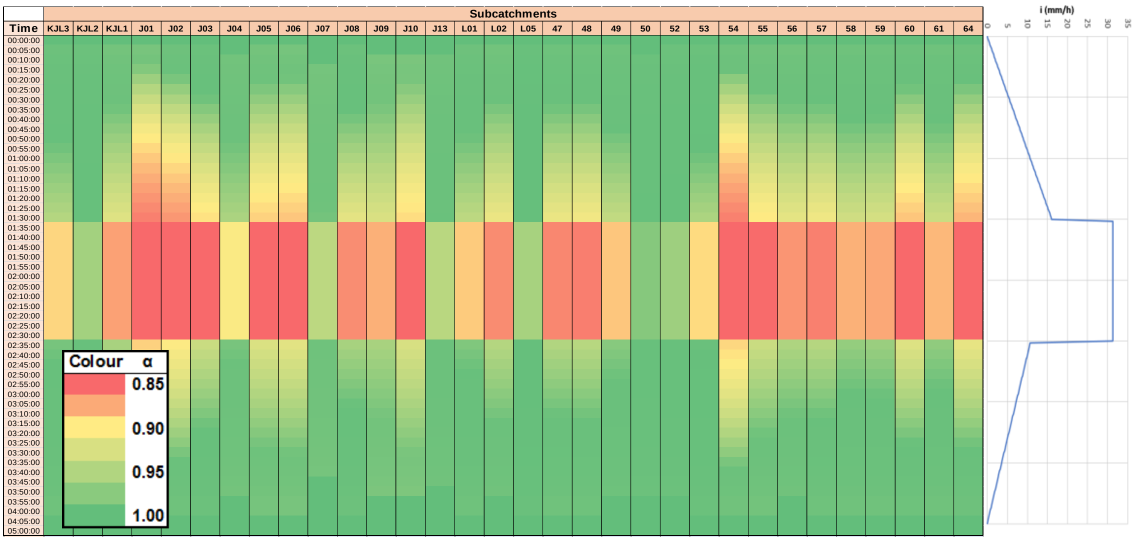

Figure 4. Different α parameter values for a 10 year return period precipitation event in the sub-catchments considered.

Figure 5 illustrates the modelled main drainage system of catchments J, L and KLJ. SWMM model results show that the drainage system presents difficulties in accommodating the generated flows, with several surcharged sewers in the Baixa and Terreiro do Paço area, leading to sewer overflow at manholes. The most critical situation occurs at 2h35.

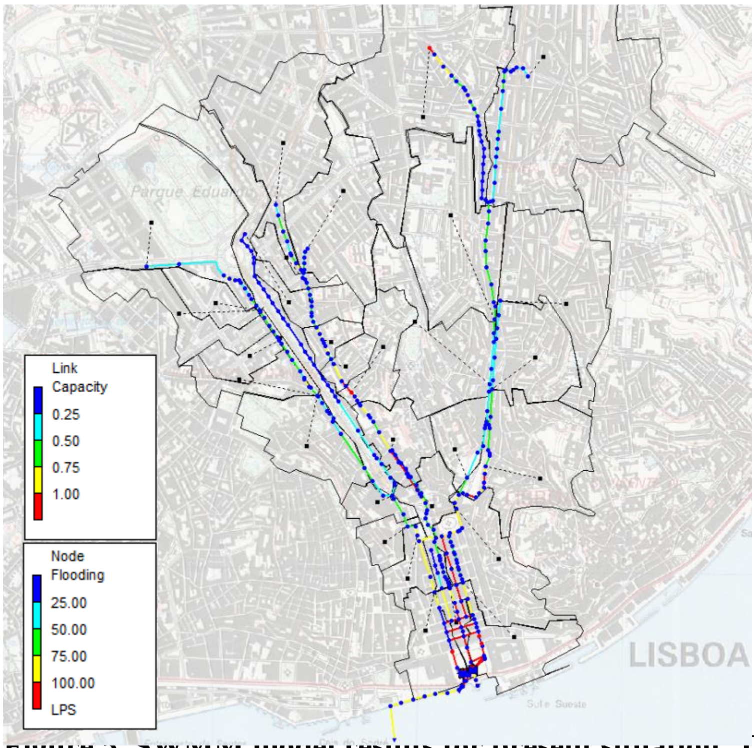

Figure 5. SWMM model results for present situation, T=10 years after 2h35.

The 2D simulation model results obtained with BASEMENT denote a significant surface water accumulation leading to floods in the downtown area, specifically in Rossio and Terreiro do Paço (Figure 6). Water heights of 60 cm and 20 cm are observed in Rossio and Terreiro do Paço, respectively.

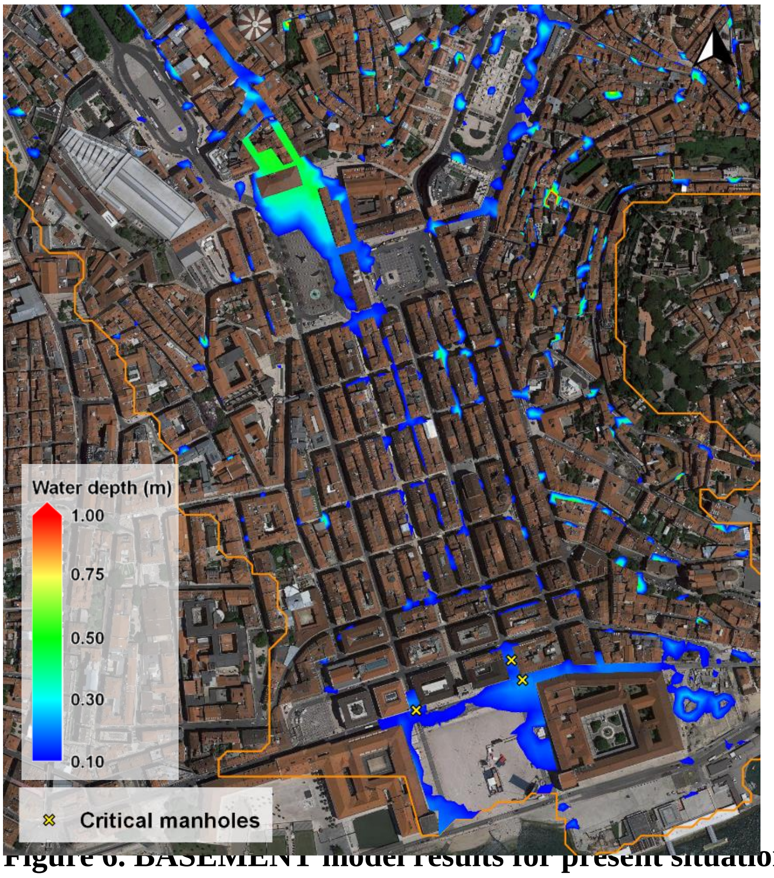

Figure 6. BASEMENT model results for present situation, T=10 years.

Considering the climate change scenario, with aggravated precipitation intensity and tidal levels, the situation is not significantly worse in relation to water heights (60 cm and 20 cm are observed in Rossio and Terreiro do Paço, respectively) but the affected area is higher, mainly at the surroundings of critical manholes.

3.3 Cascade effects resulting from flooding

For the establishment of the interdependencies in Lisbon, an effort was placed in trying to produce results as specific as possible, *i.e.*, at infrastructure level. This way, more practical results and acknowledgments about the services can be inferred from this assessment. From this approach it was also possible to extrapolate the results, at service level, to Lisbon City. Figure 7 shows the interdependencies of the services analysed. Although these interdependencies were studied in detailed for a specific area and only for critical infrastructures, they are considered applicable throughout the Lisbon city.

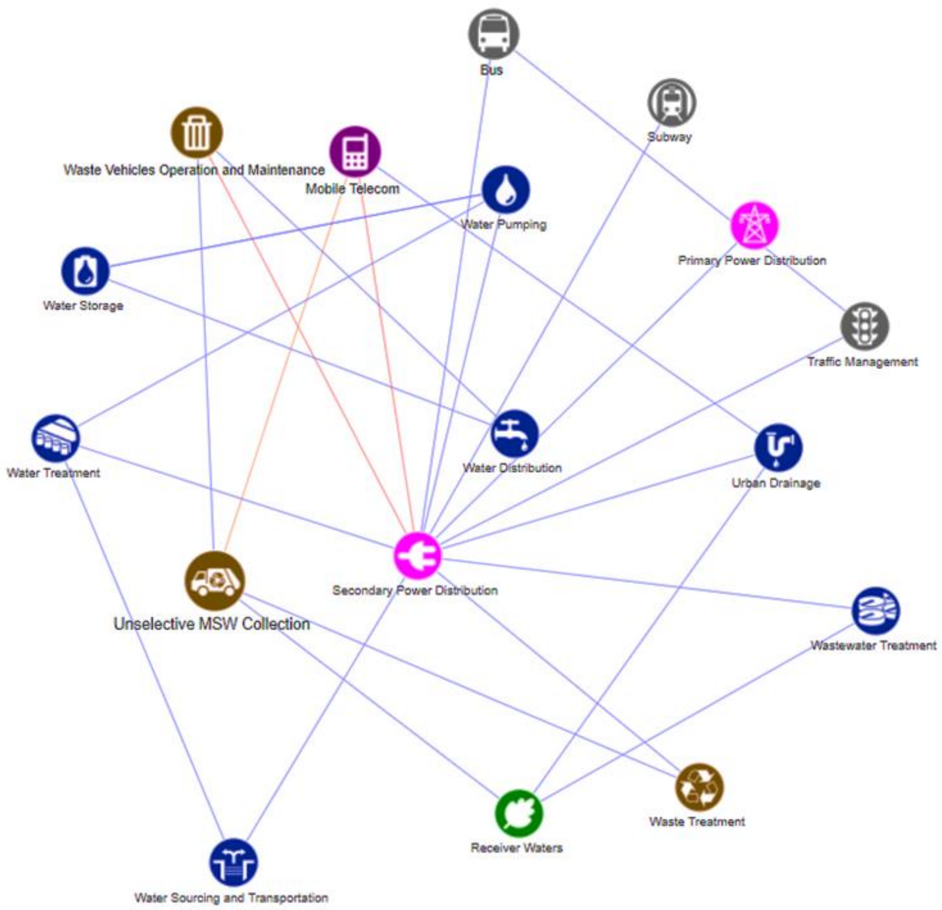

Figure 7. Service interdependencies in Lisbon (Source: Resilience Map - HAZUR®, RESCCUE project).

The cascading effects resulting from flood events can be determined taking into account the services interdependencies and its reactions during the event: which services will fail (or will be in minimum service) and how long will it take for the city to recover, if proper measures are taken. This information along with real-time data will, in the future, feed a cross-service monitoring network, enabling the simulation of risk at city level, equipping the resilience managers with tools for monitoring, assessing and managing risks and aiding decision making.

The potential services and infrastructures affected can be visualised on Hazur® GIS Map. It should be pointed out however, that although there are services/infrastructures within the flooded areas, they might not be affected by the event. In fact, most of the services analysed in the case study do not fail because of the floods, but may have their routine operations affected.

The consequences on the services and infrastructures are presented in the "What If Matrix" shown in Table 3. The recovery times presented are only indicative and may vary, not only with the extent of the failure (and the resources required to fix it), but also with the duration of the flooding. For most of the services that do not fail but are affected by the flood it was assumed that they would recover by the time the flood ended (or the level of water was compatible with the routine operations). It was considered that, in average, the areas stayed flooded during 1 to 3 hours (reported time, from previous events).

Table 3. What If Matrix description for flood events.

Service	Infras. ● Recovery time	Description
WATER SECTOR		
Water Supply	-	Service do not fail due to flooding. Eventually may affect the time of repair if a burst pipe occurs in a flooded area.
Urban Drainage	● 3h	The flows that drain to the drainage system are high, causing the surcharge of sewers and pumping systems. For this reason, overflows are activated and the wastewater is directly discharged into the Tagus River. The Recovery Time (after flooding) is set to 3h due to the possible need for cleaning, maintenance and repair works.
POWER SECTOR		
Secondary Power Distribution and Transformer substations	● 12h (substations) ● 1h (transformers)	Central Tejo; Boavista and Praça da Figueira underground substations are considered slightly vulnerable to flooding. Praça da Figueira has already been flooded and pumps were installed to drain the accumulated water. The failure of the substations may occur but the probability of other services failing is low, due to the several redundancies set in place. In case it occurs, the significance is high due to the several services and infrastructures

		dependent on these substations (see interdependence matrix above).The recovery time for the substations (after flooding) was set as 12 h due to the fact that some electric components are damaged. The transformer substations may be affected by flooding but the impact is less significant and the recovery is faster (1h).
MOBILITY SECTOR		
Subway	Intendente ● 3h Restauradores ● 3h Terreiro do Paço ● 3h Martim Moniz ● 3h Rossio ● 3h	Most of the subway stations have retaining walls near the entrances. Nonetheless, due to the configuration of the subway stations, there is a tendency for the superficial runoff to flow through the entrance stairs, flooding the station atriums and platforms. The Recovery Time is set to 3h (after flooding) due to the possible need of evacuation, cleaning, maintenance and repair works. There have already been rainfall events in Lisbon that resulted in water heights of 1.5 m in the stations, interrupting the lines. It took Metro about 2.5 hour to restore the service.
Bus	● 1.5h	Service do not fail due to flooding, but when the water level reaches a certain height, the buses must find alternative routes, and public may need to go to different stops. The recovery time was set to 1.5 h, which is the average estimated time so that water level are lower and buses can resume their routes.

Public Transport Hubs	Sul Sueste ● 1.5h Restauradores/Rossio ● 1.5h	These areas flood, hindering access to them and to the services the hubs provide. The services (bus, subway, boat, train) can also be affected.
Unselective MSW Collection	I0211 ● 2h I0212 ● 2h I0306 ● 2h I0503 ● 2h	When the water level reaches a certain height, the waste collection vehicles do not collect the waste at certain collection points. *Note:* affluence of solid waste on the drainage system may increase the impact of flooding

To summarize, extreme precipitation events resulting in urban flooding affect mostly the "end of the chain" services (those that are mainly receivers of others and whose service is addressed directly to the citizens). For this reason, significant cascade effects are not expected. However, the following considerations are highlighted:

- The performance of the drainage system results in the direct discharge of untreated effluents into the receiving waters.
- The mobility sector does not cause cascade effects since it provides services directly to the population, reflecting in the decrease of comfort and mobility.
- Waste collection service might be temporarily affected but presents no repercussions for other services, ultimately affecting the population by reducing urban hygiene conditions.
- In the power sector no significant cascading effects are expected due to the high service redundancy already installed. If a disturbance may occur it would be at a local level, affecting services such as traffic lights, commercial activities and houses.

3.4 Urban resilience evaluation

Accordingly to the proposed methodology, five urban resilience indicators were determined considering the outputs of 1D/2D models, for a rain event with 10 years return period, both for the present situation and for an aggravated scenario simulating climate change. The integrated urban resilience index (IURI) was also determined, as presented in Table 4.

Table 4. Urban resilience evaluation for the study area.

	T = 10 years Tide level = 1.95 m	**T = 10 years (+5% intensity) Tide level = 2.57 m**
I1 - Percentage of volume overflowed by the drainage system	8.6%	12.0%
I2 - Percentage of Flooded Area	4.9%	5.9%
I3 - Percentage of Flood Duration	93.8%	95.8%
I4 - Percentage of Buildings Affected	6.5%	7.8%
I5 - Percentage of Critical Services Affected	35.0%	35.0%
IURI	**70.3%**	**68.7%**

In the present situation, a 10 year return period rain event results in 8.6% of the affluent flows surcharged through manholes. In the climate change scenario, the capacity of the drainage system to accommodate affluent flows decreases, with 12% of the affluent flows surcharged. As far as the flooded areas and duration of the flood event are concerned, they are very similar in both scenarios. Consequently, the percentage of buildings and the percentage of services directly affected by flood are also similar. In fact, one-third (35%) of the analysed services are affected by the occurrence of a 10-year return precipitation event. In general, it can be concluded that the capacity of the drainage systems and the topography of the city are the most conditioning factors for the occurrence of floods.

The obtained values for the integrated urban resilience index (between 50 and 75) indicate that the urban resilience of the studied area is considered acceptable. The effects of climate change contribute to a slight decrease of IURI in relation to current scenario, without translating into an aggravation of the classification of the study area urban resilience.

4 Conclusions

This paper presents the work being carried out under RESCCUE Project (Resilience to Cope with Climate Change in Urban Areas) regarding the assessment of the urban resilience of Lisbon downtown catchments J, L and KLJ, mostly in terms of flooding and sea level rise.

The methodology followed is based on a multisectoral approach, considering service interdependences and cascading effects, and evaluates urban resilience trough simple quantifiable indicators and a resilience index, IURI. In order to determine the flooded areas for each scenario, 1D and 2D dynamic models of the drainage system were developed, and a simplified innovative process to integrate the inlets efficiency in the modulation process was proposed.

The application of the proposed methodology to Lisbon downtown case study demonstrated the usefulness and potentiality of adopting this multisectoral and cross-functional approach. The implementation of this approach has arisen critical issues, which ultimately will lead to a more sustainable management of water-cycle related hazards, guarantying that the services, and the city, will maintain its essential function, identity and structure, while also preserving the capacity for adaptation, learning, and transformation. In regard to this matter, Lisbon is already planning further approaches to increase the city resilience to flooding, namely the construction of two drainage tunnels (Monsanto-Santa Apolonia and Chelas-Beato), an antipollution basin and several retention basins (namely in Ajuda, Ameixoeira and Parque Eduardo VII). In addition, the "Monitoring and warning system plan of Lisbon drainage network" is being developed.

Acknowledgement

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MAKING COLOGNE MORE RESILIENT AGAINST URBAN FLASH FLOODS

M. Sc. Eva Müggenburg, Dipl.-Geogr. Marc Daniel Heintz & Dipl.-Ing. Ingo Schwerdorf

1. URBAN FLASH FLOODS AS A NEW CHALLENGE

One of the upcoming challenges in Cologne – like in other European cities – is heavy rainfall within a short period of time: urban flash floods. Different research studies [IPCC14, DWD16, LANUV10] have identified that, in the future, torrential rainfall events will occur more frequently and their intensity will become more severe. In densely populated cities, this development is reinforced by a high degree of soil sealing as well as a high building density. Furthermore, agglomerations with their sensitive infrastructure are more at risk than less vulnerable areas. Small-scale flood events such as in Münster in 2014 and in Southern Germany (Braunsbach and Simbach) in 2016 have shown the enormous damage potential that stems from this type of natural hazard.

Cologne, at the banks of the river Rhine, is one of Germany’s cities with profound experience in flood risk management. This broad experience and knowledge has provided a basis for the establishment of an urban flash flood risk management. Nevertheless, a distinction between river flooding and urban flash floods has to be drawn. While river flooding, especially in the downstream part of the catchments of major rivers, goes along with a sufficient timespan for early warning and is limited to those areas alongside the banks of the river, urban flash floods are characterised by short warning periods and occur at a local scale. Therefore, the prediction of torrential rainfall remains difficult. Unlike river flooding, urban flash floods are irrespective of catchment areas and can occur almost anywhere in the metropolitan area. As the two different kinds of flooding (river flooding and urban flash floods) are frequently mixed-up, it is challenging to communicate the risk associated with urban flash floods to the general public.

In order to minimise damages and adapt to the challenge of torrential rainfall, measures need to be taken. The following article presents the actions initiated by the Municipal Drainage Operations Cologne (StEB Köln) and the City of Cologne in order to make the city and its inhabitants more resilient against urban flash floods.

2 TAKING ACTION – ESTABLISHMENT A FLASH FLOOD RISK MANAGEMENT

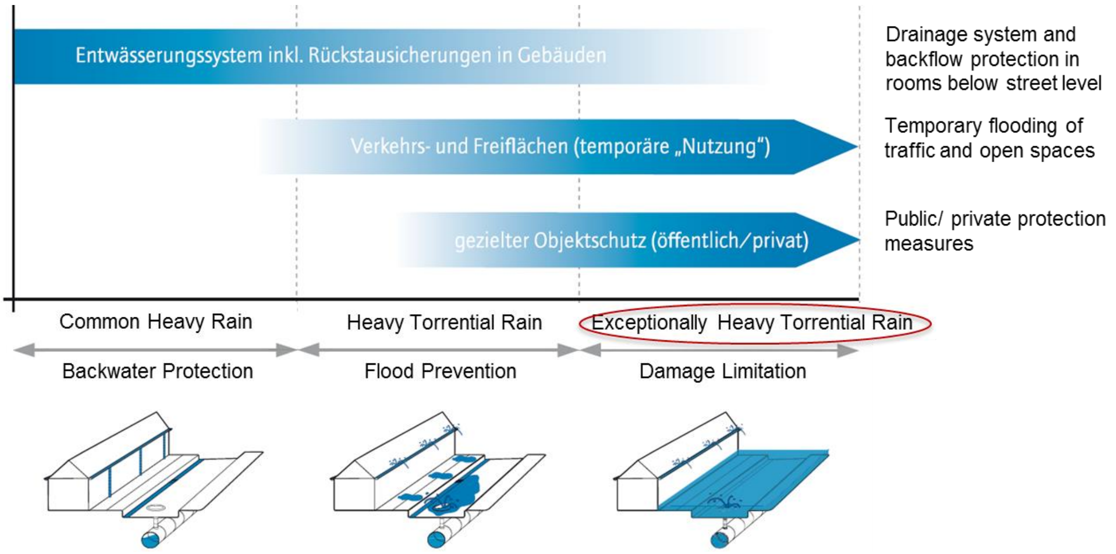
Traditionally, the StEB Köln takes care of the rainfall discharge. Even if the basis of assessment for the channels was far from exceeding, StEB Köln assumes responsibility for the climate change demands and has joined the research project *“Cologne 21 – adapting the City to Climate Change”*. The project carried out by the Environment Agency of the federal state of Northrhine-Westfalia, the German Weather Service, the City of Cologne and StEB Köln has provided a basis for further steps to improve resilience in Cologne. The project outcomes confirm that there is an increasing risk of flash floods in Cologne. Therefore, the need for action has been recognised [LANUV13].

As a first step, the responsibilities of action in case of surface flooding caused by torrential rain had to be defined. It cannot be task of the sewage system to dispose any amount of stormwater during a flash flood event. The following chart shows the drainage situation depending on the magnitude of the precipitation event.

Common heavy rainfall during a shower or thunderstorm can be managed by the municipal drainage system – provided that all private houseowners and businesses with rooms below street level dispose of a backwater protection, which is compulsory in Cologne (Picture 1, left).

The second column illustrates the event of a heavy torrential rainfall event. Whereas the public drainage system is capable of disposing parts of the stormwater, a certain amount of water will cause flooding of streets and open areas. Moreover, depending on the event’s magnitude and the topography, protection of property (private as well as public) can be necessary (Picture 1, middle).

The third case displays an exceptionally heavy torrential rainfall event. In that situation, damage limitation is the main aim. Neither the public drainage system nor public surfaces such as streets, squares and green spaces are capable of retaining such amounts of water. Subsequently, water may flow from public to private areas and cause local flooding. Thus, it is of fundamental importance that private house and business owners adopt protection measures (Picture 1, right).



Picture 1: Drainage situation and responsibilities according to the magnitude of the precipitation event [StEB Köln17].

Consequently, the strategy of managing flash floods in Cologne focuses on both measures carried out by the public administration as well as measures by private house and business owners. Whereas for public measures it is crucial to involve all different agencies that can provide a contribution (e. g. city planning, traffic planning or parks and garden department), for private measures, the role of the public institutions is to communicate the hazard to the general public and make sure they accept and recognise the need to action.

Inspired by the new tool of riverine flood risk management introduced by the European Commission in 2007, StEB Köln and the City of Cologne have developed an integrative urban flash flood risk management programme in 2014. As a starting point of the described municipal initiative aiming to strengthen resilience and reduce the damage potential, nearly 100 different measures were identified. The competent institution, additional stakeholders, the expected finishing point as well as the level of implementation have been defined for each measure (Tab. 1.1). According to the European Floods Directive [EU07], the measures were assigned to different sub-categories that include e.g.: information, precautionary behaviour, natural water retention, precautionary building, precautionary land use, technical flood protection, protection against risks and recovery. The catalogue of measures is updated regularly. Its structure helps to keep coordinate, plan and steer prospective tasks and projects.

Tab. 1.1: Extract from Cologne’s Flash Flood Risk Management Programme

Category	Description of measure	Sub-category (acc. to EU-Floods Directive)	Level of implementation	Leading institution	Stake-holders
Information procurement - preparation and provision on municipal level	Long-term evaluation of rainfall patterns	information	repetitive	StEB Köln	
	Flash flood hazard map for Cologne	information	100 % (completed)	StEB Köln	
	Identify damage potential and deduce risk potential	information	100 % (completed)	StEB Köln	statistics office, fire brigade
	Identify potential areas for prospective multifunctional usage (e.g. green areas) by using GIS and evaluate the areas	information	in progress	StEB Köln	statistics office, parks and garden office
Adapt processes on municip	Integrate water routes in land-use plan /	precautionary land use	100 % (repetitive)	StEB Köln	city planning office

al level	development plan				
Optimize above- and underground discharge capacity	Increase the hydraulic efficiency of gullys and their amount	technical flood protection	in progress	office for roads and traffic	StEB Köln
Property protection of private and municipal objects	Lower kerbstone in order to support rainwater runoff to low-lying green areas	technical flood protection	repetitive	Office for roads and traffic	

The increasing risk of urban flash floods requires new working processes, cooperations and agreements. Existing coalitions need to be strengthened, restructured and directed. Joint aims need to be worked out and identified with. The support of one or several high municipal decision-makers who support the main aim and delegate the necessary tasks according to the hierarchies is an important prerequisite. In case of Cologne, the research results of the project *Cologne 21* have helped to achieve a broad majority of support in different municipal offices. This has been the first milestone and basic requirement to pave the way for future tasks. Interdisciplinary work has been encouraged to foster water sensible urban design.

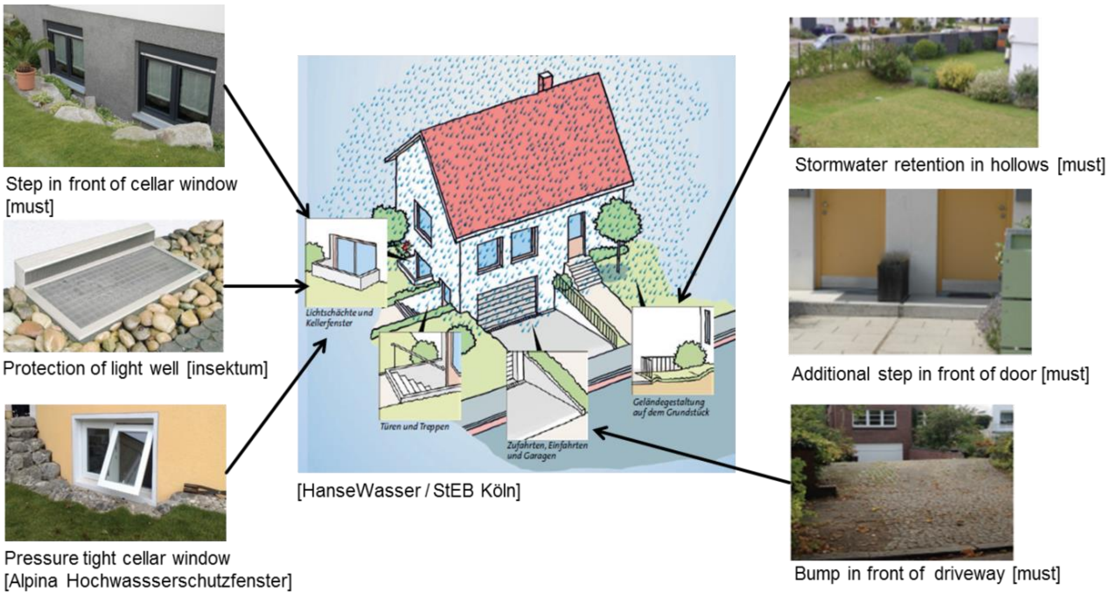
Many steps of the programme of measures have already been completed or sub goals have been achieved. Nevertheless, there are still some projects to intensify and complete.

3. TOWARDS A MORE RESILIENT CITY – MILESTONES

In the context of flash flood risk management in Cologne, some milestones have already been achieved, some of which will be presented in the following chapters: guideline for flood-safe homes, flash flood hazard map, handbook to support water-sensitive urban design and multifunctional retention areas.

3.1 Guideline for Flood-Safe Homes

Information procurement and the sensitisation of the population have been identified as one of the first measures to tackle. An important component of this approach is to enhance the resilience among private homeowners and tenants. Therefore, a guideline for flood-safe homes (“Wassersensibel planen und bauen in Köln”) has been published [StEB Köln16]. This brochure shows a variety of property protection measures. Not only surface flooding (regardless if it is caused by river flooding or urban flash flood), but also sewer backwater and seepage water is discussed. For all these potential hazards, possible measures are presented in this guideline so that a holistic flood protection can be realised (Picture 2). The solutions presented relate to existing buildings as well as new constructions and include an indication of the estimated costs.



Picture 2: Overview of measures for a flood-safe home [Hansewasser Bremen13 und StEB Köln16].

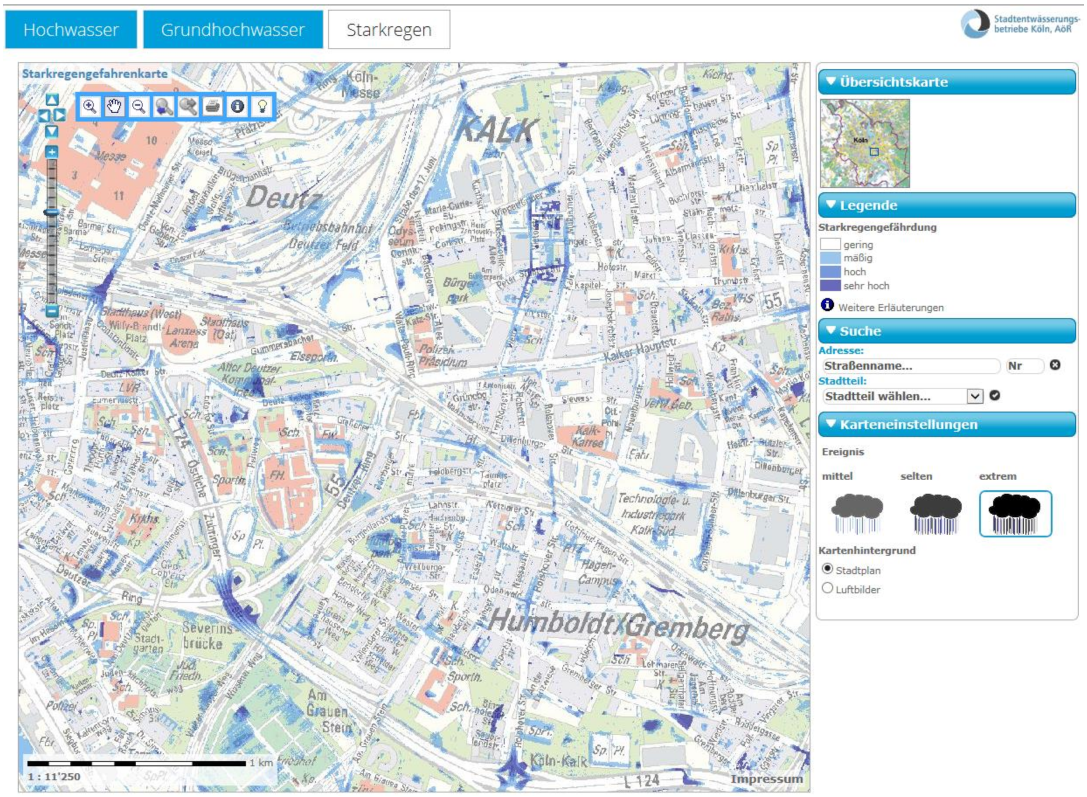
In addition to this guideline, an information campaign has been launched including posters in the public space as well as the presence of StEB Köln at townhall meetings and street festivals. The information campaign includes general information about urban flash floods, risk analysis, flood-prone areas, possible protection measures and projects realised by StEB Köln (Picture 3).

Picture 3: Guideline for flood-safe homes [StEB Köln16] and impressions from the information campaign.

3.2 Flash Flood Hazard Map

According to the European Floods Directive, it is compulsory to publish flood hazard maps showing different flooding scenarios for the areas with potentially significant flood risks by 2013 [EU07]. Cologne was one of the few cities in Germany to publish flood hazard maps for the river Rhine including an extreme event scenario years before the new European legislation came into force. There are also groundwater flood hazard maps available to the public.

Based on this positive experience, StEB Köln decided to continue taking a lead role and publish flash flood hazard maps for the entire urban area. This decision stems from the conviction that informing and sensitising about flooding and promoting prevention measures is more effective when there is concrete information about the local hazard. The Cologne flash flood hazard map is based on a flow path analysis and was published in March 2017. Cologne was the second city in Germany to publish such a map on the internet, alongside with the city of Unna. Therefore, all flooding types (river, groundwater and urban flash flood) are now combined in one map (Picture 4).

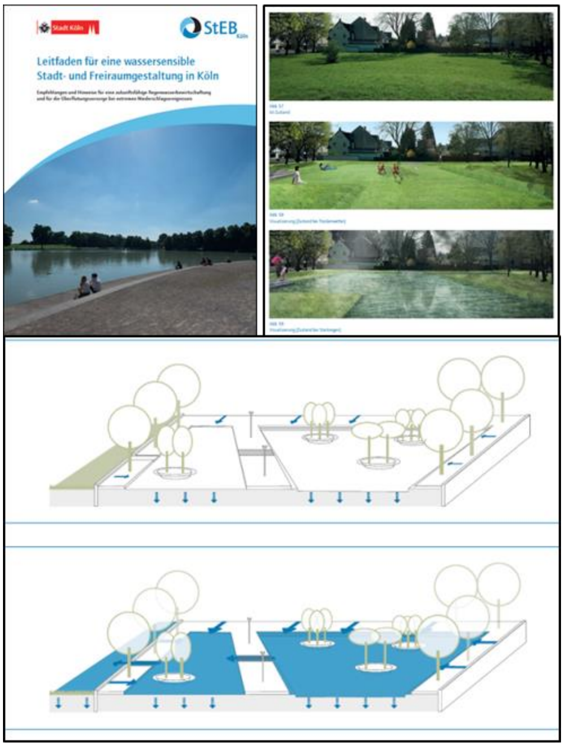


Picture 4: Cologne's Flash Flood Hazard Map [StEB Köln18-1].

The flash flood hazard map has been calculated for three different precipitation scenarios: torrential rain (once in 30 years), heavy torrential rain (once in 50 years) and exceptionally heavy torrential rain (once in 100 years). Different colours illustrate the water depths. While dark blue shows areas at higher risk, light blue represents areas with medium risk. To emphasise that every district of the city could be affected, white areas do not display "*no risk*", but "*low risk*". Data used for the calculation includes rainfall data from local weather stations in Cologne as well as a digital terrain model with a resolution of 1x1m. For the calculation, it was expected that the entire rainfall would produce runoff on the surface and not infiltrate as the soil is sealed or would be saturated quickly. The sewage system was not considered, either, since, on the one hand, the processing power is not available, yet, and, on the other hand, it must be expected that in case of such high amounts of rainfall within a short time span the stormwater cannot drain into the gullys.

3.3 Handbook to support Water-Sensitive Urban Design in Cologne

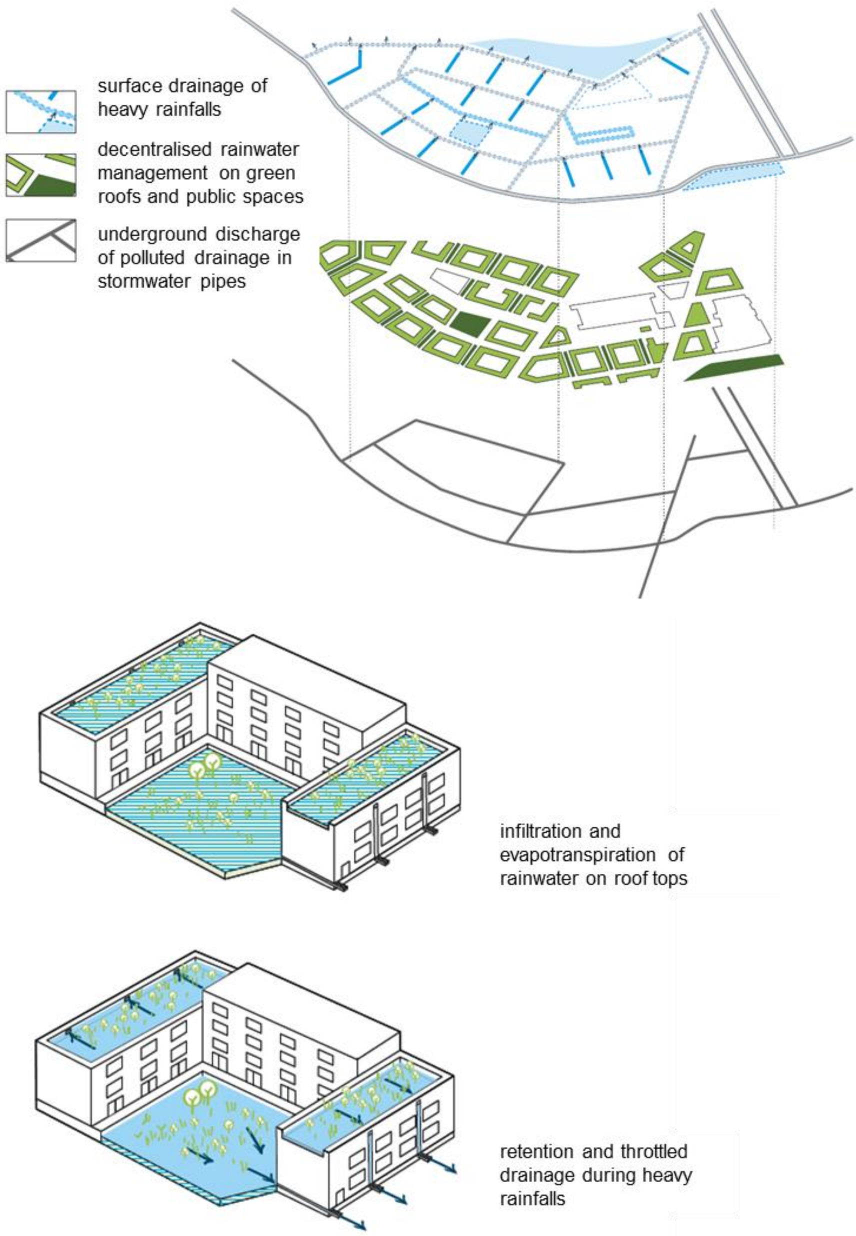
In 2016, a handbook to support water-sensitive urban design in Cologne has been compiled in cooperation with employees of the StEB Köln and many municipal offices from the City of Cologne. The brochure addresses both staff from municipal departments as well as engineering offices that work in charge of the City of Cologne. The handbook sets new standards for the development of new-built areas and conversion areas in Cologne. It recommends efficient adjustment measures that reconcile sustainable urban design and flood protection. Examples from Cologne and other European cities provide tools and support. Moreover, the guideline gives an overview of planning law indications which support the practical implementation of measures (Picture 5).



Picture 5: Handbook to support Water-Sensitive Urban Design in Cologne [StEB Köln17].

Besides the detailed information presented in the guideline, another, secondary aim has been to establish a cooperative partnership among the different municipal offices and StEB Köln. This has been a fundamental step for further joint tasks in the field of urban flash flood management. Through the participation of many different departments, a broad consensus on the benefits of water-sensitive urban design could be achieved. Furthermore, the presented measures have found a high acceptance as the participated employees can identify with the results and function as a multiplier of this working group within their institution.

Water-sensitive urban planning is by now considered in the planning process of prospective urban districts. When new development plans or proposal development planning are drawn up, the consideration of rainwater management and flood protection starts at an early stage, often in the scoping procedures. The dialogue between the different municipal departments is beneficial, as it early offers planning tools supporting to consider city polder, urban retention areas, water runoff routes and emergency water ways. This information is summed up in a “Hydrological Report” which is written for all major urban development projects relevant in terms of water management, development areas close to the river Rhine or when critical infrastructure is planned. The “Hydrological Report” is further offered to the municipal departments or urban planners (Picture 6).



Picture 6: “Hydrological Report”: information on water runoff routes, emergency water ways and urban retention areas (picture above) as well as evaporation and infiltration (picture below) [StEB Köln18-2].

3.4 Multifunctional Retention Areas

The research project *”MURIEL: Multifunctional urban retention areas – from the idea to the realisation”* (2015-2017), carried out by the Federal Foundation for the Environment, must, Dahlem, gaiac and the three municipal partners Cologne (StEB Köln and City of Cologne), Wesseling (disposal business and City) and Karlsruhe, took up on previous considerations of flash flood management (Picture 7). The aim of this pilot project was to identify solution approaches for an interdisciplinary planning and design of multifunctional retention areas. These ideas have been reviewed by means of different case studies [Benden17].

Picture 7: MURIEL – Multifunctional Retention Areas [StEB Köln18-3].

StEB Köln and the city of Cologne have been one of the participating municipalities in this research project. In the context of investigating the potential of multifunctional areas, two squares and one park have been identified as pilot measures to be converted into multifunctional areas within the next years. The areas in the district Porz-Eil are currently in planning; the construction works are supposed to be begin in 2019 (Picture 5).

4 Plans for the Future

On 19 July 2017, 7 of the 9 boroughs of Cologne where affected by a thunderstorm with nearly 70 mm of rain in two hours. This was a first stress test for the resilience against such events in Cologne. Based on the lessons learnt from this event, the next steps of Cologne’s strategy are in preparation. In order to get an overview of the impact and damages of this event, a gleaning with the municipal offices has been carried out on the initiative of StEB

Köln. Learning from the experiences of different offices, exchanging ideas and connecting with each other is part of dealing professionally with this new challenge and a main step towards further work packages. As flash flood management is an interdisciplinary topic which involves different offices, it is important to create a sustainable platform for exchange of ideas and new work processes. This is an ongoing process which accompanies many of the following steps and projects.

In order to be well-prepared for the predicted increase of urban flash floods, an analysis of further potential multifunctional retention areas will be conducted and measures for prospective conversion works derived. Further measures shall help strengthening the resilience of Cologne. Municipal infrastructure will be consulted from StEB Köln concerning flood provision and property protection to ensure the resilience of public buildings.

To be fit for the future, the communication strategy will be carried on in order to increase public awareness for the need of precautionary measures against urban flash floods. Flood prevention is a collaborative task which best functions if the public and private sector work together!

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STRENGTHENING WASTEWATER INFRASTRUCTURE RESILIENCE IN SAN FRANCISCO, CALIFORNIA

Karen Kubick, P.E.

1. Introduction

The San Francisco Public Utilities Commission (SFPUC) distributes drinking water to the San Francisco Bay region, collects and treats wastewater and urban stormwater within the City and County of San Francisco (San Francisco), supplies San Francisco with electricity for municipal uses, and more recently has become a green power provider to its residents and businesses. This complex network of infrastructure is managed by three utility enterprises within the SFPUC: Water, Wastewater, and Hetch Hetchy Water and Power; and is governed by a five member Commission nominated by the Mayor and approved by the Board of Supervisors. The Commission’s responsibilities are to provide operational oversight for rates, organizational policy, and final approval of all contracts and agreements.

San Francisco encompasses an area of 47.9 square miles (124 km^2). Located at the northern end of the San Francisco Peninsula, it is bordered on the west by the Pacific Ocean and the north and east by the San Francisco Bay. San Francisco is the fifth most densely populated United States County with a population of 870,887 and a density of 18,679 people/mile^2 (6,226.3 people/km^2). It is also the fourth-most populous city in California, and the thirteenth-most populous in the United States. San Francisco was founded on June 19, 1776 when Spanish colonists established the Presidio of San Francisco near the present day southern span of the Golden Gate Bridge. It is known for its Mediterranean climate, wet winters, foggy cool summers, and steep rolling hills.

San Francisco’s original sewer system was built during the California Gold Rush and was designed to carry combined wastewater and stormwater flows to adjacent shoreline waters. By 1899 over 300 miles of combined sewers had been built. Subsequent Sewer Master Plans were developed in 1935 and 1974 and their implementation completed the backbone of today’s wastewater system, addressing increased flows associated with a growing population and new water quality regulations.

San Francisco is also located in a seismically active area with the San Andreas Fault to the west and the Hayward Fault to the east. The two most significant recent seismic events that affected San Francisco both occurred on the San Andreas Fault respectively on: April 18, 1906 "The 1906 San Francisco Earthquake" with a magnitude 7.8 on the Richter scale, and more recently on October 17, 1989 "The 1989 Loma Prieta Earthquake", with a magnitude of 6.9 on the Richter scale. Infrastructure in areas of San Francisco that are located on bay mud and fill, particularly in the north and east perimeters of the city, are vulnerable due to liquefiable soils. Over the years California's seismic codes have become increasingly stringent to protect infrastructure, however much of the wastewater system was built before these requirements were in place.

Over the past century, evidence of Climate Change has been apparent with a sea level rise of nearly eight inches along the California coast. Sea levels are expected to continue to rise, and the rate of increase is anticipated to accelerate exacerbating the damage of storm surges to infrastructure along the city's coastline. The Wastewater Enterprise has devoted resources to develop sea level rise projections for the future, and to analyze rainfall patterns and the effect these challenges will present to the wastewater system. Projections for sea level rise are: 12 (30cm) to 24-inches (61cm) by 2050, and 36 (91cm) to 66-inches (167cm) by 2100.

This paper will focus on the Wastewater Enterprise's wastewater and urban stormwater assets, and the process that the SFPUC has gone through to plan and implement a capital program that is responsive to the challenges of today and those anticipated in the future. This 20-year capital program, valued at $6.9 Billion, is called "The Sewer System Improvement Program".

1.1.Program Overview

The responsibilities of the SFPUC's Wastewater Enterprise (WWE) are to manage, operate, and maintain San Francisco's wastewater collection and treatment systems. San Francisco's combined sewer system collects and conveys flow to the treatment plants, which treat both dry and wet weather urban stormwater flows.

The Sewer System Improvement Program (SSIP) currently includes 70 projects to improve the functionality and resiliency of the system. It is the culmination of over ten years of planning and public meetings to develop these proposed improvements to address the following challenges:

- Aging infrastructure
- Seismic resiliency

- Limited operating flexibility and lack of redundancy
- Compliance with future regulatory requirements
- Adaptation to climate change
- Sustainability
- Affordability

1.2.Program Description

The purpose of the SSIP is to upgrade San Francisco's wastewater system so that it can meet the challenges of today and anticipated needs of the future, corresponding with the SSIP's adopted Goals and Levels of Service (LOS). The SSIP includes projects that will provide major upgrades to the three existing treatment facilities located within San Francisco, and provide improvements to stormwater management in specific high risk areas subject to flooding. See *Figure 1* for a schematic of San Francisco's Wastewater System and Eight Urban Watersheds.

FIGURE 1- San Francisco's Wastewater System and Eight Urban Watersheds

The SSIP's treatment facilities upgrades focus on improving the two existing secondary treatment plants (Southeast and Oceanside Water Pollution Control Plants) which are located in San Francisco's Bayview Hunters Point and Lake Merced neighborhoods, respectively; and, the single wet-weather treatment facility (North Point Wet-Weather Facility) located in the North Shore neighborhood. The treatment plant improvement projects include: process modernizations with innovative technology; mechanical, electrical, and instrumentation improvements; as well as system-wide seismic and operation controls upgrades. The major projects at the Southeast Treatment Plant include: construction of a new headworks facility; new biosolids digester and energy recovery facilities; and seismic and reliability improvements to both the liquids and solids processing facilities. Projects at Oceanside and North Point treatment facilities include both seismic and reliability improvements.

The collection system projects include: conveyance, pump station, and green infrastructure enhancements which will provide improvements needed for seismic reliability, redundancy, climate adaption, and stormwater management. Conveyance assets to be improved include: tunnels, transport/storage boxes, force mains, and outfalls. Green Infrastructure will include projects such as: bioretention planters, permeable pavement, porous concrete, and creek daylighting, to allow for stormwater capture and reuse with the added benefit of improvements to the public right-of-way.

The SSIP was developed by staff and presented to the Commission for approval after approximately five years of analysis, planning, and public meetings. A program management firm was retained by the SFPUC in the fall of 2011 to validate the projects, their cost estimates and schedules, and to prioritize project implementation.

The Goals and LOS, as well as, the scope, schedule, and budget for the $6.9 Billion (5.5 Billion Euro) SSIP were approved by the SFPUC in 2012, and staff was directed to begin the Phase 1 projects. The Phase 1 projects’ scope, schedule, and budget were adopted in 2016 and will have biennial reviews until completion.

The SSIP Goals and LOS objectives are to:

- Provide a compliant, reliable, resilient, and flexible system that can respond to catastrophic events;
- Integrate green and grey infrastructure to manage stormwater and minimize flooding;
- Provide benefits to impacted communities;
- Modify the system to adapt to climate change;
- Achieve economic and environmental sustainability; and,
- Maintain ratepayer affordability.

1.3.Levels of Service

Underlying each of the SSIP’s Goals are specific metrics which define the ultimate Level of Service for the Wastewater System.

Goal #1: <u>Provide a Compliant, Reliable, Resilient, and Flexible System that can respond to Catastrophic Events</u>

- Reduce the long-term annual average number of Combined Sewer Discharges
- Treat biosolids to Class A standards
- Build redundant infrastructure to support critical functions
- Initiate primary treatment with disinfection within 72-hours of an earthquake
- Design critical and new facilities to withstand earthquakes with a magnitude 7.8 on the San Andreas Fault, and magnitude 7.0 on the Hayward Fault

Goal #2: Integrate Green and Grey Infrastructure to Manage Stormwater and Minimize Flooding

- Manage maximum storm flows generated by 1.3-inches of rain over a three hour period

Goal #3: Provide Benefits to Impacted Communities

- Limit odors generated by treatment facilities to within their fence lines
- Adhere to the SFPUC's Environmental Justice and Community Benefit policies

Goal #4: Modify the System to Adapt to Climate Change

- Build infrastructure to accommodate expected sea level rise within the service life of the asset (i.e., 12 inches by 2050, 24 inches by 2070, 36 inches by 2100)

Goal #5: Achieve Economic and Environmental Sustainability

- Use 100% of biosolids and 100% of the biogas generated by treatment facilities for beneficial purposes
- Use non-potable water sources to meet WWE non-potable water demands

Goal #6: Maintain Ratepayer Affordability

- Limit combined sewer and water rates to not exceed 2.5% of an average household income for a single family

2. Incorporating Resiliency into the SSIP's Implementation

The SSIP is being implemented in three overlapping phases as shown in *Figure 2*. Phase 1, which has been underway since 2012, represents 70 projects that are identified under the grouping of either Treatment Plants or Collection System. The current status of Phase 1 is reflected in *Figure 3*.

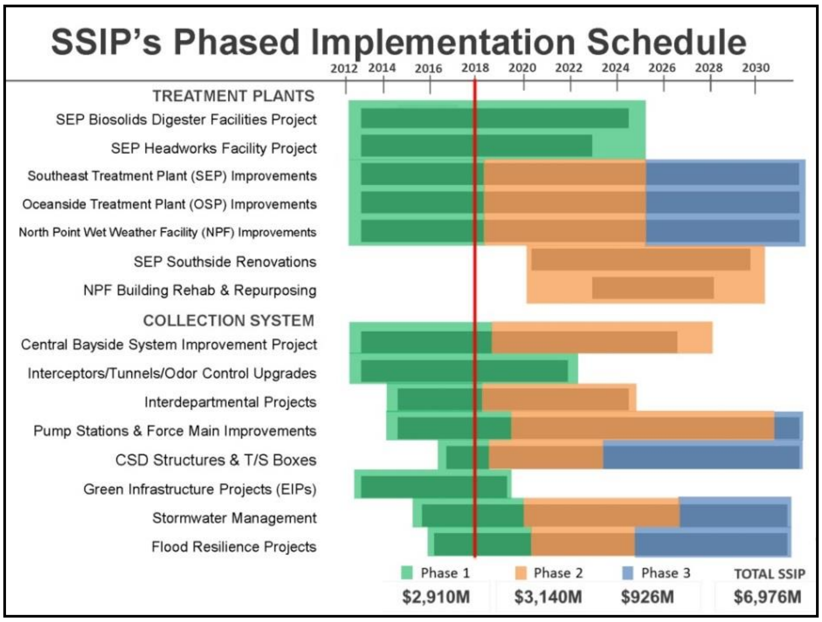

FIGURE 2 – The Sewer System Improvement Program's Budget and Three Phases

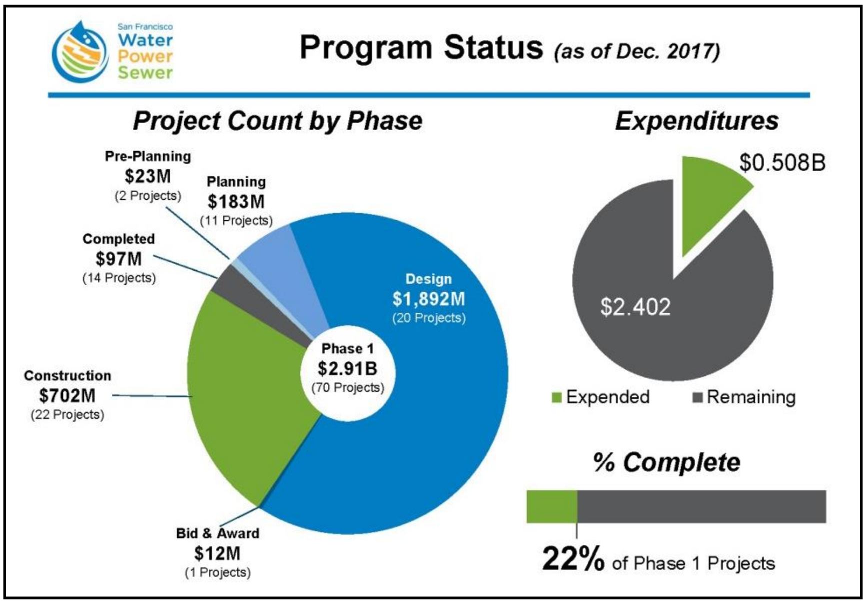

FIGURE 3 – The Sewer System Improvement Program's Current Status

2.1.Using an Urban Watershed Approach

The Urban Watershed Assessment (UWA) defines a new process by which the SSIP collection system projects were developed and evaluated, to ensure that the SSIP Goals and LOS were being met. The UWA conducted these evaluations for each of the city's eight urban watersheds:

1. Characterizing each watershed (e.g. soil types, underlying geology, age of infrastructure, and urban development patterns)
2. Developing and screening watershed alternatives
3. Developing and screening watershed alternatives to meet the Goals and LOS applicable to the collection system
4. Evaluating the screened watershed alternatives to optimize financial, social, and environmental benefits using the SSIP's Triple Bottom Line
5. Recommending an implementation strategy for all of the preferred watershed alternatives (the goal is to determine a recommended plan of collection system projects for all eight of the urban watersheds)

This watershed-based strategy focuses project planning on characterizing the performance, needs, and challenges of each of the eight individual urban watersheds in San Francisco. Integrated watershed planning recognizes that stormwater can be a valuable resource for non-potable water use, recharging groundwater, and sustaining wetland or repairing ecosystems.

The watershed approach also engages communities at the local level, to allow people to provide feedback on projects that most directly affect them.

2.2.Triple Bottom Line

Like other leading utilities, the SFPUC is using a Triple Bottom Line (TBL) approach to develop and evaluate alternative project solutions, maximize return on investment, and communicate decision-making. The TBL assessment addresses three areas of concerns: social (people), environmental (planet), and financial (cost-effectiveness). The SFPUC’s TBL model is a customized assessment addressing the City and County of San Francisco’s unique goals, policies, and communities. Managers from multiple City departments, citizens, engineers, and economists contributed to its development. As a result, the TBL model uses established City policies and level of service standards that have been adopted by publicly appointed boards or commissions. In this manner, the TBL model does not only rely on internal staff values and rules but also applies values and goals established through an official city public process. Additionally, the SFPUC’s customized and visual model converts the traditional financial bottom line evaluation into an integrated assessment of costs and benefits, to facilitate balanced decisions about where to invest funds and the potential impact of those investments.

The TBL assessment provides a multi-criteria decision support platform to evaluate project alternatives. This platform enables selected projects to generate the highest value of environmental improvements, social benefits, and economic gain in accordance with SFPUC’s objectives, requirements, and priorities and ultimately, its ratepayers.

The SSIP has utilized the TBL assessment model to evaluate a range of green and grey infrastructure types, for individual projects and for larger watershed alternatives (groups of projects). The TBL model generates summary graphics that display overall results for each type of evaluation, as well as other views with detailed information per criterion. The TBL evaluation pie chart is shown below as *Figure 4.*

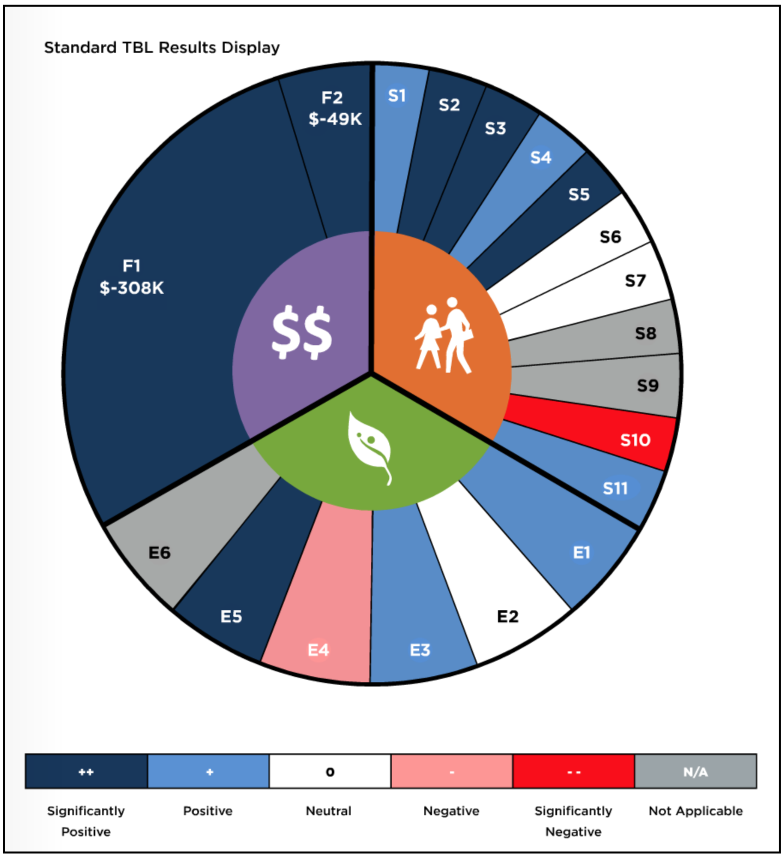

FIGURE 4 – Standard TBL Assessment Pie Chart

2.3.Climate Change Resiliency

As new wastewater infrastructure is planned along San Francisco's shoreline, or existing assets are modified or improved, risks of impact due to: rising sea levels, storm surge, and extreme precipitation events, are being considered. Through the SSIP, citywide studies were commissioned to assess the vulnerabilities of these assets under various tide and sea level scenarios and their likelihoods of occurrence. San Francisco ultimately settled on a planning criterion of 36-inch permanent sea level rise by the year 2100, and created maps illustrating infrastructure risk for up to a 100 year tidal frequency. The analysis evaluated the impact of the combination of increasing sea and tide levels on wastewater facilities based on their elevation and proximity to the shoreline.

The SSIP is employing the climate change adaptation recommendations for project planning purposes, which covered: design tide levels for existing San Francisco Bay conditions, relevant information on sea level rise, extreme tides, and coastal erosion.

Through the Urban Watershed Assessment process, system performance was evaluated within the planning horizon based on the project’s lifespan. For example, the life of a pump station is assumed to be 75 years, and the life of a tunnel is assumed to 150 years.

SSIP project planners will consider 1) future design tides to evaluate performance of existing wastewater facilities discharges, 2) project vulnerability to inundation from future daily tides, and 3) project vulnerability to a variety of related factors, such as extreme tide, wave run-up, erosion, and liquefaction. Impacts to wastewater assets may be physical or operational, direct or indirect, long-term or temporary. All of these factors are being evaluated prior to developing project specific criteria.

The SSIP projects incorporate various adaptions elements. In the case of the collection system located on the Bayside of San Francisco, this includes modification of combined sewer discharge structures to allow flows to exit the system while preventing salt water from entering the system. Also on the Bayside, treatment system improvement projects will address adaptations to new and existing facilities such as: increasing building elevations and grades where possible, or employing flood-proofing where buildings cannot be raised, and locating electrical equipment a minimum of 4-feet above City datum. Wastewater facilities on the west coast of San Francisco are at risk from coastal erosion due to wave action, and will require re-enforcement to protect the Lake Merced Tunnel, Westside Pump Station, and the Oceanside Treatment Plant.

3. Conclusion

A lot of time and resources were invested in planning the SSIP to ensure that the appropriate projects would be implemented and prioritized to solidify the resiliency of San Francisco’s wastewater system now and for future generations. The SFPUC encouraged staff to take the time for a careful and thoughtful planning process that utilized an urban watershed approach, considering risks from: climate change, potential seismic activity, aging infrastructure, and oftentimes competing City objectives. Staff was able to complete and calibrate the hydrologic and hydraulic model, analyze rainfall patterns (or lack thereof), and use a Triple Bottom Line evaluation for project alternative analysis. Treatment projects benefitted from the planning process because the Wastewater Enterprise staff was able to provide input as well as assess the benefits of new technology using sustainability factors, including: lifecycle cost, long-term air quality, and greenhouse gas impacts.

The SSIP’s efforts to focus on public outreach provided very useful information which was incorporated into project designs. The public support for the SSIP grew, and new initiatives, such as bike and walking tours of the system became extremely popular, to the point of requiring reservations.

In order to pull in all of the resources needed to complete the SSIP the SFPUC hired a program manager to augment staff and create an efficient and integrated team that was made up of both public and private professionals. This enabled the team to be more flexible, as resources could be pulled in quickly when they were needed. This process provided a multi-discipline team, not typically available within the SFPUC, which included: economists, modelers, communications specialists, graphic artists, scientists, cost estimators, schedulers, grant specialists, and risk assessment professionals.

A strategic engagement process was deployed to gain input from and inform multiple stakeholders, including: ratepayers, regulators, special interest groups, the San Francisco Board of Supervisors, State and local commissions, and state leaders in an effort to build and maintain support. Casting a wide net has proved beneficial in numerous areas, including: obtaining alternative sources of funds for multiple projects, securing necessary rate increases, and providing supporting testimony at key hearings.

Phase 1 of the SSIP is currently 22% complete with two of the highest value marque projects on schedule to enter construction this year. Most of the remaining high priority projects are being implemented as recommended; and a plan is in place for projects that have been deferred, due to resources and/or affordability considerations.

At the conclusion of the SSIP twenty year program, in addition to addressing threats of aging infrastructure, the San Francisco sewer system will have a greater resiliency to seismic events and the challenges created by climate change. The program represents a successful integrated planning process that was the first of its kind for the San Francisco Public Utilities Commission.

Seismic Retrofitting Measures for Sewerage Structures in Tokyo

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Key Words

Capital core functions, Earthquake resistance measures, Trenchless technology, Working time efficient

Abstract

The capital city Tokyo is the center of Japan's politics and economy, and urban infrastructure such as roads and water supply and sewerage support vigorous urban activities. For this reason, it is of utmost importance to take countermeasures against earthquakes for urban infrastructure. The Bureau of Sewerage, Tokyo Metropolitan Government has been working on earthquake resistance measures such as making manholes and pipe connections earthquake resistant and prevention of manhole floating. This paper introduces earthquake resistance measures for sewer pipes in Nagatacho and Kasumigaseki District where the capital's core functions are concentrated. Although there were many restrictions regarding construction time etc. due to necessity for coordination with many government offices and competing constructions, we could complete the work by making use of the features of seismic reinforcement technology by trenchless technology to make work procedure and working time efficient and minimize the impact on road traffic and the surrounding environment.

Introduction

1. The Importance of Earthquake Resistance Measures in Tokyo

Picture 1: Damage Occurred between the Sewer Pipes

Picture 2: Manhole Floating because of Liquefaction Phenomena

Japan was hit by major earthquakes until now often, and the sewerage facilities were damaged due to those earthquakes. In the Great Hanshin-Awaji Earthquake occurred in January 1995, damage, protrusion, misalignment and cracking of the sewage pipes occurred, and damages were frequently observed at the connection between the sewer pipes and manholes. These damages were caused by rigid joint structure between manholes and sewer pipes which cannot absorb the difference of movement between manholes and sewer pipes induced by earthquake motion (Picture 1). In the Niigata-ken Chuetsu earthquake in 2004, liquefaction phenomena occurred due to strong tremors, and it caused many cases of manhole floating. Manhole floating not only impairs the function of the sewers but also hindered road traffic by salient manholes above the ground and affected emergency restoration activities and relief and rescue activities at the time of earthquakes (Picture 2).

In the Great East Japan Earthquake that occurred in 2011, the administrative buildings in the coastal area of Tohoku District were damaged, administrative functions and economic activity stagnated. In the Kanto Region, liquefaction phenomena occurred and damage was extensive. Tokyo is said that within the next 30 years there will be a 70% chance of an epicentral earthquake directly under the capital occurring, and if Tokyo were to be damaged similarly, the whole country would be affected enormously. In particular, in Nagatacho and Kasumigaseki district, core functions of the Japanese capital such as the National Diet are concentrated, and the importance of countermeasures against earthquakes for sewer pipes is extremely high.

2. Seismic Reinforcement Technology Supporting Countermeasures against Earthquake

The Bureau of Sewerage, Tokyo Metropolitan Government supported the development of seismic reinforcement technology of private enterprises in response to the damage of sewer pipes caused by earthquakes and put them into practical use. We jointly developed a technology to make the junction of a sewer pipe and a manhole with flexible structure (trenchless technology of seismic reinforcement construction) and a technology to prevent liquefaction phenomena around manholes (trenchless technology of manhole floating prevention) with private enterprises and have been promoting earthquake resistance of sewer pipes.

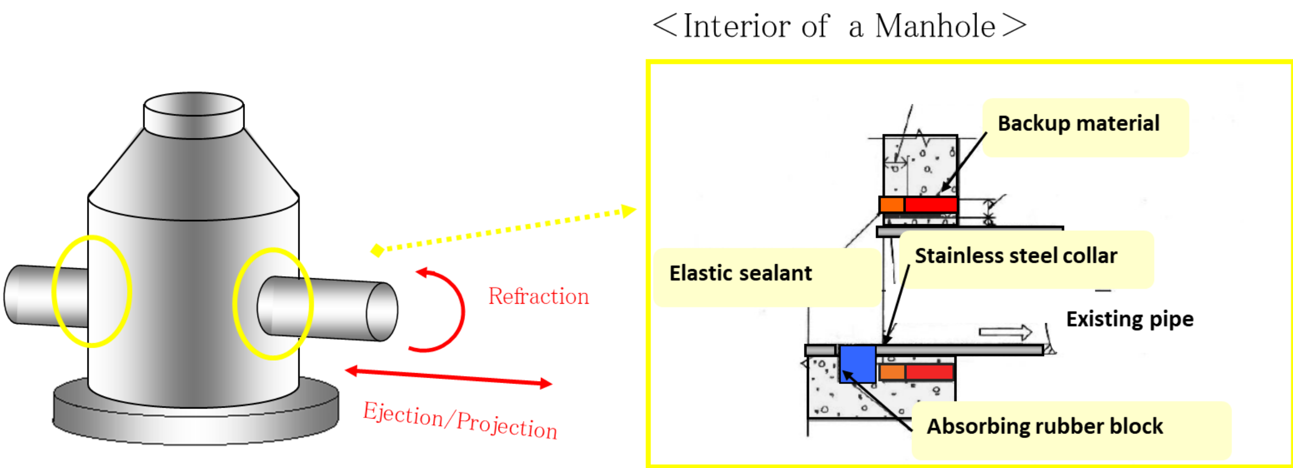
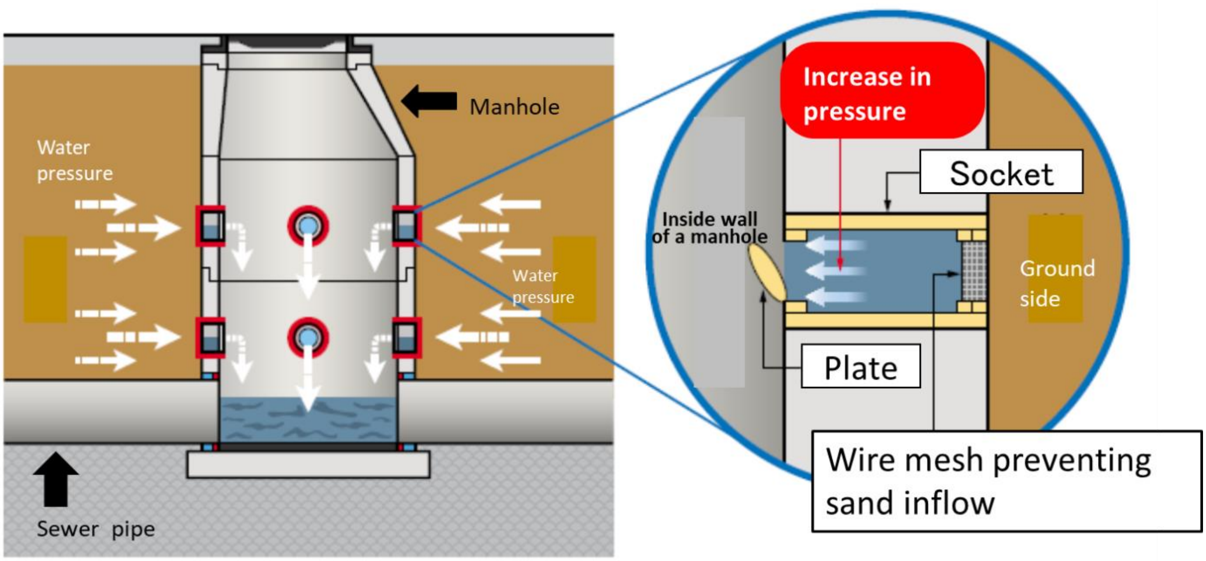


Figure 1: Model Chart of Trenchless technology of Seismic Reinforcement Construction

The trenchless technology of seismic reinforcement construction responds to bending and protrusion at the time of earthquake by cutting the outer parts of the pipe (manhole side wall part) with a cutting machine from inside the manhole and injecting elastic joint material into the cut part. By doing this, it is possible to secure the flowing function of the sewer (Figures



1).

Figure 2: Model Chart of Manhole Floating Prevention

The trenchless technology of manhole floating prevention refers a method that a wall is drilled from the interior of a manhole, a pressure relief valve (dissipation valve) is attached, and the excess pore water pressure is dissipated into the manhole through the dissipation valve (Figure 2). By suppressing the impact on the manhole caused by liquefaction, it is possible to prevent manhole floating and to reduce the influence on the road traffic.

Since these two construction methods apply seismic reinforcement from the inside of the existing manhole, construction can be done without road excavation by keeping sewage flowing, and the cost is lower and the construction time is shorter than the construction method to replace the manhole. In addition, since the equipment used is small and easy to move, the noise and vibration accompanying the work is also small. Furthermore, as only few ground facilities are required and the work can be done inside the manhole, using these methods can also suppress the impact on road traffic and pedestrians.

3. Countermeasures against Earthquakes for Sewer Pipes in Tokyo Metropolis

The total length of sewer pipes managed by the Bureau of Sewerage, Tokyo Metropolitan Government is approximately 16,000 km and the number of manholes reaches 480 thousand, and thus, it takes a lot of time and expense to apply seismic reinforcement to all of these sewer pipes. For this reason, Tokyo Metropolitan Government gave priority to districts where people gather at the time of earthquake disaster and facilities targeted as important and has been taking countermeasures against earthquake disaster for these prioritized areas and facilities. The trenchless technology of seismic reinforcement construction has been applied to sewer pipes receiving sewage from evacuation centers where people gather at the time of earthquake, disaster recovery bases designated by the state, the Metropolitan Government or each ward, terminal stations, areas where evacuation is not necessary where people can stay within the districts as there is no fear of large-scale fire and evacuation is not required, etc. In particular, since the damage of the sewage was concentrated on the sewer pipes with the diameter of 800 mm or less, we have been working on the pipes with diameter of 800 mm or less.

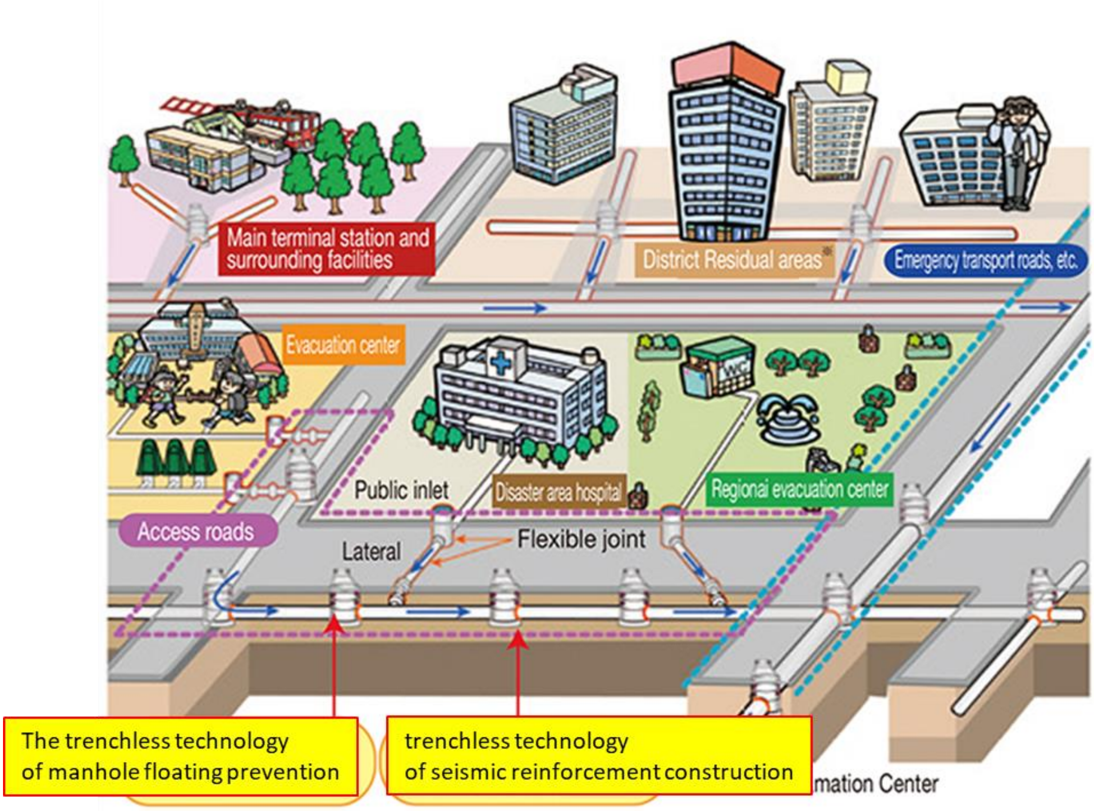


Figure 3: The Images where Countermeasures against Earthquakes for Sewer Pipes in Tokyo are Carried out

In addition, the trenchless technology of manhole floating prevention has been applied to emergency transportation roads that support material transportation and emergency restoration at the time of earthquake and access roads connecting the emergency transportation roads to each evacuation center and disaster recovery base within the areas where liquefaction is predicted (Figure 3).

Problem definition

1. Overview of Nagatacho and Kasumigaseki District

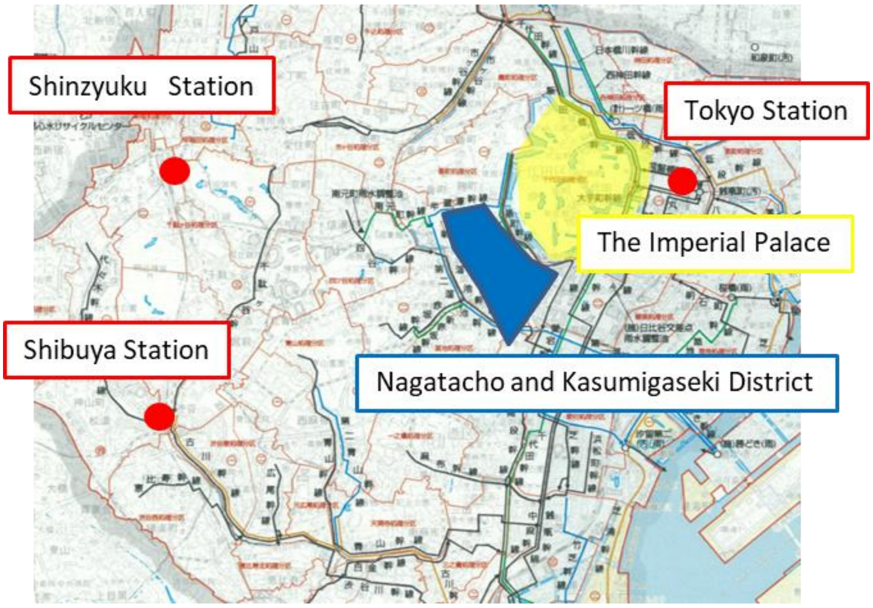


Figure 4: Position relations with around the Nagatacho and Kasumigaseki District

The Nagatacho and Kasumigaseki District, located in the southwest of Tokyo Station, has an area of 210 hectares, and it is a government office area with a population of 200,000 in the daytime (Figure 4). As there are many state guests and government dignitaries visiting important institutions of the country in this district, we regularly conduct facility inspections in a systematic manner in preparation for terrorism such as intrusion into facilities via sewer pipes and dangerous acts. On the other hand, as many of the sewer pipes in this district exceeded the legal service life of 50 years, there has been concern about the deterioration in function at the time of earthquake. Liquefaction is also presumed in most parts of the district. For this reason, in this work, priority is given to 17 facilities (Table 1) and 6 km of emergency transportation roads both of which are important as recovery bases at the time of earthquake, and we decided to implement seismic reinforcement by the trenchless technology of seismic reinforcement construction and the trenchless technology of manhole floating prevention (Figure 5).

Table 1: the Name of 17 Facilities for Seismic Reinforcement of Sewer Pipes

Number	Facilities
1	National Diet
2	Legislative Bureau of House of Councilors
3	Prime Minister's Office
4	Board of Audit
5	Cabinet Office
6	Financial Service Agency
7	Ministry of Internal Affairs and Communication
8	Ministry of Foreign Affairs
9	Ministry of Education
10	Culture, Science, Sports and Technology, Agency for Cultural Affairs
11	Japan Patent Office
12	Ministry of Land, Infrastructure, Transport and Tourism
13	Tokyo Metropolitan Police Department
14	NTT DOCOMO, Inc.
15	National Personnel Authority
16	Ministry of Health, Labor and Welfare
17	Ministry of Economy, Trade and Industry

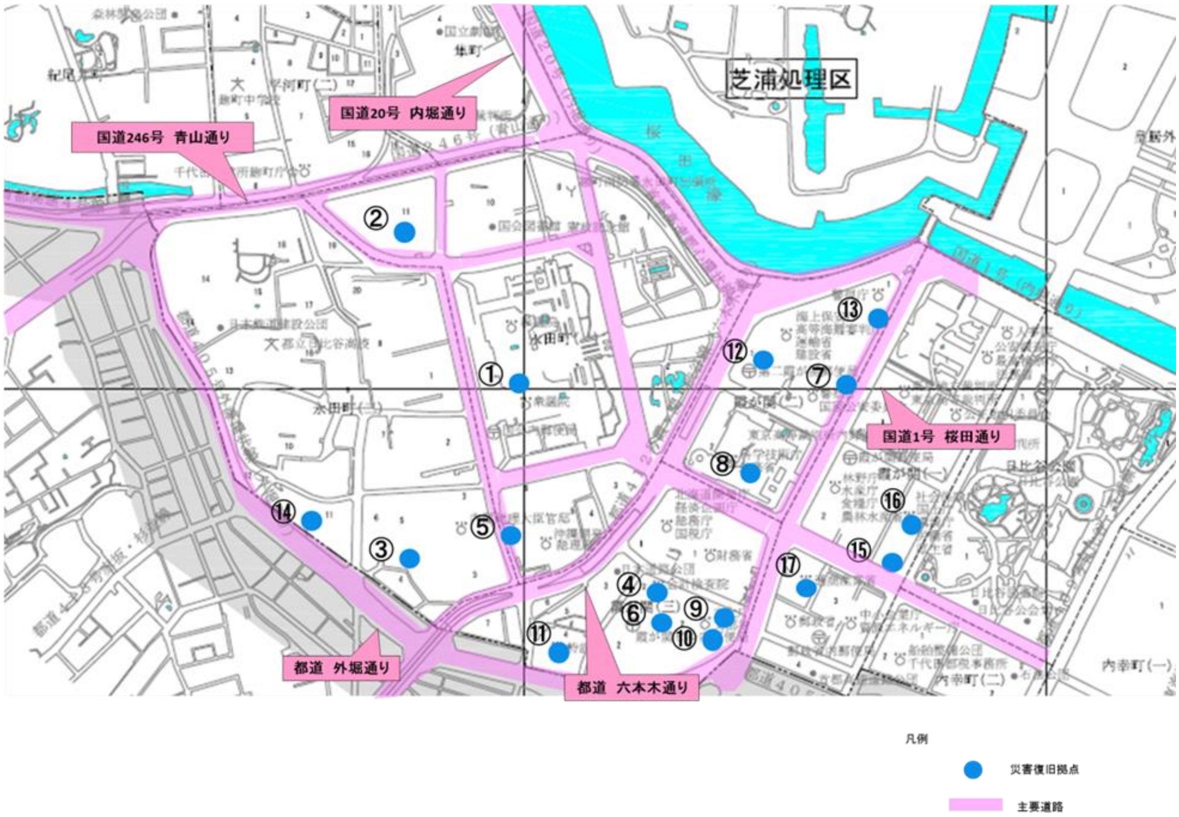


Figure 5: the Construction Map in Nagatacho and Kasumigaseki District

The details of the construction work are as follows:

Construction period: from 7 August 2015 to 5 July 2016, 220 days.

Construction purpose: seismic reinforcement of sewer pipes in Nagatacho and Kasumigaseki District.

Target facilities: seismic reinforcement of sewer pipes receiving sewage from disaster recovery bases (17 facilities, Table 1) and manhole floating prevention along 6 km of emergency transportation roads

Construction quantity:

131 spots for the trenchless technology of seismic reinforcement construction and 47 spots for the trenchless technology of manhole floating prevention

2. Challenges in Proceeding the Construction

In Nagatacho and Kasumigaseki District, many underground buried objects are congested, and it has large traffic volume and many parked vehicles so that traffic regulation has been difficult. As the Diet, ministries and government agencies are located in this district, it was also requested to minimize the influence of construction as much as possible. On the other hand, other lifeline constructions and redevelopment projects were carried out within the same district, and the construction period and the working time were restricted when implementing the construction. In particular, due to the difficulties in coordination with government agencies and in traffic regulation, even during the construction period, it was required to implement the construction on holidays or between 21: 00 and 6: 00 with less traffic volume. Furthermore, in order to avoid overlapping with other constructions, construction period was also limited at some construction sites. In response to such site conditions, ingenuity of the construction method was required in order to complete the construction within the initial construction period.

Approaches

Specifically, we addressed the following three points to solve the above-mentioned challenges:

First, we tried to speed up the work by reducing the work waiting time and travel time. The trenchless technology of seismic reinforcement construction has 4 main stages in its process, namely (i) invert chipping, (ii) cutting, (iii) sealing, and (iv) invert restoration, and each stage requires different equipment to be used and technical experts (Figure 6).

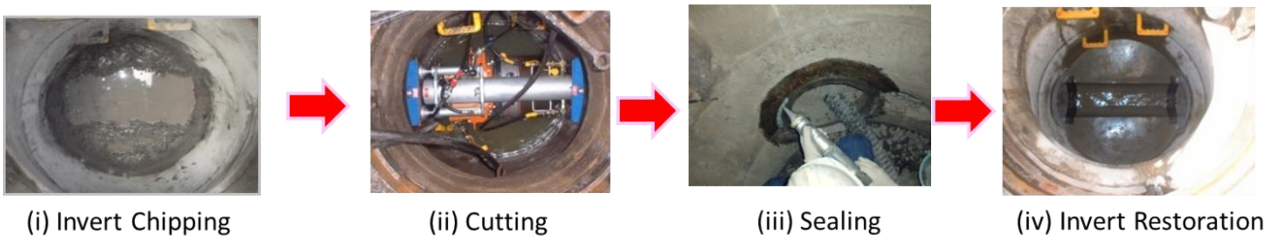


Figure 6: Execution Procedure for Trenchless technology of Seismic Reinforcement Construction

In the construction procedure at the design stage, it was planned to complete the work on manholes one by one by replacing equipment to be used and replacing workers for each stage. Movement between construction sites would also create a loss of time.

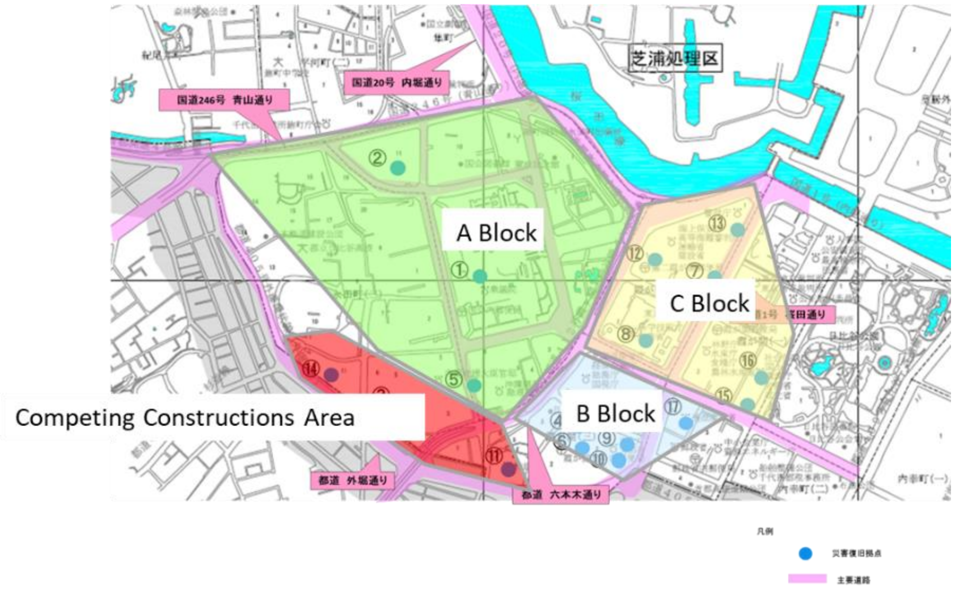


Figure 7: Working Zone Map in Nagatacho and Kasumigaseki District

However, in practice, for 100 sites excluding the overlapping sites out of the 140 sites subject to construction, considering the maximum amount of work per day, we divided the construction range into three blocks and increased the number of work units at one time up to 3 at the maximum (Figure 7).

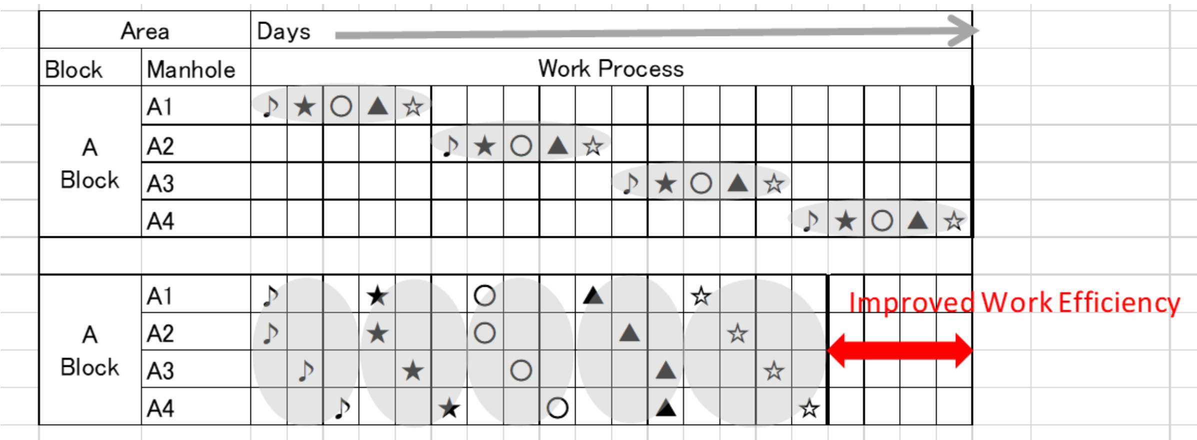


Figure 8: Difference in Work Efficiency by the collection of the Work Process

The same work was done continuously in a few days within one block and after the work was completed, the team moved to the next block so that the work process transferred not for each manhole but for each block. By reducing time for retooling equipment to be used and time for shifting workers, we reduced the waiting time and travel time for work, made full use of working time, and improved work efficiency (Figure 8). As a result of preparing the single work process, the amount of work per day increased and the construction period could be shortened.

Secondly, by assembling the equipment outside the construction site and loading it to the site, the work at the site became more efficient. In the trenchless technology of seismic reinforcement construction, when cutting, cutting equipment is normally assembled on site (Figure 9).

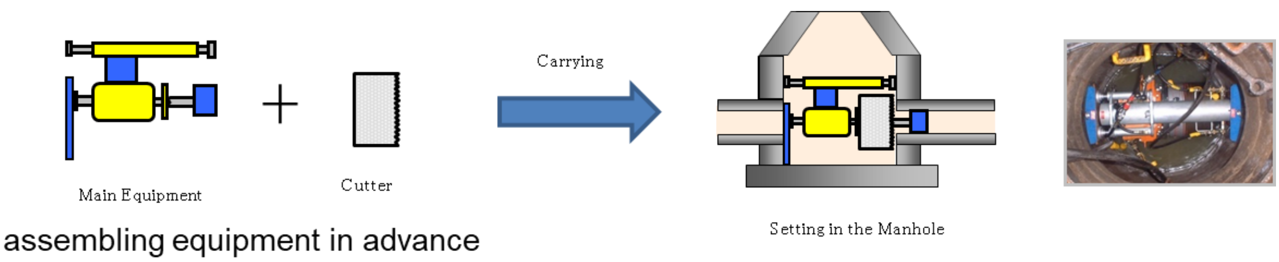


Figure 9: Schematic Picture Before and After Assembling Cutting Machine

For the construction this time, as the working time at the site was limited, we made it possible to secure longer time for working on site by assembling equipment in advance at the factory and loading it to the site.

Thirdly, for 40 sites overlapping with other construction works, we narrowed down the working zone and realized competing constructions. In order to perform on-road construction, it is required to reduce the influence on road traffic. In particular, if the working zones are adjacent to each other, they would become an obstruction to road traffic and it might be impossible to get permission for construction from the traffic administrator. The trenchless technology of seismic reinforcement construction.

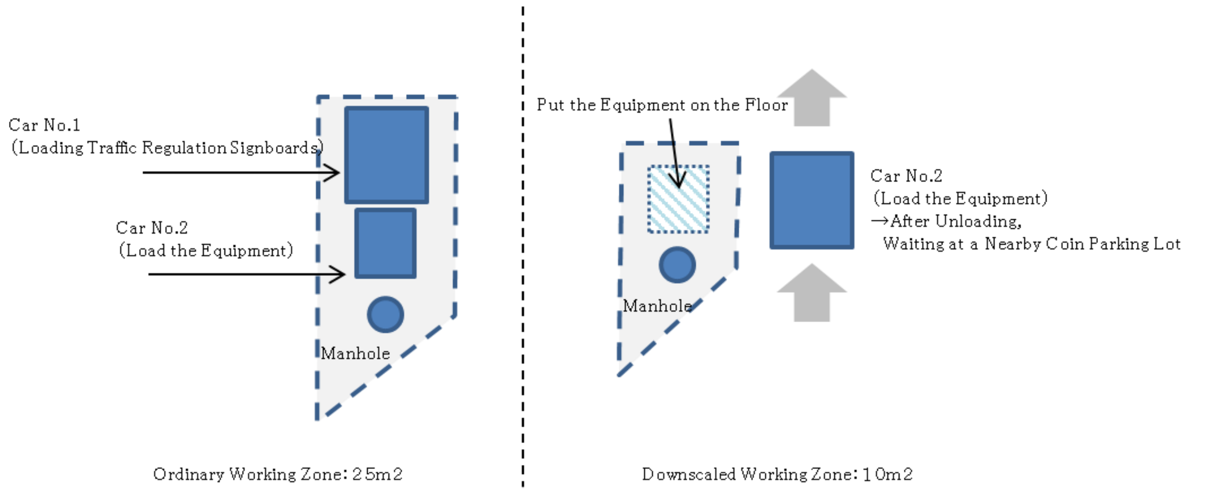


Figure 10: Difference from Working Zone

Picture 3: Ordinary Working Zone

Picture 4: Downscaled Working Zone

For example, for the trenchless technology of seismic reinforcement construction, a work area of 25 m2 is required at the time of construction. In order to implement construction at the same time at two adjacent places, it has been required to separate them more than 300 m between each other. In order to realize the construction at the adjacent places this time, we parked the work vehicle carrying the equipment to the work zone at a different place and reduced the work area to 10 m2 (Figure 10, Picture3&4). By reducing the influence on road traffic, we could obtain the understanding of traffic administrators and carry out competing constructions.

In this construction work, we tenaciously consulted with concerned organizations in Nagatacho and Kasumigaseki District and competing construction providers, and adjusted the construction date, construction time, construction sites to prepare conditions for launching the work on site. In addition, by making full use of the features of the trenchless technology of seismic reinforcement technology, we minimized the influence on road traffic and the surrounding environment. We also worked on ingenuity at the work site and completed the work by shortening construction period to 5 months, about half of ordinary construction period.

Conclusion

Tokyo Metropolitan Government has been making its efforts in realizing an earthquake resistant town in preparation for an epicentral earthquake directly under the capital which is expected in the future. Considering the priority of target areas and target facilities, the Bureau of Sewerage is promoting countermeasures for sewer pipes against earthquake by actively utilizing the trenchless technology of seismic reinforcement construction and the trenchless technology of manhole floating prevention that can be implemented while draining sewage without excavating the road.

In the future of Nagatacho and Kasumigaseki District, we will work on earthquake resistance of the whole sewer pipes throughout the area for 3 years starting from 2021 to improve earthquake resistance of the entire area. In addition to this, the Bureau of Sewerage will implement seismic reinforcement of the sewer pipes for 2000 facilities in the Metropolis and manhole floating prevention for 750 km of roads for 5 years starting from 2016. We will continue to steadily promote earthquake resistance of sewer pipes and will further enhance the safety and security of the capital Tokyo.

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Integrated Resiliency Planning
City to City Cooperation on evaluation of flood risk and co-benefits from mitigation measures

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Keywords: Integrated Resiliency Planning, Combined probability, pricing of co-benefits, liveable cities, blue-green infrastructure BGI

ABSTRACT

The City of Copenhagen and New York City have entered into an agreement with the aim of taking concrete steps to increase resilience based on an in-depth partnership to share and test experience from both cities. The focus is mainly to test the Copenhagen Cloudburst Management Program in a New York City context and to draw upon New Yorks post Sandy experience in preparing the Storm Surge Management Plan for Copenhagen. This paper focus on the implementation of 4 step approach to cloudburst management - based on experience from Copenhagen - in the catchment of Southeast Queens in New York City.

NYC Department of Environmental Protection (DEP) is by this cooperation and implementation of a new methodology seeking to address extreme weather events through integration of grey and blue-green strategies into ongoing urban infrastructure planning. This ties very well in with NYC's aspirations towards a greener and more liveable city.

The implementation is based on an integrated planning process allowing for synergies across budgets from Department of Transportaion (DOT), Parks and Recreation, The Housing Authority (NYCHA) and Department of Design and Construction etc.

Especially calculations of the combined probability and potential correlation of extreme rainfall and storm surge and the monetization of the co-benefits of the measures are in focus.

The study is centered on the development of a flood protection (cloudburst and storm surge) masterplan for a selected catchment area. Interactive workshops help facilitate the dialogue

across the city agencies. Spatial, hydraulic and economic analysis help iterate the right combinations of projects in the cloudburst masterplan and to understand the climate adaptation effect over time.

The outcome of the cloudburst resiliency planning study is an investment plan including pilot project designs for a network of blue-green infrastructure projects developed by several city agencies and a lasting relationship among key stakeholders in the different city agencies involved in the process.

Introduction

Like many coastal cities globally, New York City is confronted with increasing risks from the impacts of global climate change combined with urbanization and a higher level of expectation from the citizens regarding the level of protection against flooding.

Extreme rain events and coastal flooding, have already demonstrated that the city's water and wastewater systems are stressed beyond their capacities during extreme weather. The increased risk from these events must be addressed through implementation of further climate adaptation interventions.

Therefore, NYC Department of Environmental Protection (DEP) has started to develop innovative solutions to heavy rainfall and associated physical and societal impacts by conducting the Cloudburst Resiliency Planning Study, focusing on a pilot area in Southeast Queens. DEP is seeking to address intense rainfall through integration of grey and blue-green strategies into ongoing urban infrastructure planning with focus on optimizing the mix traditional drainage and blue-green storage including surface flow conveyance. And to test if a higher protection level against flooding is a better business case than business as usual.

The study analyses best-available data related to NYC rainfall and storm surges, recommends methodologies for incorporating findings into ongoing resiliency planning initiatives, and identifies best practices for considering climate change in future neighborhood-specific planning studies.

As an outcome of the study opportunities for intervention are identified within the designated study area to provide retention and conveyance for extreme conditions, while also offering communal and environmental benefits in normal conditions.

The 4-step approach is an iterative process of moving from initial determination of risks, to the development of a resiliency plan, and documenting the adaptation effect. The outcomes are incorporated into a Direct Cost Analysis comparing investment and avoided damage costs over time.

Methodology

The study is designed around two main pillars: Integrated Planning (IP) and Blue-Green Infrastructure (BGI). In trying to understand the potential of integrated planning of BGI in NYC the questions illustrated in Figure 2 are used as inspiration for the study.

Figure 2 Guiding research questions for the study

The study findings are communicated through three overall elements (see Figure 3): (A) a literature review summarizing challenges and approaches from six cities that are leading the world on climate change, (B) a cloudburst masterplan for a selected study area, and (C) conceptual designs for pilot project areas.

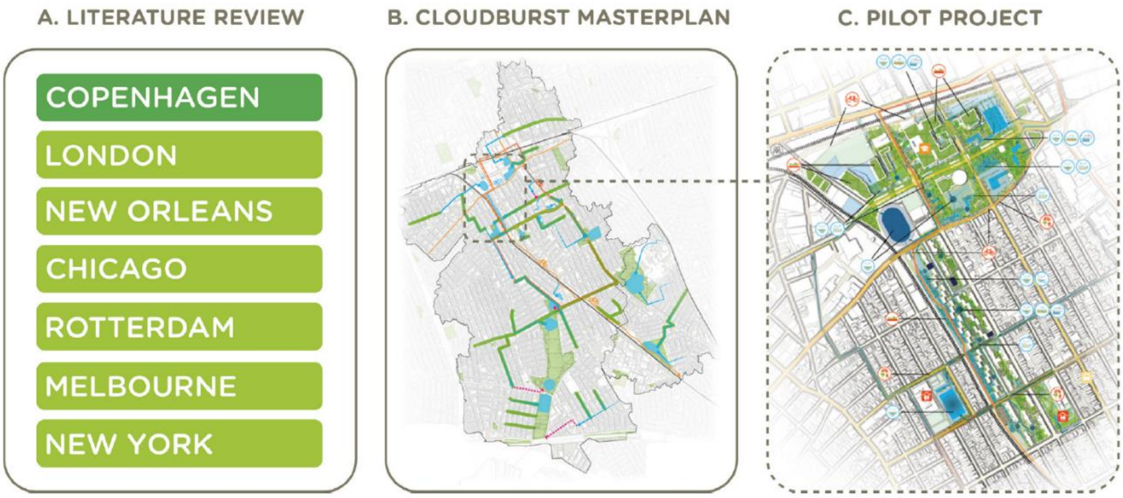
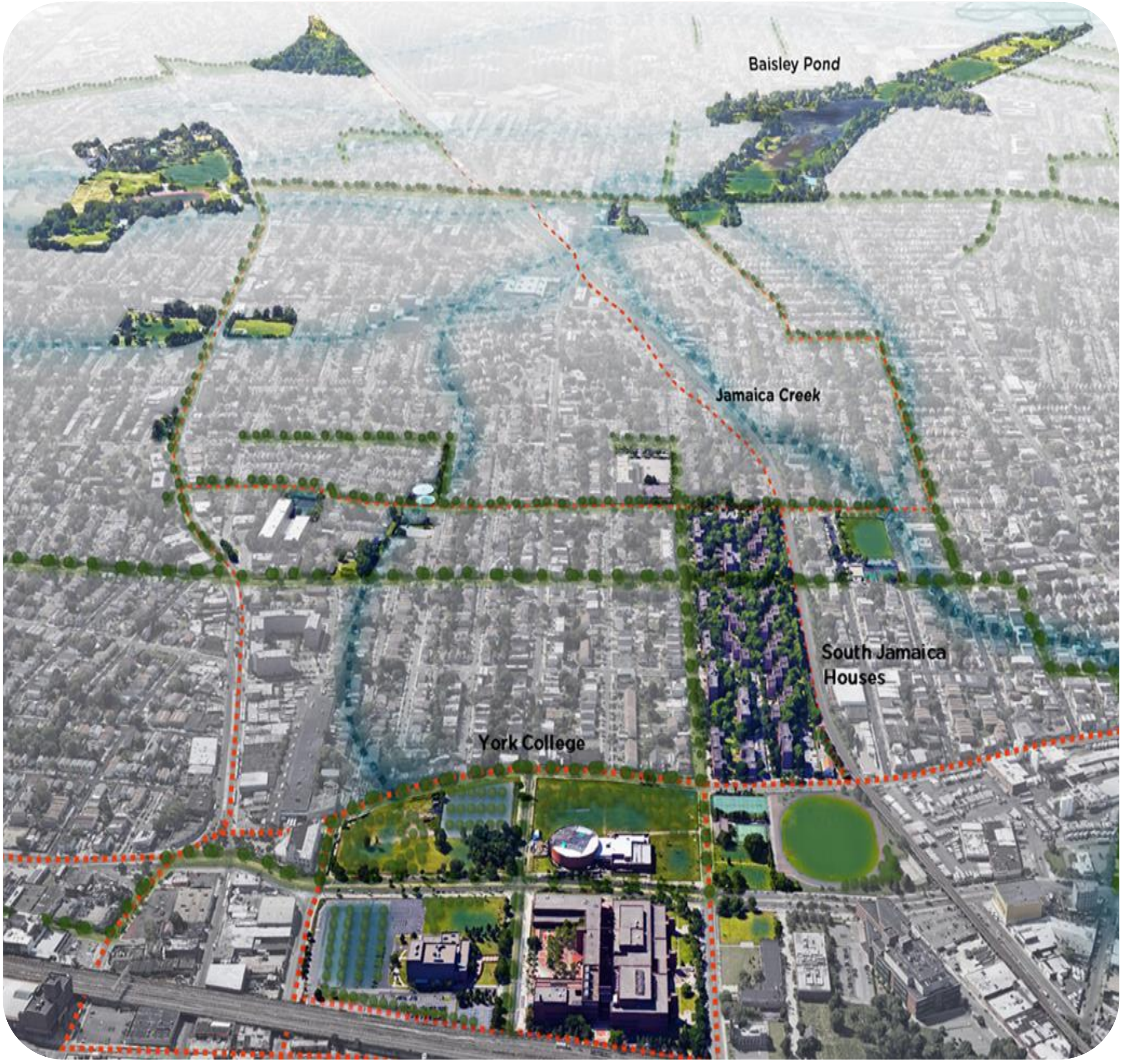


Figure 3 The overall project elements: A literature review of six selected cities other than Copenhagen (A), a cloudburst masterplan for a selected study area (B) and a conceptual design of a selected pilot project (C)

Before and during the preparation of the cloudburst masterplan a series of multi-disciplinary inter-agency workshops were arranged and carried through with the aim of 1) creating a vision and specific goals, 2) identifying existing plans and projects in the area of relevance for the plan and 3) developing specific solutions for the catchment.

Additionally the workshops would facilitate an increased inter-agency cooperation and common ownership of the plan and specific solutions.



The overall vision plan for cloudburst network

Ramboll has developed a 4-step approach to cloudburst resiliency planning based on experiences from Copenhagen and abroad, see Figure 4. GIS data act as the foundation of the study and are crucial in providing a solid basis for informed decision-making. Spatial overlay of datasets and analyses at multiple levels help to identify potential synergies and cumulative effects.

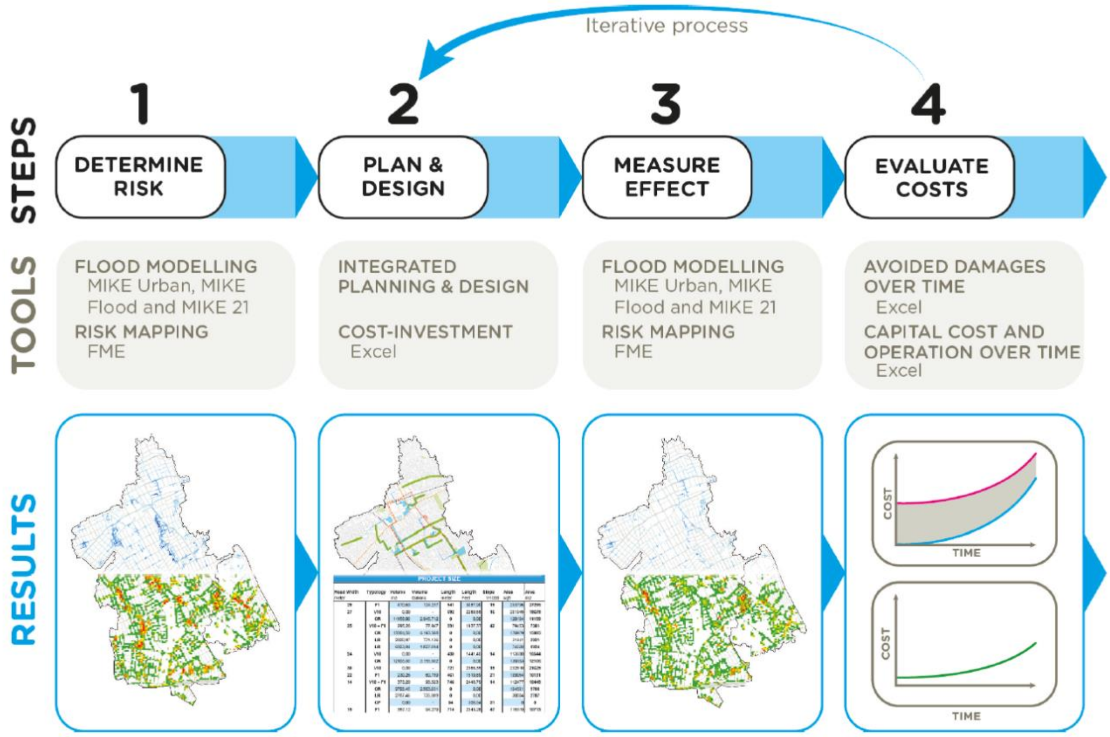


Figure 4 The 4-step approach to cloudburst resiliency planning developed by Ramboll

The 4-step approach is an iterative process from initial determination of risks, to the development of a resiliency plan, and documenting the adaptation effect.

The outcomes are incorporated into a Direct Cost Analysis comparing investments in construction and operational cost with avoided damage costs over time. If the effect or cost of the developed plan does not meet predetermined visions and goals (or existing environmental standards), Step 2 is repeated in order to adjust designs and plans.

The approach is often extended to also evaluate co-benefits as a result of the masterplan in a Cost-Benefit Analysis (CBA). The CBA includes the direct costs in the project area and extends to the broader environmental and social impacts of a masterplan.

Below the 4-step approach is described when applied to a study area in South-East Queens in New York City.

Results

The first step in the 4-step approach is to prepare the baseline with the risk in the existing situation (or in the case of Southeast Queens the situation after implementation of an already approved plan). The baseline is established in the existing and future climate.

DETERMINE RISK

Calculation of risk is defined by combining the probability of flooding (in varying levels) with the financial impacts of theses floods. Results from a hydrodynamic model simulating drainage and overland flow is used to estimate the spatial probability of flooding.

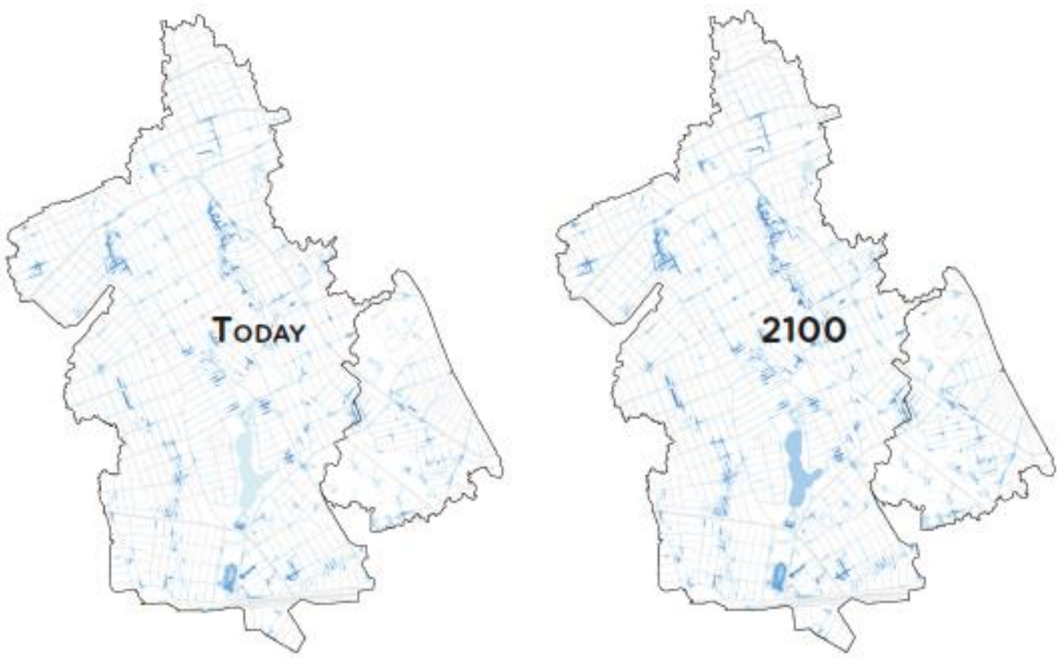


Figure 5 Illustration of a cloudburst event (defined as a rain with a 100-year return period), today and in 2100

To obtain the full risk profile as average per year - and not just the cost of a chosen extreme event - the risk is calculated using hydraulic results for a 10-, 50-, and 100-year storm today and in 2100. A GIS land-use data model combined with property value data is used to calculate estimates of potential damage costs.

Figure 6 illustrates the risk in the area, the product of the highest probability of flooding in a given cell and the potential damage costs. The anticipated increase in precipitation causes the risk to increase over time.

The hydraulic calculations are validated comparing the flood prone areas from the model with flood complaint data registered in the catchment area.

PLAN AND DESIGN

As step 2, based on the hydraulic calculations, a masterplan is developed as network of mainly BGI elements designed to convey or delay the cloudburst run-off.

The masterplan is developed based on the input from the interagency workshops, spatial analysis and design sessions. Information regarding legal grade and existing utilities were incorporated to the extent possible through as-built drawings and site visits etc.

It is tested in the hydrodynamic models and detailed in a database based on experience from implemented projects in terms of overall flow or storage capacity and rough cost estimates.

Figure 6 Illustration of the spatial risk in the study area today and in 2100. The red cells are high risk areas, orange cells medium risk and green cells low risk.

MEASURE EFFECTS

In step 3, the effects of implementation of the masterplan is tested in the hydrodynamic model, to establish the reduced damages by the projects in plan.

After 5 main iterations and sub-iterations the final cloudburst masterplan was finalized, see Figure 7. The masterplan comprises 11 cloudburst roads, 16 cloudburst roads with retention, 15 retention streets, 4 cloudburst pipes, and 18 central and 4 local retention projects; a total of 68 BGI projects. Biking and walking paths are suggested in connection to the proposed BGI network.

Figure 8 shows the impacts of a 100-year storm in 2100 in baseline conditions, and after implementation of the masterplan (top).

For the masterplans, the associated risks are determined based on the cloudburst flood results and land-use data. The colour scale indicates risk in terms of damage costs from green (low) to red (high). There are considerable less flooding and lower risks after implementation of the masterplan.

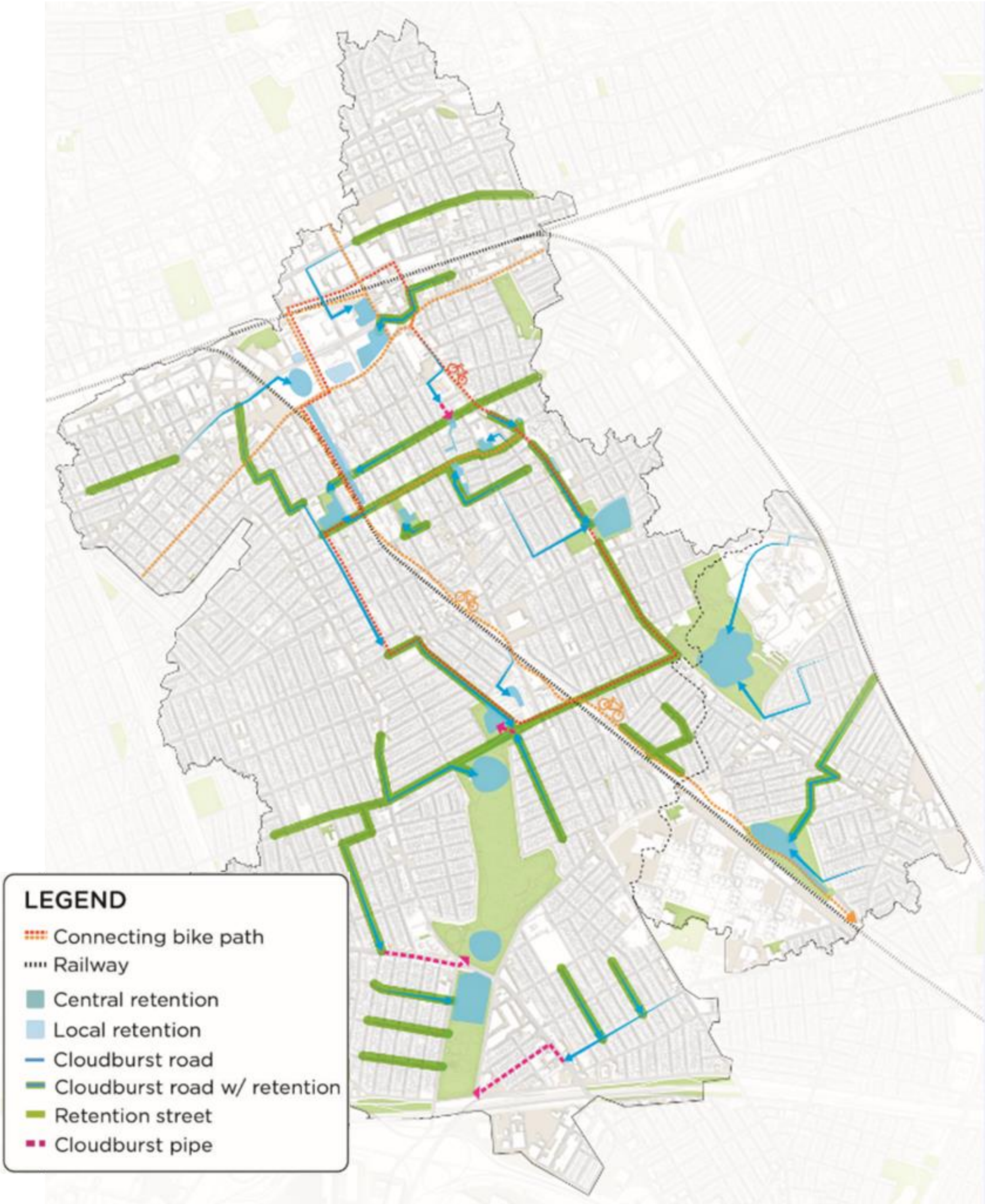


Figure 7 The 68 projects comprising the cloudburst network

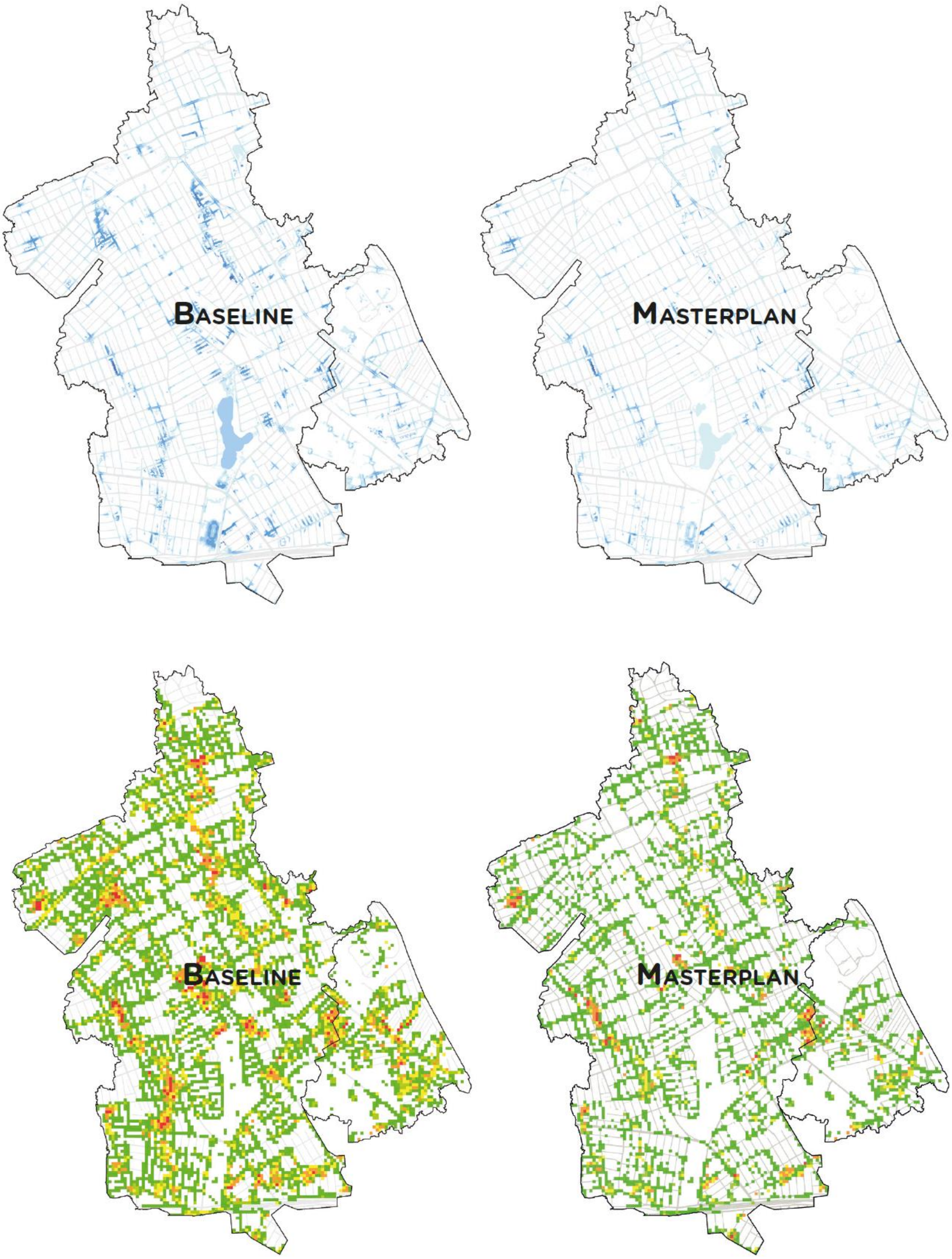


Figure 8 A 100-year cloudburst event in 2100 before (baseline) and after (masterplan) implementation of the masterplan in the hydraulic model (top) and calculated risk before and after (bottom)

EVALUATE COSTS

In the last step the costs are evaluated. Capital (CAPEX) and operational (OPEX) costs are compared to the avoided risk costs over time in a Direct Cost Analysis.

CAPEX in this example cover implementation including financing costs of potential loans.

The cloudburst masterplan was designed to a 100-year storm based on the vision plan from the initial workshop - from experience deducted from the Copenhagen case and the literature review. Costs amount to approximately $370 million in capital investment costs and $1.7 million/yr in operational costs.

In a 100-year period with a discount rate of 7% and including financing costs, the total present value of the costs of the masterplan is approximately $330 million assuming that the capitals investment are made primarily during the first decade – similar to the existing approved long term investment plan.

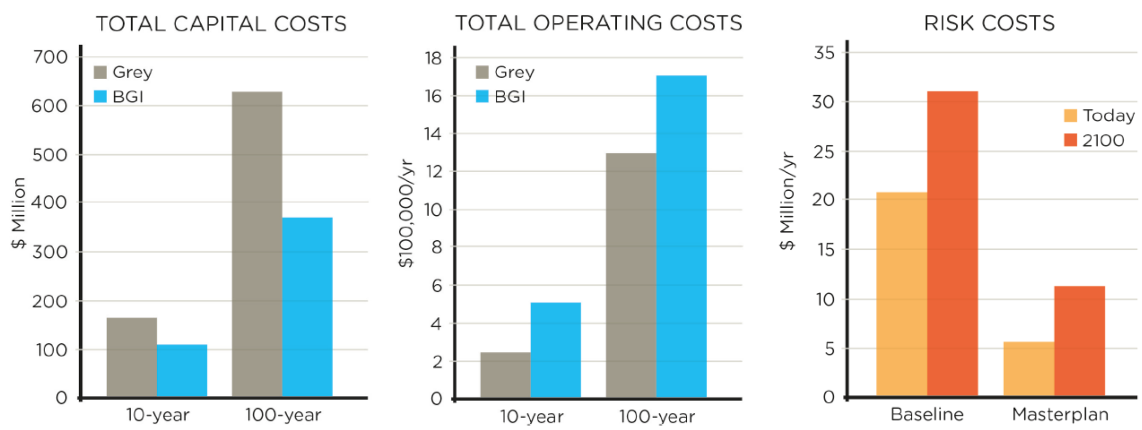


Figure 9 Left plot shows total overall construction costs for the cloudburst masterplan, when designing using BGI (blue) or traditional grey infrastructure (grey) either to a 10-year storm (left) or 100-year storm (right). Middle plot shows annual estimated operating costs associated with the four different masterplan constallations. The right plot shows the annual risk costs today (light orange) and in 2100 (dark orange) in baseline scenario (left) and after implementing the masterplan (right).

The cost to implement the Masterplan for a 100 year return period using grey infrastructure rather than BGI is approximately double up, see Figure 9 left, but the annual operational costs are roughly 30% higher for BGI than grey infrastructure, see Figure 9 middle. If the design criteria is lowered to a 10 year return period, the additional capital investment is approximately 50 % higher than the BGI plan.

The existing approved investment plan is designed to a protection level corresponding to a 5-year return period using grey infrastructure.

On the benefit side, the avoided risk is based on comparing masterplan and baseline calculated as the present value of the damage costs over the project time, Figure 9 right, minus the damage costs.

Due to the climate change the calculated baseline damage costs will increase 50% by 2100. The damages will be reduced by 75% after implementing the Masterplan.

The avoided damages over the entire period of 100 years totals approximately $310 million in net present value, hence the result of the Direct Cost Analysis shows that the present values of the direct costs over the entire period is a net loss of $20 million. Not taking any of the co-benefits of the additional green and savings by co-investments into account.

It is however worth noting that the calculated damage costs are significantly lower than in many other city catchments, probably due to the quite low plot ratio in this specific catchment in Southeast Queens. A densification in the catchment is to be expected, which will strengthen the business case of implementing the BGI masterplan since the reduced damages will be larger in a densified catchment.

COST-BENEFIT ANALYSIS

To evaluate the full impact of the cloudburst masterplan, a Cost-Benefit Analysis (CBA) was performed by considering also the social and environmental costs and benefits associated with a project. In this specific CBA the BGI masterplan is compared to a baseline scenario which describes the situation without the masterplan.

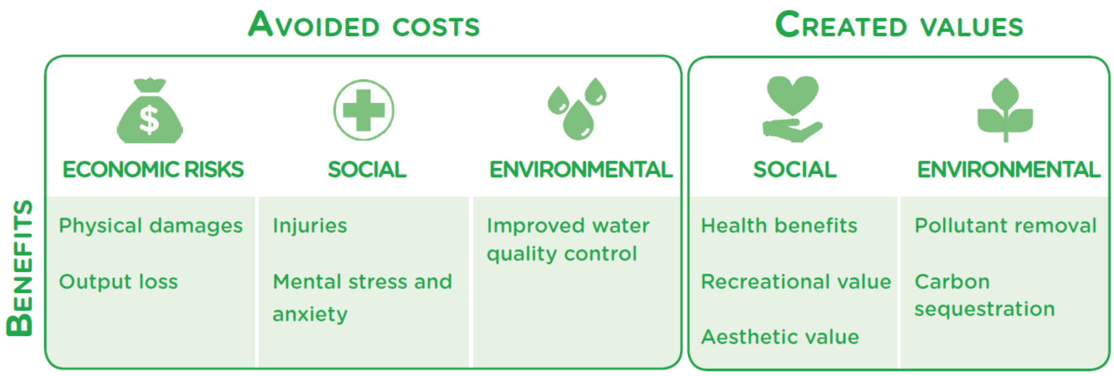


Figure 10 Benefits in terms of avoided costs and created values included in the CBA

Benefits include the avoided damages and also cover the positive impacts of the created social and environmental co-benefits from the positive effect Blue-Green Infrastructure has on the local community and society as a whole. These include improved health (air quality and improved micro climate etc.), recreational values, as well as pollutant removals and carbon sequestration, see Figure 10.

Health benefits, recreational value and other co-benefits are documented in studies on an international scale, e.g. health effects from cycling studies in Copenhagen, studies on improved air quality and aquatic environment on EU level, studies on use of the Bishan Park in Singapore and implementation of the harbor baths and greening of Søndre Boulevard in Copenhagen.

The results from the CBA shows that when socio-economic parameters are included, the project provides a return.

Depending on the design and monetizing of the co-benefits, the Net Present Value can amount to more than $250 million, with a benefit-cost ratio of 1.8, see Figure 11.

Thereby the CBA indicates that the cloudburst masterplan provides social and environmental benefits that outweigh the small deficit in the Direct Cost Analysis.

The social and environmental co-befit parameters included in the CBA were discussed in detail across agencies in order to highlight the parameters that were essential to the agencies and the common vision of the project. And to establish a set of parameters that all stakeholders would accept in terms of accuracy of the monetizing of the effects.

Figure 11 Costs and benefits of the CBA

Conclusion and recommendations

In the literature review on top-tier climate adaptation cities, it is found that the case cities generally offer a higher level of protection than the standard design criteria, when referring to stormwater management for extreme rain events. Most widely used is a 100-year return period, including an increment on precipitation intensity to take climate into account. The basis of choosing a 100 year storm varies – some cities have performed analysis to find the socio-economic optimum while others have selected based on a vision of being in the top-tier regarding resiliency and climate adaptation.

The city to city agreement to improve resiliency in the City of Copenhagen and New York City has created valuable insight, tangible projects and not least a basis for future cooperation between the two cities but also between the agencies in the cities on both sides.

This study and plan has formed the basis for construction projects being implemented in Southeast Queens following a vision to seek co-benefits and an approach that is based in tangible Cost Benefit Analysis to test the business case of the plan and the projects.

FINDINGS

Some of the main findings in relation to integrated resiliency planning using blue-green infrastructure are listed below.

The CBA shows, that including “urban” value for capital investments by using mainly BGI for stormwater management, is an important parameter when planning for city-wide or catchment-wideresilienvy. When socio-economic parameters such as social and environmental values are included in terms of avoided or created costs, the benefits of the masterplan outweigh the costs, even for a masterplan designed to a 100-year storm.

The inclusive CBA process also clearly demonstrates the differencies (and similarities) across geographical borders in terms of which social parameters that is predominant and decisive.

The integrated planning process allowing for more synergies shows that it is possible to increase the capacities/reduce damages using mainly BGI for a similar or significantly lower budget than traditional grey stormwater infrastructure..

The inclusive and interactive workshops were an important factor in the increased cooperation across city agencies allowing for a smoother and more efficient integrated planning and spending of capital investment. There was an extended willingness to testing alternative operational practices and new ways of collaboration and funding.

It was concluded in the workshops that the preparation using detailed flood models and easy accessible and understandable result presentation in 3D and 2d interfaces was very useful in the idea generation phase and to understand the origin of the flooding. Also the

NEXT STEPS

The Cloudburst Resiliency Planning Study was a pilot testing of new methods of cloudburst management although the masterplan and CBA from the study is directly applied in the ongoing planning and project implementation in Southeast Queens.

The study has identified three overall phases to lay down the tracks for future resiliency planning in NYC using BGI.

First phase is to carry out a detailed drainage master plan based on detailed hydraulic modelling should map the dynamics of risk and in general provide the basis for informed decision- making and cloudburst resiliency planning.

In second phase an analysis to identify the socio-economic optimum level of protection for cloudburst management should be conducted. The risk and adaptation needs to be balanced and viable pathways should be developed.

Third phase will be to prepare catchment-wide plans like the pilot for Southeast Queens including investment plans and multi-criteria models to prioritize the projects.

The integrated planning methodology tested in this study should be further developed and applied in preparation of the next catchment plans.

COMPARING THE VULNERABILITIES OF SEMI-CENTRALIZED AND CENTRALIZED URBAN WATER SYSTEMS IN THE CASE OF QINGDAO, CHINA

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1. Introduction

Centralized water supply and sanitation infrastructures have been widely implemented in industrialized countries over the past 150 years. Such systems have been integrated into the infrastructure design of many developing and emerging countries as well. However, population growth in urban agglomerations, for instance in China, India and Brazil, is much higher compared to western countries. This is a major challenge for centralized water infrastructures in terms of planning and operation, e.g. due to dimensioning issues and under- or over-utilization. These challenges can be met with more adaptable and flexible concepts [1,2,3]. Novel water infrastructures, for instance, are decentralized or semi-centralized, enable a modular architecture and the reuse of water by source separation and the provision of drinking and service water [4,5,6,7,8,9,10]. In particular, the modular design of semi-centralized systems allows for the flexible adaptation of urban supply and disposal systems to the rapidly growing population [8]. In addition, the reuse of water contributes to a more sustainable management of natural resources.

Water supply and disposal systems are essential for the functioning of a society and its economy. For this reason, it seems appropriate to compare the vulnerability and resilience of centralized and novel water infrastructures to certain hazards, such as internal and external hazards (e.g. technical failure, drought) as well as their dependencies on other infrastructures (e.g. energy supply). A comparison of the vulnerabilities of these different systems can illustrate their corresponding strengths and weaknesses. This approach was chosen because vulnerability and resilience should be considered as a priority in the context of the envisaged further transferability of novel concepts.

2. Case Study

The vulnerability analyses in this paper focused on the pilot plant of a semi-centralized water infrastructure and a generic centralized wastewater system typical for Chinese conditions. The novel urban water infrastructure concept called "Semizentral" was implemented in 2014 at the World Horticulture Exhibition (WHE) site in the city of Qingdao in northeastern China. The semi-centralized concept comprises the collection and treatment of domestic wastewater from 12,000 residents in two residential areas, two hotels and offices in a treatment plant, the so-called Resource Recovery Center (RRC) [11]. A key aspect of the concept is the separate collection and treatment of partial waste water flows (Figure 1). Purified grey water from showers, wash basins and washing machines is reused as service water (SW) for toilet flushing in the area. Purified black water from toilets is used for the irrigation of public green spaces. By doing so, drinking water consumption can be reduced by up to 30 percent under ideal conditions. Furthermore, the energy requirements of the RRC can be covered by biogas production from the digestion of biowaste and sewage sludge [12]. It should be noted that the actual implementation differs to some extent from the case study described. The differences comprise, among other things, the RRC's degree of capacity utilization and the share of buildings using service water for toilet flushing.

The generic centralized wastewater system corresponds to the state of the art of a plant that would now be built in China. It is assumed to treat the wastewater of 69,000 residents. Unlike the semi-centralized system, the centralized one does neither provide for source separation nor for water reuse. The wastewater is collected, conveyed and conventionally treated by using activated sludge (Figure 2). An aerobic simultaneous sewage sludge treatment is applied. The sludge is not used for energy recovery and is deposited.

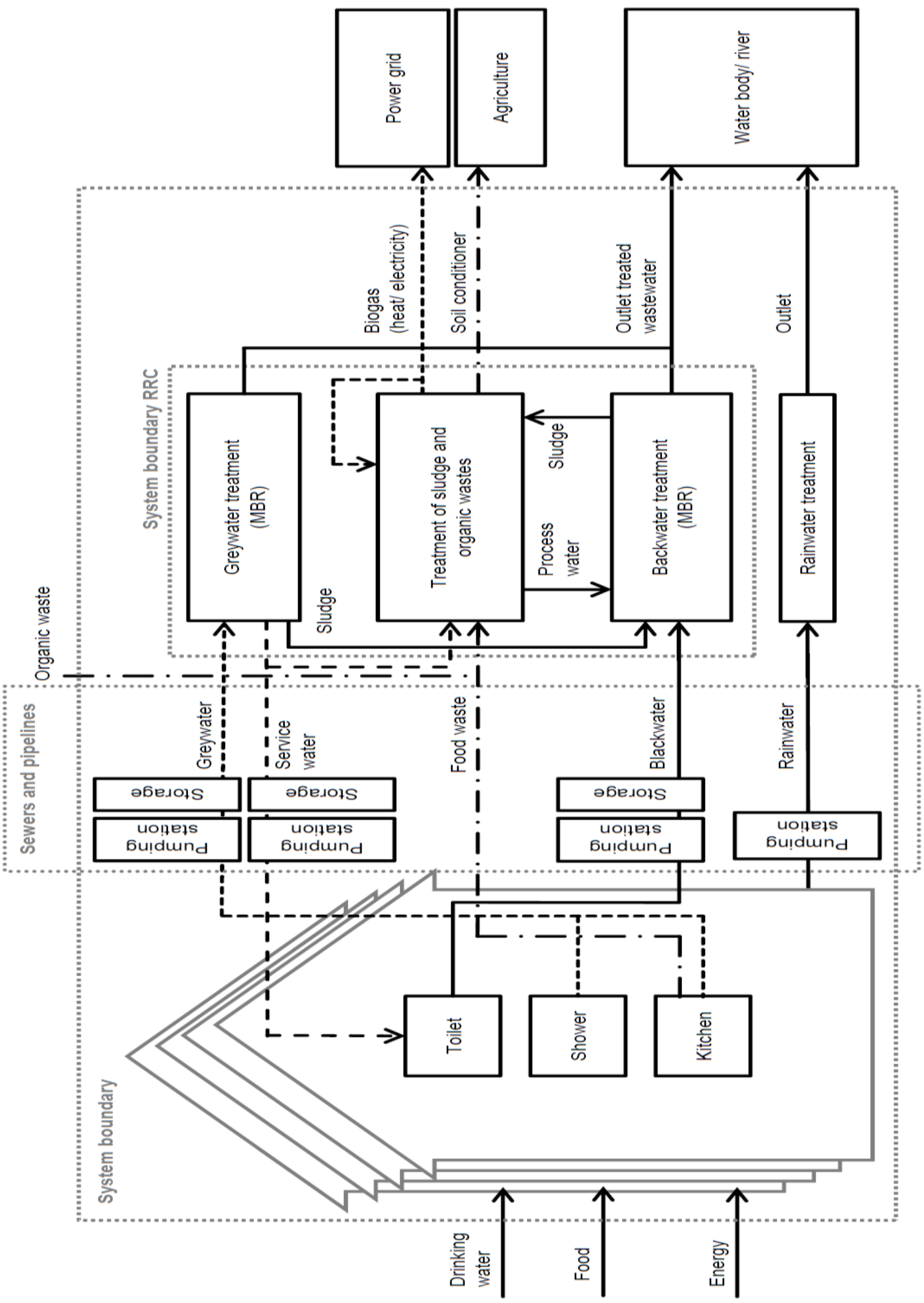

Figure 1: Scheme of the semi-centralized system (based on [20])

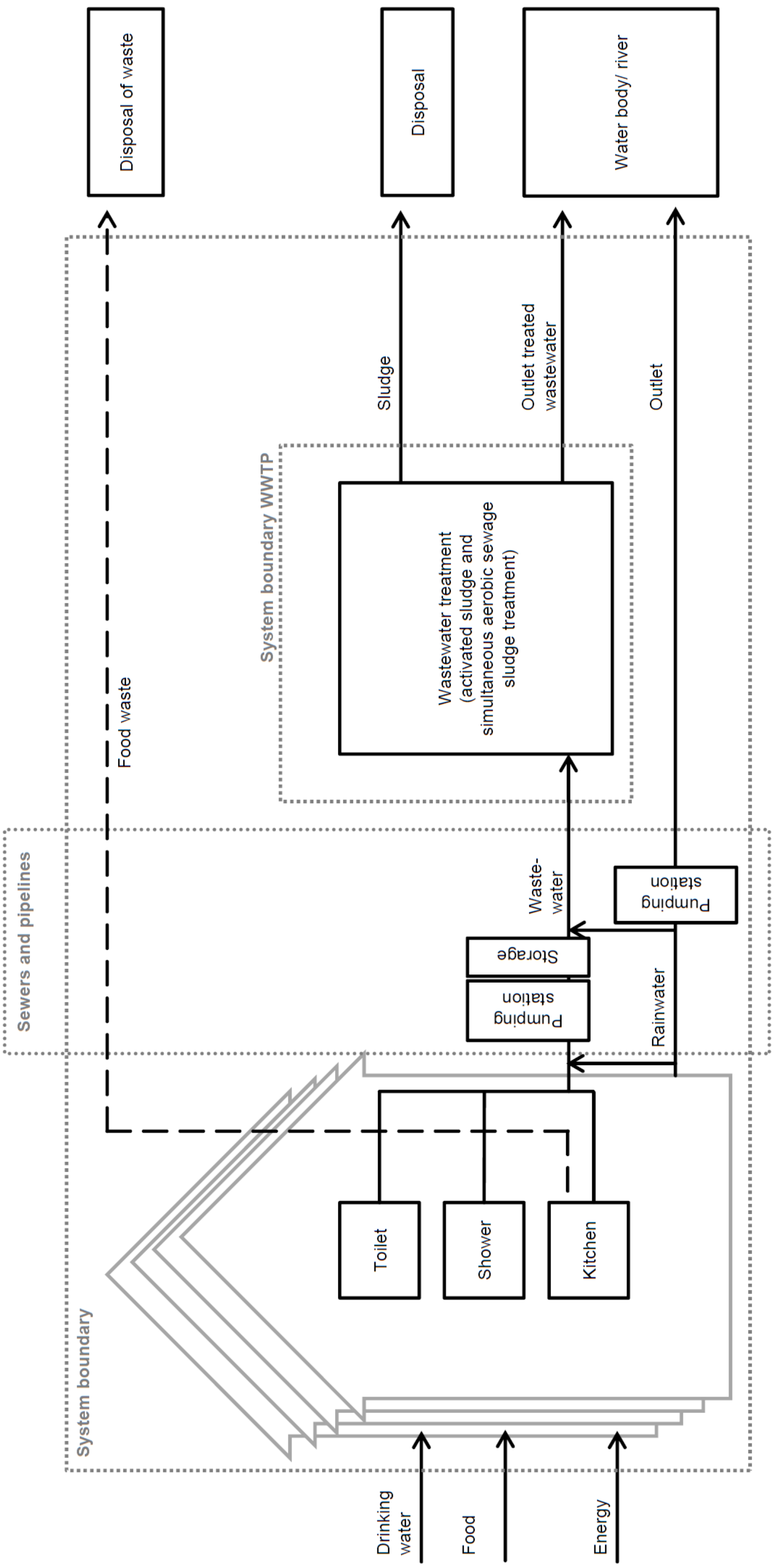

Figure 2: Scheme of the centralized system

3. Theoretical Background and Methodology

A methodology combining expert discussions, questionnaires and a vulnerability assessment heuristic was used. The analysis was conducted each for the semi-centralized and the centralized system. Vulnerability concepts usually consist of the three components exposure, susceptibility and coping capacity (or resilience) [13]. Exposure refers to the fact that protected goods are spatially and temporally exposed to a hazard [14]. Vulnerability means that an endangered protected good is impaired in its functionality [15]. Finally, coping capacity describes the available options to compensate for the negative effects of a hazard [16,17]. Regarding infrastructures, vulnerability means that they become inoperable due to a threat and therefore the supply and disposal of the population is no longer guaranteed [18]. Krings [19] developed a heuristic for the vulnerability analysis of municipal infrastructures, which can be used to classify the vulnerability of technical system components into five vulnerability classes (Figure 3). These classifications were recorded and evaluated in a vulnerability matrix in terms of row sums of hazards and column sums of system components [20].

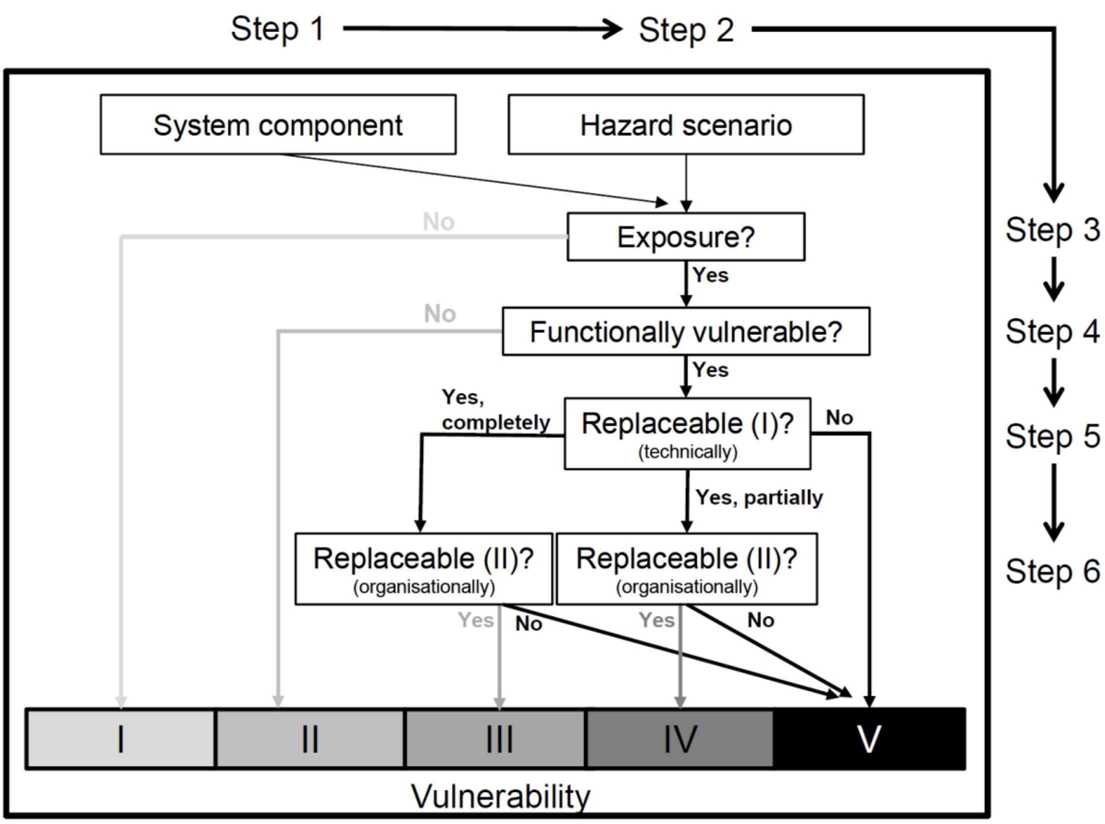

Figure 3: Heuristic for the assignment of vulnerability classes (based on [19])

The spatial system boundaries were determined by the socio-technical system of the water infrastructures. This included the catchment area, its sewers and pipelines as well as the RRC or the wastewater treatment plant (WWTP) respectively. Changes in user numbers, the behavior of users and staff as well as vandalism and sabotage were also taken into account. The temporal system limits included the occurrence of hazards and the immediate compensation of the failure of technical components.

Table 1: List of hazards and priorities of the semi-centralized and the centralized system (based on [20])

Hazard	**Priority**	
	Semi-centralized	**Centralized system**
Internal		
Technical failure (system component)	3	3
Technical failure (building)	3	3
Human failure	3	3
Extreme user numbers	1	1
Misuse by residents or hotel guests	2	1
Misuse by hotel operator	2	1
Wastewater cross connections	2	-
Cross connections of supply lines	3	-
Boycott of service water	1	-
Changing usage patterns	1	1
Vandalism	2	2
External		
Drought	1	1
Heavy rainfall	1	1
Landslide at RRC	3	-
Dam break	1	1
Earthquake	2	2
Sabotage (e.g. terror, hacking)	2	2
Fire	2	2
Cold wave	1	1
Heat wave	1	1
Lightning strike, tornado	1	1
Urbanization (demographic change)	-	2
Dependencies		
Drinking water supply	1	1
Energy	2	3
Delivery of food waste	2	-
Transport connection	1	1
Finances	3	3
Operating materials	2	2
Communication/IT	2	3

In cooperation with experts involved in planning and operation (e.g. scientists, engineers, architects), both analyzed systems were broken down into reasonable functional technical units. The centralized system was subdivided into 23 system components, the semi-centralized system into 44. The technical system components can be roughly divided into three groups: Components within residential and office buildings as well as hotels (e.g. toilets and service water connections, water pipes in buildings), sewers and pipelines in the public space as well as components of the RRC or the WWTP. The RRC consists, among other things, of treatment steps for grey and black water treatment (e.g. membrane bioreactors or MBR, disinfection), service water storage tanks, the energy module as well as the control system.

In addition, relevant hazards were defined in a workshop with the same experts. These included not only negative consequences of exceptional situations, but also undesirable effects during normal operation. The list of hazards for the semi-centralized system comprised 28 elements, the one for the centralized system 24 (Table 1). The hazards can be divided into three groups: internal and external hazards as well as dependencies, e.g. on other infrastructures. In addition, the hazards have been prioritized by experts to reflect the relevance of the hazards, i.e. the attention that has to be paid to hazards during operation of the water infrastructure. Priority is therefore not necessarily the likelihood of a hazard occurring. A scale of 1 (low priority of a hazard) to 3 (high priority) was selected.

4. Results and discussion

The vulnerability analysis first of all provided an overview of the impacts of hazards on the vulnerability of the components of both systems. Overall, the impacts on the semi-centralized and the centralized system are similar in many respects (Figures 4 and 5). Higher row sums in the case of the semi-centralized system are only due to the fact that it consists of significantly more system components.

The hazards with the highest impacts in both cases are human failure, sabotage (e.g. terrorism, hacking), technical failure and fire. Hazards such as earthquakes or dependency on financial resources have the potential to disable any system component, which is why they seem to be very severe but cannot be used for more differentiated statements on the vulnerability of the system.

The list of hazards that have the least impact on the vulnerability of system components includes an above-average number of natural hazards (e.g. cold waves, heavy rainfall, heat waves, droughts) and dependencies on other infrastructures (e.g. transport connection, drinking water supply). All in all, internal threats such as human and technical failure therefore appear to increase the vulnerability of system components much more than natural hazards.

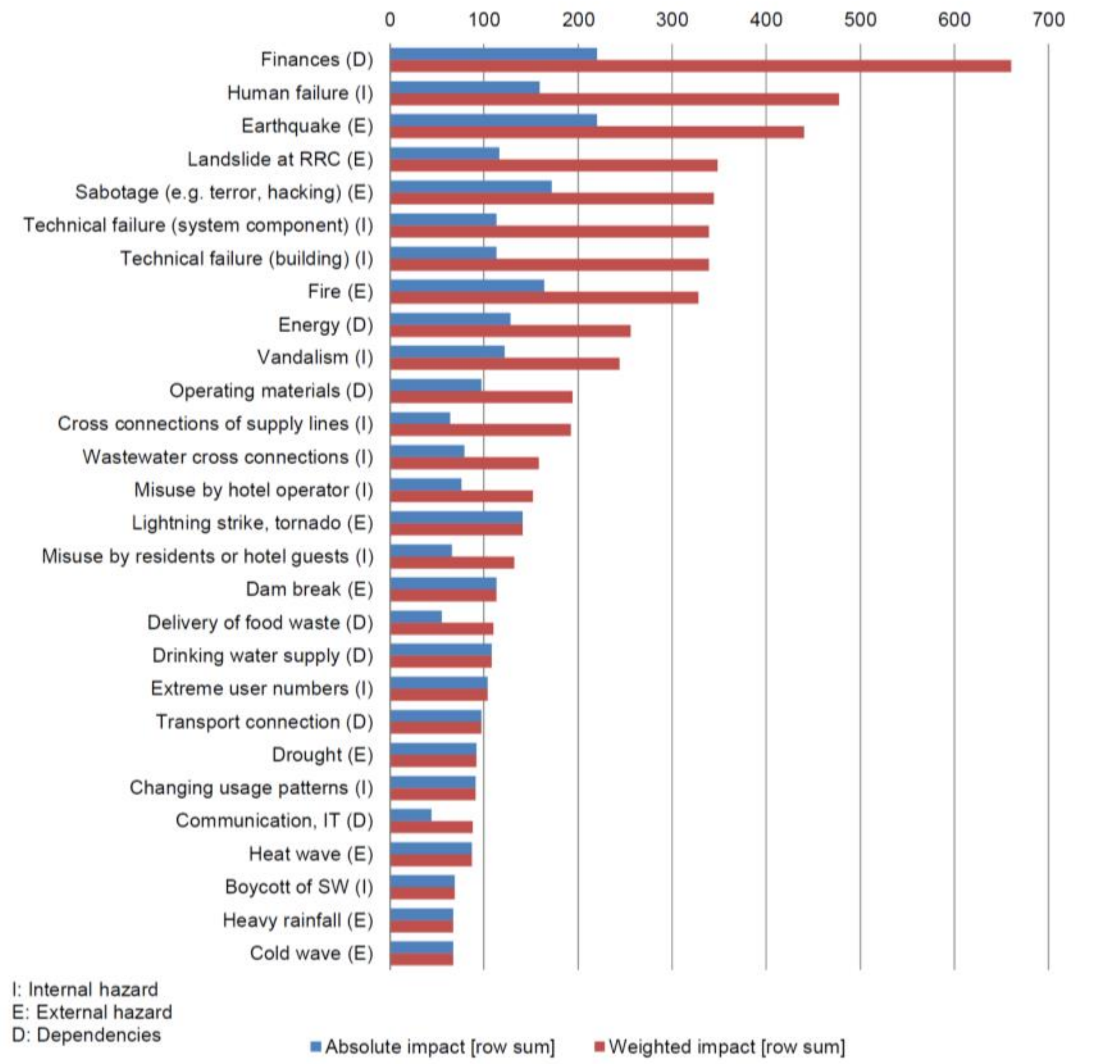

Figure 4: Impact of hazards on the vulnerability of components of the semi-centralized system (based on [20,21])

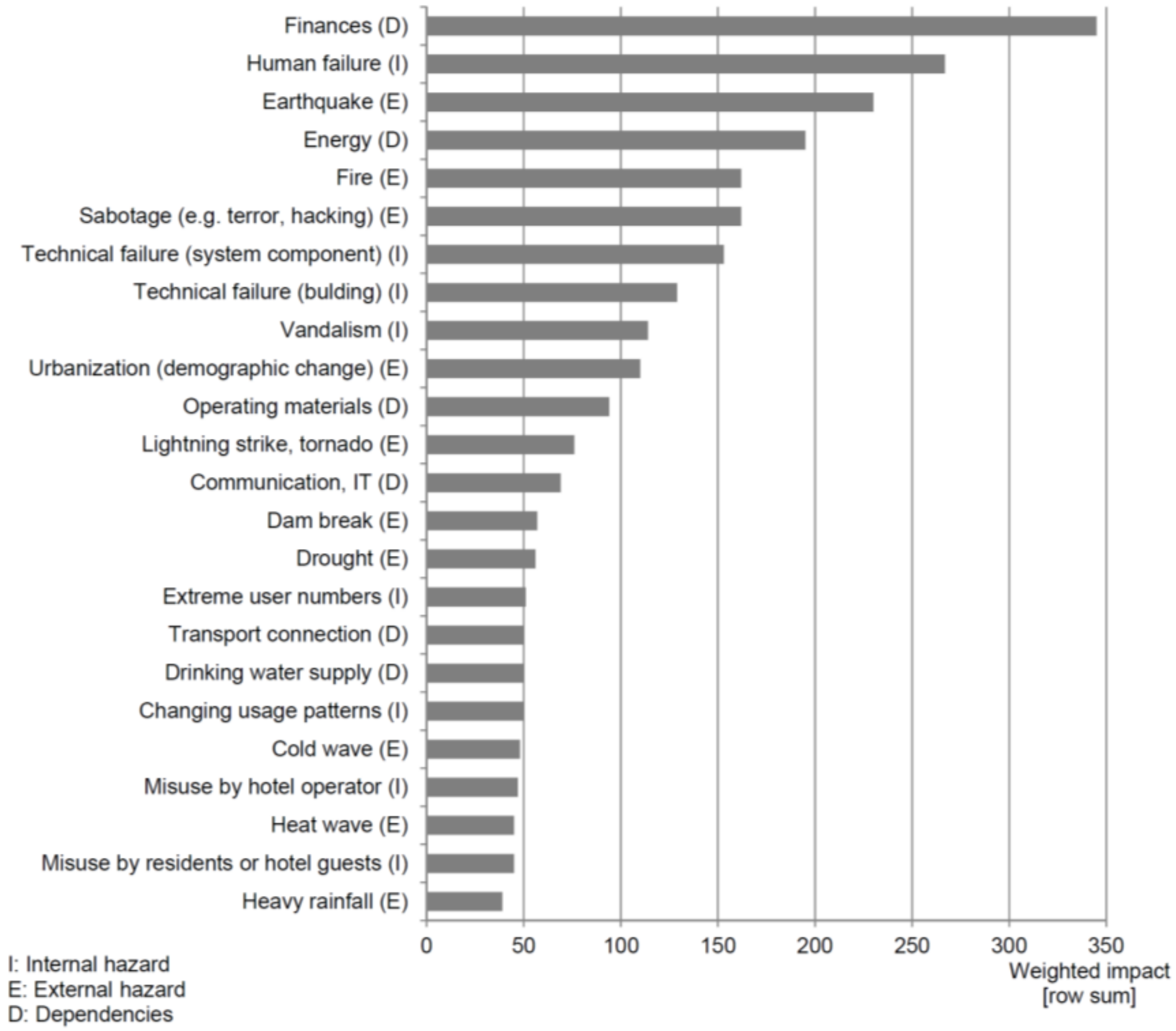

Figure 5: Impact of hazards on the vulnerability of components of the centralized system

Apart from the fact that certain hazards only apply to the semi-centralized (e.g. landslide at the RRC, cross connections) or the centralized system (e.g. urbanization), slight differences can nevertheless be seen in the results. First of all, semi-centralized systems seem to be less affected by external hazards such as natural hazards than centralized ones. This applies particularly to droughts and cold waves. Secondly, regarding internal hazards, semi-centralized systems seem to be better able to compensate for extremes in the number of users (due to holidays or events) and changes in the patterns of use (e.g. changing drinking or service water consumption). However, other internal hazards seem to affect semi-centralized systems more than centralized ones, especially technical failure and misuse. Thirdly, semi-centralized systems are more independent of other infrastructures than centralized ones. This applies in particular to energy supply and communication/IT.

Another finding of the vulnerability analysis relates to the dependency of system components on hazards regarding both the semi-centralized and the centralized system. Vulnerabilities of RRC or WWTP components are more susceptible to hazards than other parts of the system (cf. [20]). The components located in buildings in the catchment area (residential areas, hotels, offices) are least dependent, while sewers and pipelines have a medium dependence. This is mainly due to the fact that local hazards have the potential to render individual RRC or WWTP components inoperable, while it is highly unlikely that this will be the case for all components in the catchment area (such as toilets) at the same time.

At a higher level, it must be emphasized that 5 to 6 semi-centralized systems are required for an appropriate comparison in order to serve the same number of users as the centralized one. Apart from the above mentioned benefits of semi-centralized systems (e.g. service water and energy production), it can be assumed that their modular architecture alone makes them more robust in terms of hazards than centralized systems. In particular, they can adapt more flexibly to changing conditions such as urbanization and population growth. Furthermore, such systems can be more cost-effective, for instance in the development of new districts, as investments can be made in stages (adapted to the population growth) and less capital costs are necessary.

Conclusions

By comparing the vulnerabilities of semi-centralized and centralized urban water infrastructures, their strengths and weaknesses could be shown. By doing so, the question could be answered under which conditions the different system approaches are more prone to hazards and undesired effects. Since such a comparison has not yet been carried out, the results presented here contribute to a better planning and operation of urban water systems in general, but in particular to future replications of semi-centralized systems.

It can be concluded that vulnerability management measures need to focus on minimizing vulnerability by either preventing hazards that can be influenced or by strengthening the resilience of the identified system components. Specific hazard scenarios need to be examined with regard to the semi-centralized system, in particular cross connections of supply and disposal pipelines, a boycott of service water and dependence on the supply of food waste.

It must also be taken into account that certain effects and causes are outside the selected system boundaries. The users and operators of the system (residents, hotel guests and staff) have a considerable influence on the functionality of the system. For this reason, it is particularly important to identify specific measures to minimize health risks in the case of the semi-centralized system, such as those arising from cross connections [22]. In this respect, measures such as technical solutions (e.g. color coding, different threads) or training of craftsmen and other staff members can make a contribution.

In a second phase of the vulnerability analysis, the effects of system components’ failures on the vulnerability of other system components will be compared between the semi-centralized and the centralized system. This allows the system components that are most susceptible to the failure of other system components to be identified in both cases.

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Optimization method for sustainable wastewater treatment systems in the population declining society

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Key words

Wastewater treatment system, Population declining, Operating rate, Sustainable, Maintenance cost

Introduction

In japan, local governments have adopted the waste water treatment system which is suitable for their regional condition. The wastewater treatment service ratio in Japan has reached to 90.4% as of FY 2016. New installment of wastewater treatment system is still needed for remaining non-service area. But now, the maintenance of existing facilities and the reconstruction / renewal of aged facilities has become main work. In Japan, a lot of wastewater treatment facilities have been constructed along with the high economic growth period.

According to the local conditions including the population density, the centralized piping system for urban area (sewage) and for rural area (agricultural community effluent), and non-piping collection system (human waste treatment which collects and treats night soil) are serving as major domestic wastewater/waste collection and treatment systems in Japan. They occupy approximately 90% of the total wastewater treatment (sewerage 78%, agricultural community effluent 3%, human waste treatment facilities 9%).These facilities contribute greatly to improve the living environment of residents.

Meanwhile, the overall population of Japan, which had been increasing until around 2010 but has been declining recently, is expected to fall from the present level of about 130 million to about 88 million in 2065, according to the median value estimate by the National Institute of Population and Social Security Research, which means that the service population of wastewater treatment also will decrease.

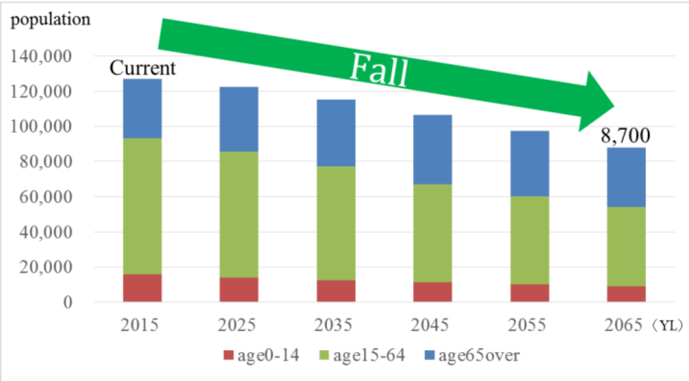


Figure-1 Future population estimation of japan

The decrease of the service population and then its sewage inflow will result in the following difficulties.

- The operation efficiency of the facilities with lower inflow volume than the designed capacity could be decreased.
- The revenue from user-fee would also be decreased.
- The situation of local governments, in addition to the shortage of financial resources and the shortage of technical staff, will face problems such as increasing demand for the reconstruction / renewal of aged facilities in the near future.

The sustainability of the service is now on crisis. These difficulties are expected to occur especially in small cities.

Therefore, it is necessary to introduce sustainable wastewater treatment system especially in small cities. As shown in Figure-2, it is necessary to consider reducing the facility size (downsizing) according to the decrease in inflow at the reconstruction / renewal. Additionally, it is also important to study integrating multiple treatment areas and difference type of treatment systems (for example, integration of sewerage and agricultural community effluent).

Currently, available cost functions related to the construction and maintenance of wastewater treatment facilities are not considering the declining population (decreasing operating rate). Also, there is no systematic optimizing method to study the integration of multiple treatment areas, including different type of wastewater treatment systems.

Thus our group have been conducting research on the efficient (sustainable) wastewater treatment systems in the population declining society.

In this paper, our group report the research results about the relationship between the operating rate and the maintenance cost (and the power consumption), and the estimation method of the maintenance cost in the future when the operating rate will decrease. Also, our group report the optimization method of wastewater treatment systems from the comprehensive viewpoints including the economical, technological and environmental ones in the population declining society.

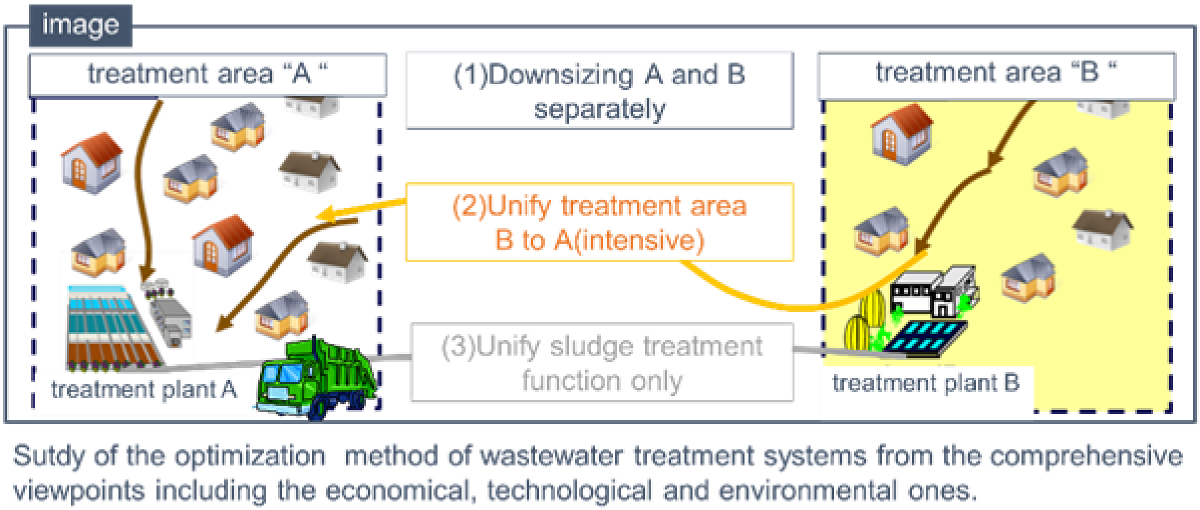


Figure-2 Concept of optimization for sustainable wastewater treatment systems in study

Material and Methods

2.1 Examination of calculation method of cost in case of the reconstruction / renewal facilities

In this research, for sewerage, agricultural community effluent, and human waste treatment which collects and treats night soil, especially, small to medium-sized treatment plants which would be sensitively affected due to decrease in inflow with the population declining were targeted. Regarding the capacity, 10,000 m^3 / day or less in the case of sewerage, 1,000 m^3 / day or less in the case of agricultural community effluent, 100kl/day or less in the case of human waste treatment plants were targeted. Regarding the treatment process, those accounted for about 80% of the total were targeted, which the sewerage were oxidation ditch process (OD) and conventional activated sludge process (CAS), the agricultural community effluent were JARUS-Ⅰ,Ⅲ,ⅩⅠ,ⅩⅡ,ⅩⅣ. Since the number of human waste treatment facilities was smaller than that of sewerage and agricultural community effluent treatment, the treatment process of human waste treatment was not distinguished. Regarding sludge treatment, the examination of the process up to dewatering was carried out.

(1) Collection and creation of cost functions

Cost functions for the calculation of cost and energy were organized and created through past documents and questionnaire survey. Firstly, the organizing information about useful cost functions from past documents was conducted. Then, in order to newly create a cost function (such as cost function of 10,000 m 3 / day or less of sewage treatment facility etc) which have not be considered in past documents, renewal cost and maintenance cost (the renewal cost, the electricity cost, utilities expense, the inspection cost etc of main equipment※ in FY 2004) were organized. The number of questionnaire survey is shown in Table-1. Additionally, the lack information about the costs for maintenance was collected by questionnaire through hearing with companies.

※ Water treatment (pumps for inflow, blowers , stirrers , pumps for return activated sludge)
※ Sludge treatment (thickeners, dehydrators, deodorization equipment)

The maintenance cost for each capacity of each wastewater treatment facilities was calculated based on these survey results including the electricity cost, the labor cost, the utilities expense and the inspection cost. The electricity cost unit price and the labor cost was calculated as 15 JPY / kWh, and 7 million JPY / person / year, respectively.

	number
sewerage(CAS)	84
sewerage(OD)	27
agricultural community effluent	78
human waste treatment	72

Table-1 the number of survey facilities (FY 2004)

(2) Relationship between the operating rate and the power consumption

The relationship between the operating rate and the power consumption (and the maintenance cost) was summarized quantitatively.

1) Preliminary survey

First, the relationship between the operating rate and the total maintenance cost was confirmed using the results of survey which was mentioned above (Table-1).

In addition, for some of facilities ,we focused on the power consumption which was considered to be affected by the operating rate, and tried to grasp the change in the power consumption.

2) Detailed validation

Based on the results of the preliminary survey, detailed survey was carried out in order to clarify the relationship between the operating rate and the power consumption.

Table-2 the number of survey facilities (10years)

	number
sewerage(CAS)	125
sewerage(OD)	50
agricultural community effluent	71
human waste treatment	33

The relationship between the operating rate and the power consumption in the sewerage systems with 10 years (From FY 2004 to FY 2013) were organized using published materials. The same relationships in agricultural community effluent and human waste treatment facilities were examined by questionnaire surveys to their operators. In order to clarify the influence of the operating rate, the survey was targeted for facilities with stable operating conditions, which has passed five years or more after the start of service, have not changed their capabilities within the period , had not receiving sludge from other treatment plants , and so on. Table -2 shows the number of survey facilities. Using the results of this survey, the relation between the operating rate and the power consumption for the past 10 years at each treatment plant was sorted out.

The operating rate x is expressed by the following equation.

Operating rate $x^* =$ (average inflow volume) (m^3/day) / (the facility capacity) (m^3/day)

**At each facility, the ratio of facility capacity (adapted to design maximum daily wastewater flow) to average inflow rate is different in design, so maximum operating rate is also* *different. For example, in the case of sewerage facilities, the ratio of facility capacity and average inflow volume is 1: 0.7. Therefore maximum operating rate of sewerage facilities was set to 0.7.*

In order to simplify and clarify the influence of the operating rate, the power consumption was arranged as a coefficient by the following equation. This power consumption coefficient was defined as P-coefficient. The larger the P-coefficient indicates the more inefficient operation situation.

P-coefficient *kp(x)* = (Unit of power consumption at a certain operating rate x) (kwh/m^3)

/ (Unit of power consumption at the maximum operating rate) (kwh/m^3)

(3) Relationship between the operating rate and the maintenance cost

The relationship between the operating rate and the maintenance cost was found out using the survey result described above in (2) 1). In this process, the relation between the operating rate and the power consumption of each wastewater treatment facility was used. In order to simplify and clarify the influence of the operating rate, the maintenance cost was defined as a coefficient(M-coefficient) by the following equation simillar to the power consumption. The larger the M-coefficient indicated that the operation was more inefficient situation.

M-coefficient *km(x)* = (Unit of maintenance cost* at a certain operating rate x) (JPY/m^3)

/ (Unit of maintenance cost* at the maximum operating rate) (JPY/m^3)

** Unit of maintenance cost = (Annual total maintenance cost) (JPY/year) / (Annual total inflow) (JPY/m^3)*

M-coefficient was calculated by the following procedure.

- ✓ The power cost of each facility at a specific operating rate was extracted from the total maintenance cost by using survey results. In this step, the average value of surveyed facilities was defined as a specific operating rate.
- ✓ The power cost was recalculated in each operating rate. On the other hand, the cost of others was fixed because of its independence with the operating rate.
- ✓ Power cost for each operating rate was calculated, by using P - coefficient.

- ✓ Total maintenance costs of each operating rate were recalculated by adding the power cost of each operating rate and the others.
- ✓ Finally, made the unit of maintenance cost and further made it a coefficient.

2.2 Problems of acceptance of night soil or sludge

In considering the optimization method for efficient wastewater treatment systems, in order to confirm the problems of night soil and sludge acceptance, the questionnaire survey was conducted targeting 41 facilities which accepted night soil or sludge.

2.3 Optimization method for sustainable wastewater treatment systems

Based on the above survey (influence of operating rate etc.), the optimization method for the selection of the sustainable wastewater treatment systems, which can be utilized by local governments was considered. For the creation of this method, information from questionnaire survey and public information on local governments about preceding cases of optimization consideration were combined. A trial optimization process by this method was carried out by using the virtual city conditions in order to check its validity.

2.4 The model case study in real cities

In order to confirm the usefulness and improve the accuracy of the optimization method for sustainable wastewater treatment systems, model case studies targeted real cities were conducted. Four cities which have been already considered the optimum system were selected as the model. The model case study (optimization study) based on the optimization method created in this research was conducted by using various basic information (e.g. future water estimation) on the selected cities. The model cities was selected from the different regions. The comparison between the method which was adapted for the optimization of model cities and our optimization method was conducted to improve our method.

Table-3 cities selected as the model case study

region	name of city	optimization examined
Hokkaido	Obihiro	sewaage + sewage
Kanto	Isesaki	sewaage + agricultural community effluent ,human waste treatment
Chubu	Iizuna	sewaage + agricultural community effluent
Chugoku	Matsue	sewaage + agricultural community effluent

Figure-3 cities selected as the model case study

Results and Discussion

3.1 Examination of calculation method of cost in case of the reconstruction / renewal facilities

(1) Collection and creation of cost functions

As shown in Table-4, the main cost functions were sorted out in this survey. Functions to be applied to 10,000 m 3 / day or less at sewerage facilities, functions of human waste treatment facilities, functions of only machine equipment, etc. were newly created for applying the functions to various studies.

	facilities , equipment			variable (x)	usable range	function(y)
reconstruction / renewal cost [thousand JPY]	sewerage	CAS	●overall※	m^3/day	10,000～50,000m^3/day	$y = 1{,}550{,}000(x/1{,}000)^{0.58} \times (103.3/101.5)$
			mechanical	m^3/day	1,000～10,000m^3/day	$y = 72{,}734x^{0.26}$
			mechanical(water treatment)	m^3/day	1,000～10,000m^3/day	$y = 978x^{0.59}$
		OD	●overall※	m^3/day	～299m^3/day	$y = 14{,}680x^{0.49}$
			●overall※	m^3/day	300～1,300m^3/day	$y = 505{,}000(x/1{,}000)^{0.64}$
			●overall※	m^3/day	1,400～10,000m^3/day	$y = 1{,}380{,}000(x/1{,}000)^{0.42} \times (103.3/101.5)$
			mechanical(water treatment)	m^3/day	1,000～10,000m^3/day	$y = 1{,}580x^{0.66}$
		common function	sludge treatment	m^3/day	15～170m^3/day	$y = 112{,}140x^{0.26}$
			deodorization	m^3/day	1,000～10,000m^3/day	$y = 125{,}019x^{0.04}$
	agricultural community effluent		●overall	person	-	$y = 2271.2x^{0.6663}$
	human waste treatment	over all	standard process	kl/day	20～100kl/day	$y = 237{,}636x^{0.4571}$
		pretreatment equipment	standard process	kl/day	20～100kl/day	$y = 57{,}548x^{0.5274}$
	pipe	construction	●manhole type pumping station	point	-	$y = 9{,}200x$
			●gravity system	m	-	$y = 63x$
			●pressurized sewer	m	-	$y = 45x$
			●small scale	m	-	$y = 56x$
maintenance cost [thousand JPY /year]	sewerage	CAS	overall	m^3/day	1,000～10,000m^3/day	$y = 2{,}468x^{0.382}$
			●overall		10,000m^3/day～	$y = 18{,}800(x/1000)^{0.69} \times (103.3/101.5)$
		OD	●overall	m^3/day	300～1,300m^3/day	$y = 19{,}000(x/1000)^{0.78}$
					1,400～10,000m^3/day	$y = 28{,}600(x/1000)^{0.58} \times (103.3/101.5)$
	agricultural community effluent		●overall	person	-	$y = 37.811x^{0.6835}$
	human waste treatment	over all	overall	kl/day	20～100kl/day	$y = 17{,}845x^{0.57}$
		pretreatment equipment	overall	kl/day	20～100kl/day	$y = 6{,}716x^{0.2692}$
	pipe		●manhole type pumping station	point	-	$y = 220x$
			●pipe(standard)	m	-	$y = 0.060x$
			●pipe(small scale)	m	-	$y = 0.031x$

●The function described in the past document
*EUR/JPY=130.85(As of March 15, 2018)
*Including structures, machinery and electrical equipment

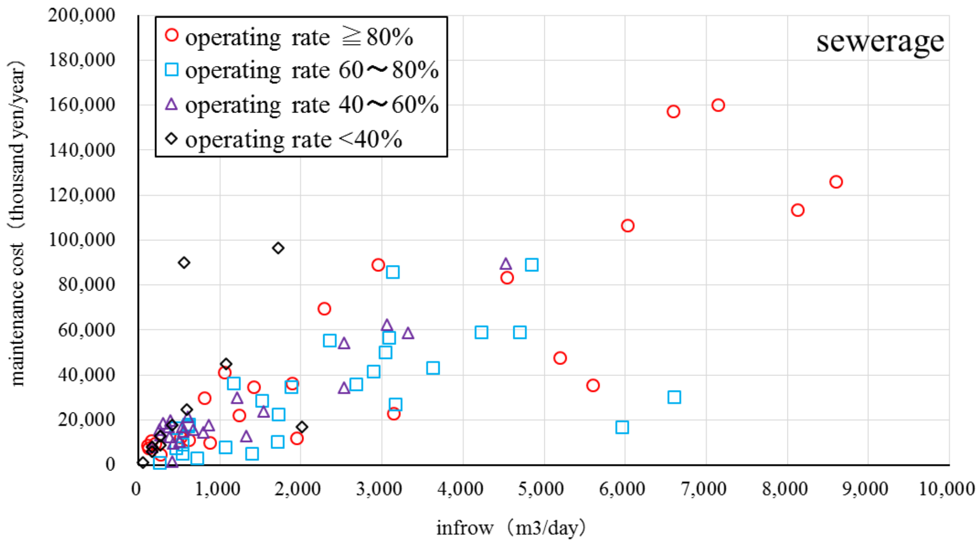
Table-4 the main cost functions

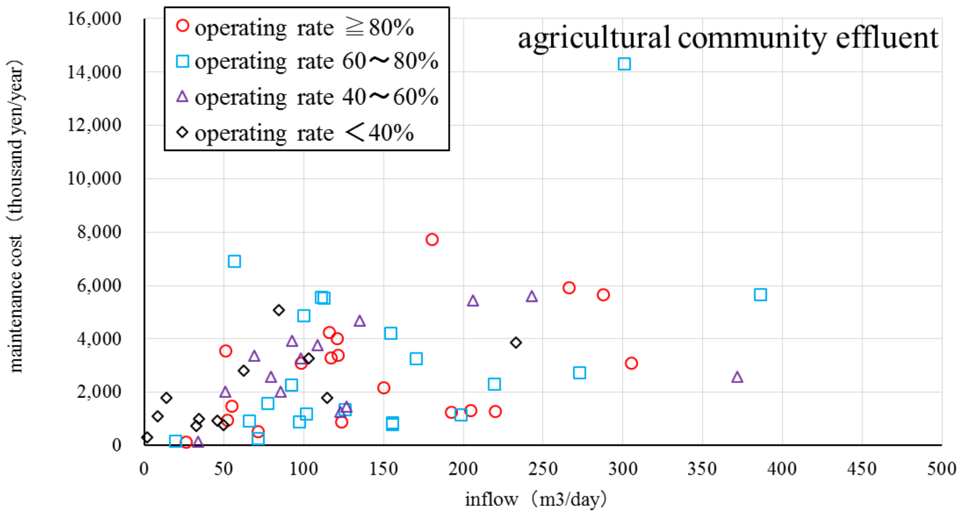
(2) Relationship between the operating rate and the power consumption

1) Preliminary survey

Fig-4 shows the relationship between inflow rate and the maintenance cost for different inflow. From these results, it was difficult to clarify the relationship between the operating rate and the maintenance cost.

On the other hand, Fig- 5 shows the relationship between the power consumption per inflow and the operation rate in each treatment facility. From these relationship, it was possible to confirm the tendency that the power consumption per inflow became smaller as the operation rate was higher. Considering these results, to clarify the influence of the operating rate on the power consumption, the detailed validation was carried out.





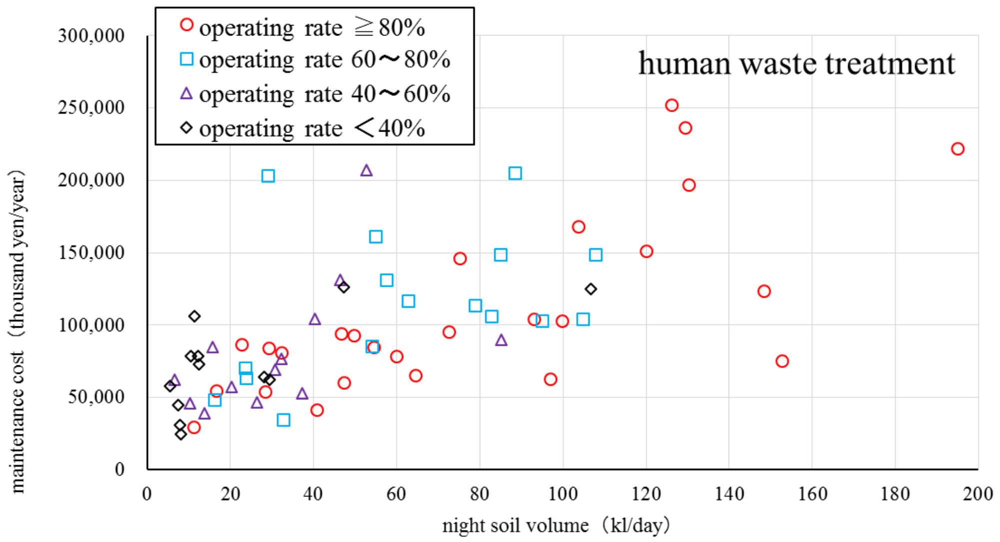
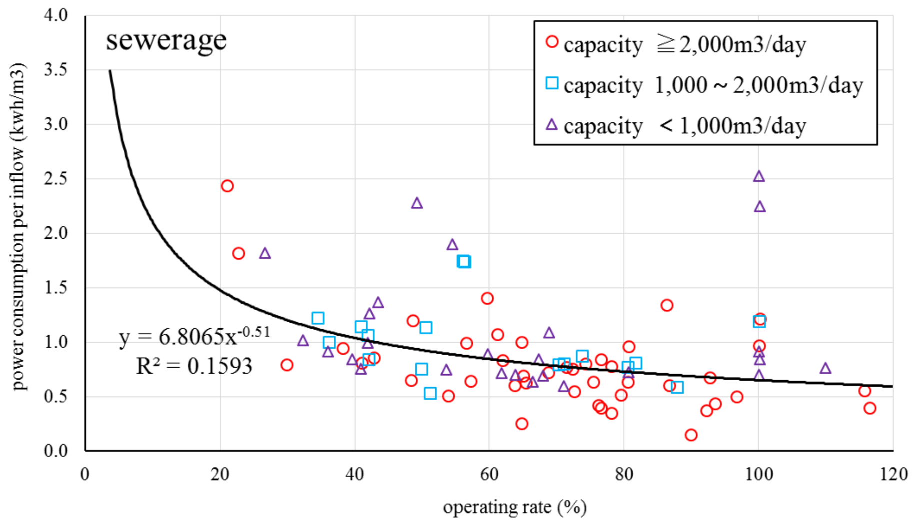
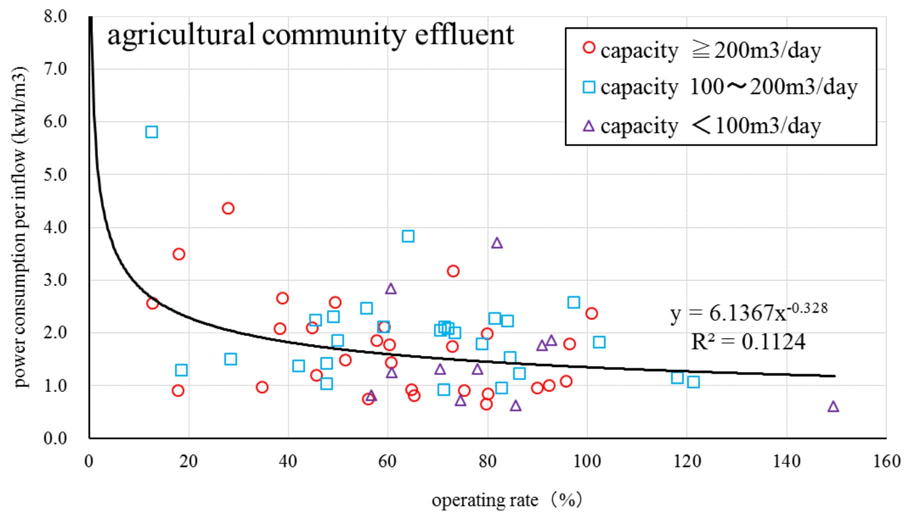


Figure-4 preliminary survey result (total maintenance cost)





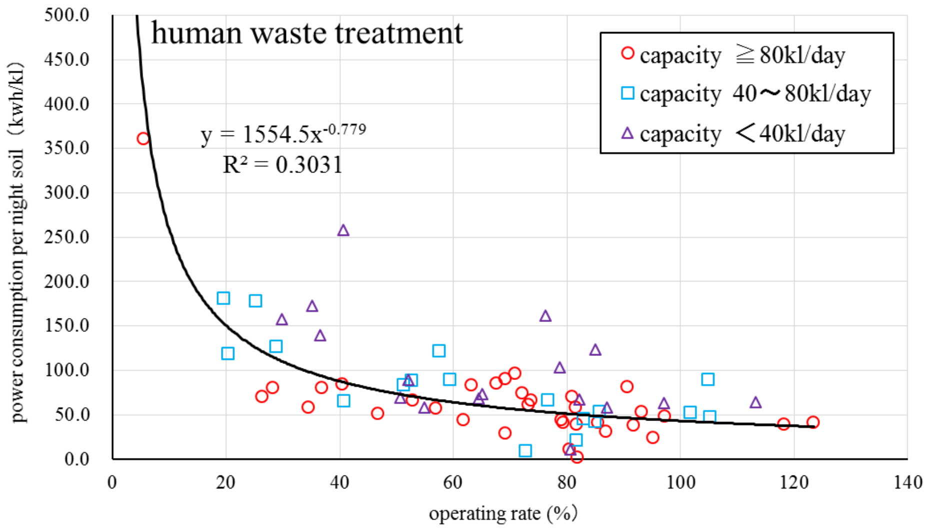


Figure-5 preliminary survey result (power consumption)

2) Detailed validation

The P coefficient for each inflow (operating rate) was calculated for each treatment facility, and the median value was taken as the P coefficient at each operating rate. Figure-6 shows the relationship between the operation rate and the power coefficient in each facility.

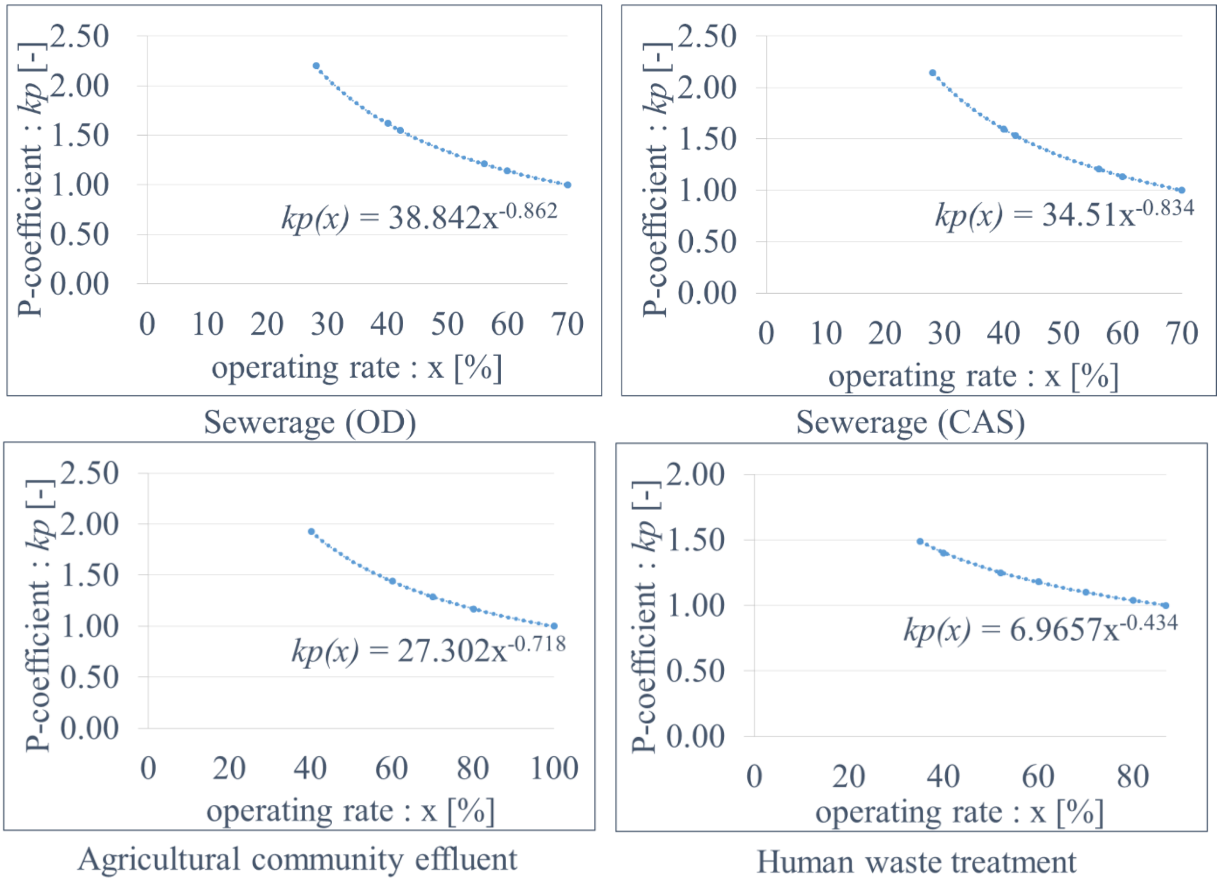


Figure-6 relationship between the operating rate and the power coefficient

The unit of power consumption and the power coefficient kp(x) increased as the operating rate x declined in each facility. Small and medium-sized facilities, which were the target of this research, often was not controlled aeration such as the control of the number of blowers against changes of the inflow.

Therefore, in these facilities, it could be considered that the power consumption did not decrease so much even if the inflow decreased. The fluctuation of P-coefficient in Human waste treatment facility was smaller than that of other facilities. It was thought that the amount of treatment in each day did not fluctuate so much, because Human waste treatment kept the collected night sole at once, and then treated it.

(3) Relationship between the operating rate and the maintenance cost

Table-5 Maintenance coefficient of OD

unit of the power costs (a) (JPY/m^3)

capacity[m^3/day] / operating rate(%)	1,000	2,500	5,000	7,500	10,000	P-coefficient
28 (40)	20.7	16.9	14.4	13.2	12.3	2.2
42 (60)	14.6	11.9	10.2	9.3	8.7	1.6
56 (80)	11.4	9.3	7.9	7.2	6.8	1.2
70 (100)	9.4	7.7	6.6	6.0	5.6	1.0

the power costs (A) (thousand JPY/year)

capacity[m^3/day] / operating rate(%)	1,000	2,500	5,000	7,500	10,000
28 (40)	2,117	4,307	7,370	10,092	12,612
42 (60)	2,240	4,556	7,796	10,674	13,340
56 (80)	2,331	4,741	8,112	11,108	13,882
70 (100)	2,406	4,894	8,375	11,468	14,332

the others (B) (thousand JPY/year)

capacity[m^3/day] / -	1,000	2,500	5,000	7,500	10,000
-	26,701	44,628	65,654	82,188	96,331

total maintenance costs (T=A+B) (thousand JPY/year)

capacity[m^3/day] / operating rate(%)	1,000	2,500	5,000	7,500	10,000
28 (40)	28,818	48,936	73,024	92,280	108,943
42 (60)	28,941	49,184	73,450	92,863	109,671
56 (80)	29,032	49,369	73,766	93,296	110,213
70 (100)	29,107	49,523	74,029	93,656	110,662

unit of the maintenance costs (JPY/m^3)

capacity[m^3/day] / operating rate(%)	1,000	2,500	5,000	7,500	10,000
28 (40)	282.0	191.5	142.9	120.4	106.6
42 (60)	188.8	128.3	95.8	80.8	71.5
56 (80)	142.0	96.6	72.2	60.9	53.9
70 (100)	113.9	77.5	57.9	48.9	43.3

Maintenance coefficinet

capacity[m^3/day] / operating rate(%)	1,000	2,500	5,000	7,500	10,000	**M-coefficient (average)**
28 (40)	2.48	2.47	2.47	2.46	2.46	**2.47**
42 (60)	1.66	1.66	1.65	1.65	1.65	**1.65**
56 (80)	1.25	1.25	1.25	1.25	1.24	**1.25**
70 (100)	1.00	1.00	1.00	1.00	1.00	**1.00**

*EUR/JPY=130.85(As of March 15, 2018)

Table-5 shows the calculation results of maintenance cost and the maintenance coefficient for each operating rate in the case of sewerage (OD) as an example. The relationship between the operating rate and the maintenance coefficient for each facility is shown in Fig-7. The increasing maintenance cost with the decline of operating rate was represented by using the relationship between the operating rate and M-coefficient in each facility. The slopes which was calculated using M-coefficien were almost the same, which would be attributable to the small occupation of the cost for power. From these results, the influence of operating rate was successfully quantified and clarified in this study.

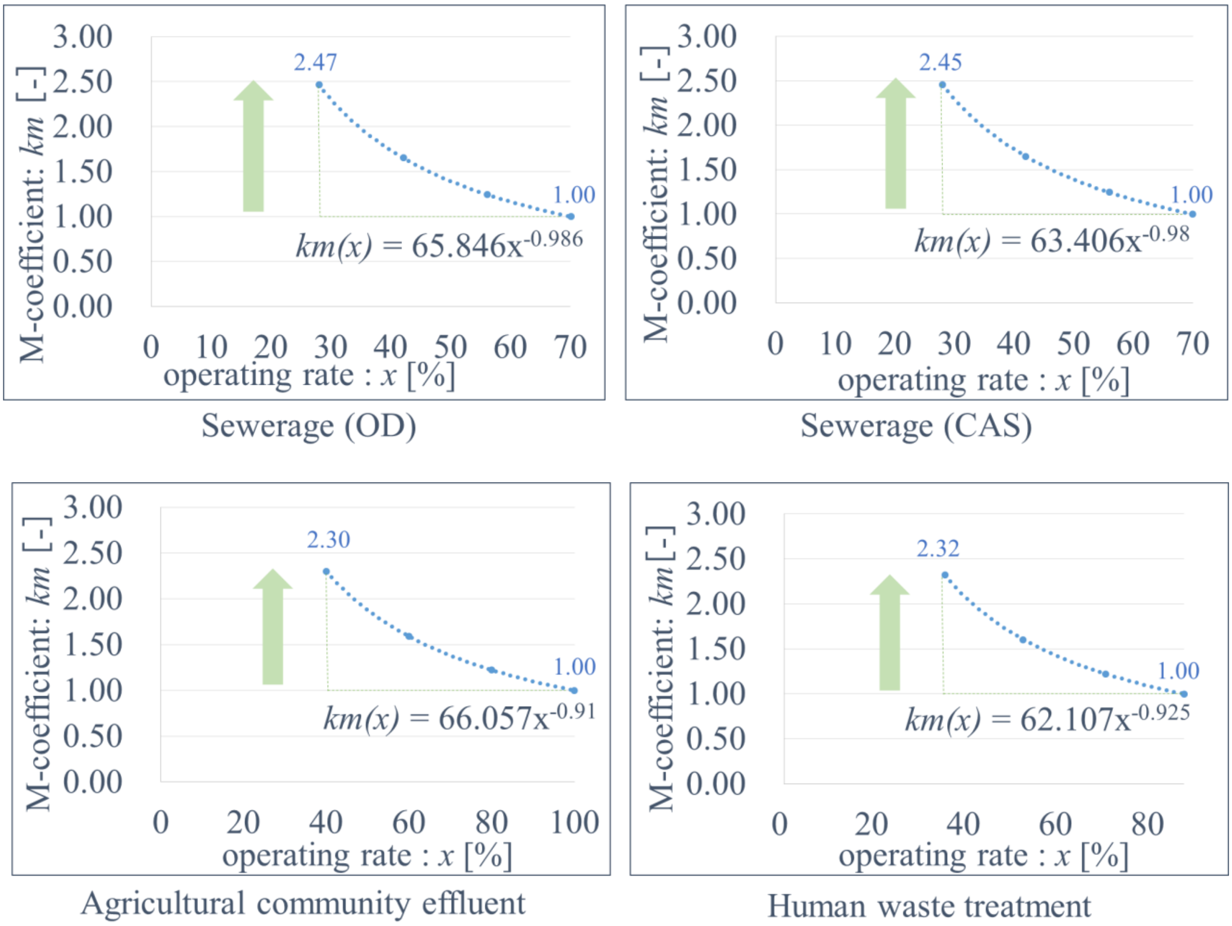


Figure-7 relationship between the operating rate and the maintenance coefficient

It would be possible to estimate the future maintenance cost by using the M-coefficient and the current operating rate, the current unit of maintenance cost and future operating rate. An example of estimating the future maintenance cost is shown in Fig-8. The cost estimation with higher accuracy than before would become possible.

1.Current unit of maintenance cost 65,000,000 / 1,000,000 = 65 JPY / m^3

2.M-Coefficient ratio (current and future) 1.65 / 1.00 = 1.65

3.Future unit of maintenance cost 65 × 1.65 = 107.25 JPY / m^3

4.Future maintenance costs 107.25 × 600,000 = 64,350,000 JPY / year

Reference: Estimated results without considering operating rate *Big difference*

65(using current unit of maintenance cost) × 600,000 = 39,000,000 JPY / year

Condition

Facility type	Sewerage(OD)
Current maintenance cost	65,000,000JPY/year
Current inflow	1,000,000m^3/year
Current operating rate	70%
Future inflow (estimate)	600,000m^3/year
Future operating rate	42%

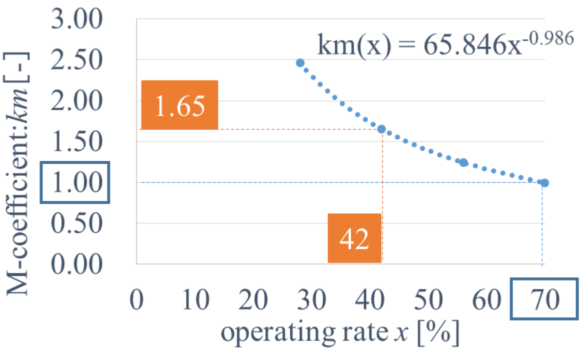


Figure-8 the future maintenance costs estimation example by using M-coefficient

3.2 Problems of acceptance of night soil or sludge

The results of questionnaire survey on problems of accepting night soil or sludge is shown in Fig-9. About 20% (8/41) of facilities which were accepting night soil had problems such as an increase in maintenance (cost / work) except for increase of sludge disposal cost. More than half of these 8 facilities with problems had a relatively high receiving ratio (received volume / facility design sludge volume before received) of night soil etc. (10% or more).

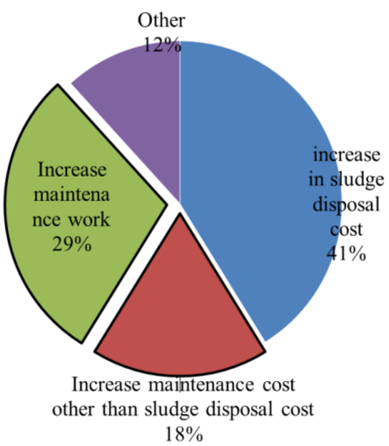


Figure-9 survey result

Therefore, in the case of accepting of night soil or sludge etc by facility integration, sufficient consideration is required. In the optimization method described later, as the technical confirmation, check the influence on that on existing facilities.

“In the case of accepting night soil or sludge etc, its receiving ratio should be considered.”

From the past survey, it was considered that stable treatment could be maintained if receiving ratio was 0.5% or less, but detailed investigation is required when receiving ratio exceeds 0.5%.

“The influence on water treatment such as alkalinity and load”

Particularly when the night soil is received using the sewerage, it is necessary to confirm the decrease in alkalinity due to the nitrification process. The following countermeasures should be considered.

- Switching to operation to suppress nitrification
- Recovery of alkalinity by promoting denitrification such as increasing return sludge ratio
- Use of calcium carbonate.

As a result of hearing survey to three facilities (Table-6), it was found that they had the following problems. These facilities accept sludge from agricultural community effluent facilities.

facility	facility design sludge volume before received (m^3/year)	received volume (m^3/year)	receiving ratio (%)
A	8,000	2,902	36%
B	1,500	532	35%
C	5,750	2,199	38%

Table-6 hearing facilities about receiving sludge

- Sludge dewaterability deteriorated (deteriorated by about 3%)
- Increase load on water treatment facility
- Increase odor

3.3 Optimization method for sustainable wastewater treatment systems

The optimization method was suggested in this study to select the sustainable wastewater treatment systems based on the comprehensive viewpoints including the economical, technological and environmental ones. The outline of its process flow is shown in Fig-10. Through this process, the most suitable one is selected from the three representative integration scenarios shown in Fig-11.

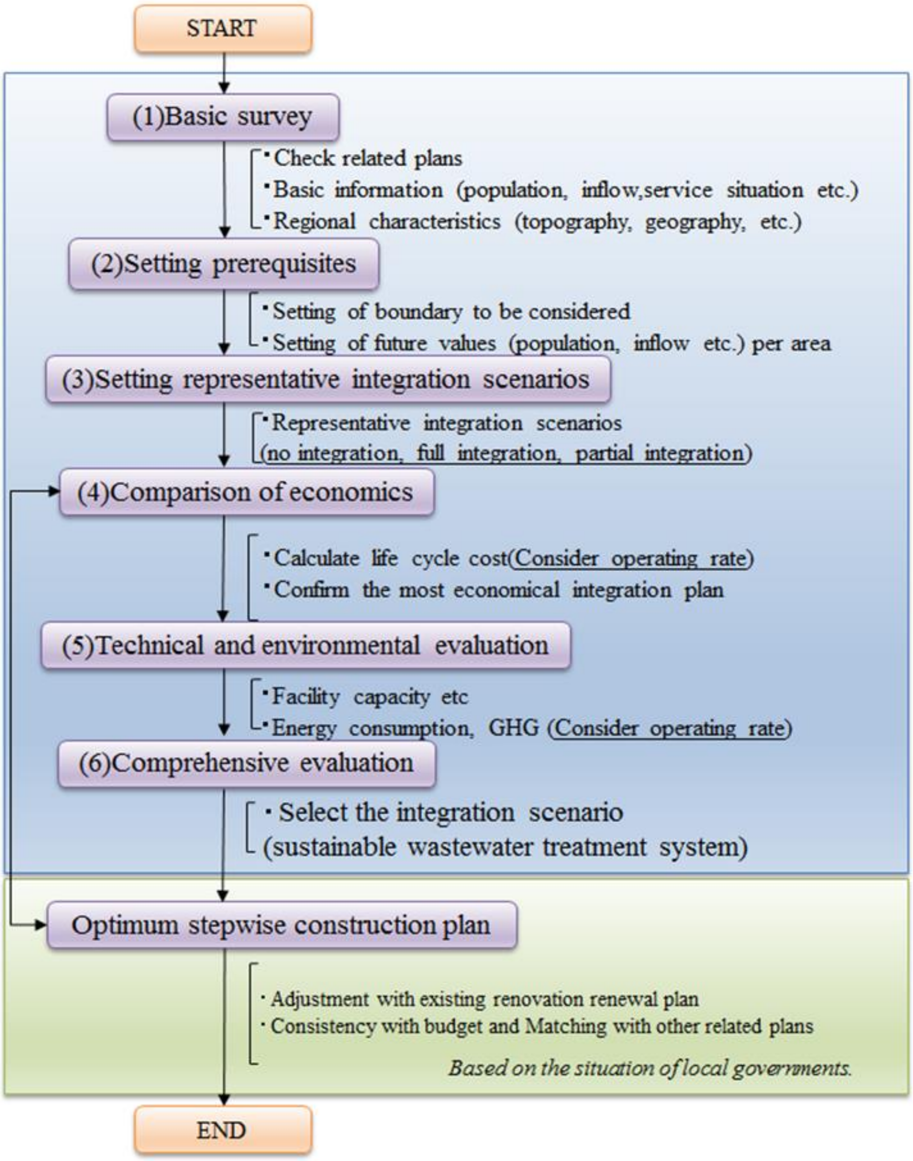


Figure-10 the outline of optimization method process

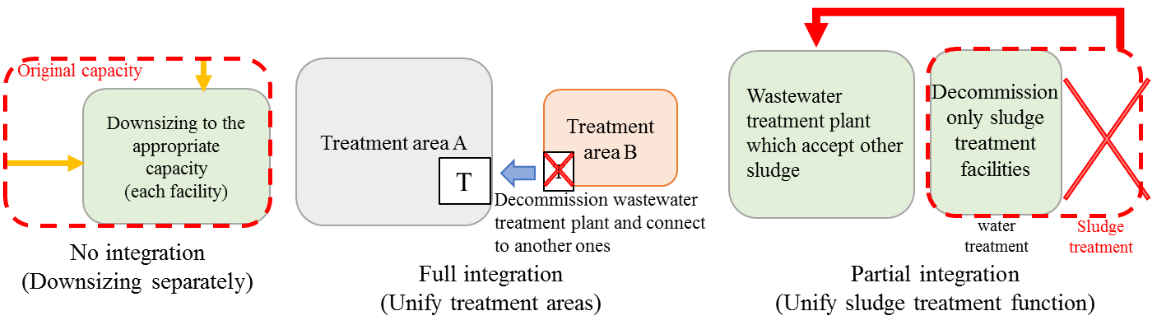


Figure-11 representative integration scenarios

The most efficient scenario should be selected by comparing the life cycle cost of each representative integration scenario. In this step, the cost should be calculated using the M coefficient based on the future change in the operating rate.

As a technical evaluation, important points for the examination in case of the integration is listed in Table-7. In the case of acceptance of night soil or sludge, sufficient consideration based on the receiving ratio as described in 3.2 was required.

Table-7 Check list for technical evaluation (some examples)

Sort	problems that must be checked
Pipe	Whether the flow capacity is satisfied or not
	Whether the flow velocity is satisfied or not
	(If the flow velocity isn't enough) How often the pipe cleaning is required
	If there is a part of force main, whether there is no problem with its structure.
pumping station	Whether the pumping capacity is satisfied or not
	Influence of sludge deposited in pump facilities
Wastewater treatment plant	Whether the capacity is satisfied or not
	When receiving night soil or sludge etc, its receiving ratio
	Also ,influence on water treatment such as alkalinity and load

Furthermore, regarding the environmental evaluation, the energy consumption and greenhouse gas emissions were calculated from the power consumption (using the P-coefficient), and the merit of sludge concentration by integration (increase of digested gas generation amount, etc.) was taken into consideration. On the other hand, for the integrating different types of wastewater treatment facilities, differences in energy consumption and discharge load (environmental loading) due to differences in their processing processes should also be considered (For example, in general, the quality of treated water of human waste treatment facility was worse than that of sewerage, although the total load per part was small.).

By using this optimization method, the sustainable wastewater treatment system based on the comprehensive viewpoints including the economical, technological and environmental ones would be selected.

A trial optimization process by this method was carried out by using the virtual city conditions in order to examine its usefulness. The virtual city had two treatment area (A and B) which treated sewage. And the design wastewater flow (future prediction) for 25 years from now is shown in Fig-12. Table-8 shows the current facilities capacity and operating rate of each treatment facility.

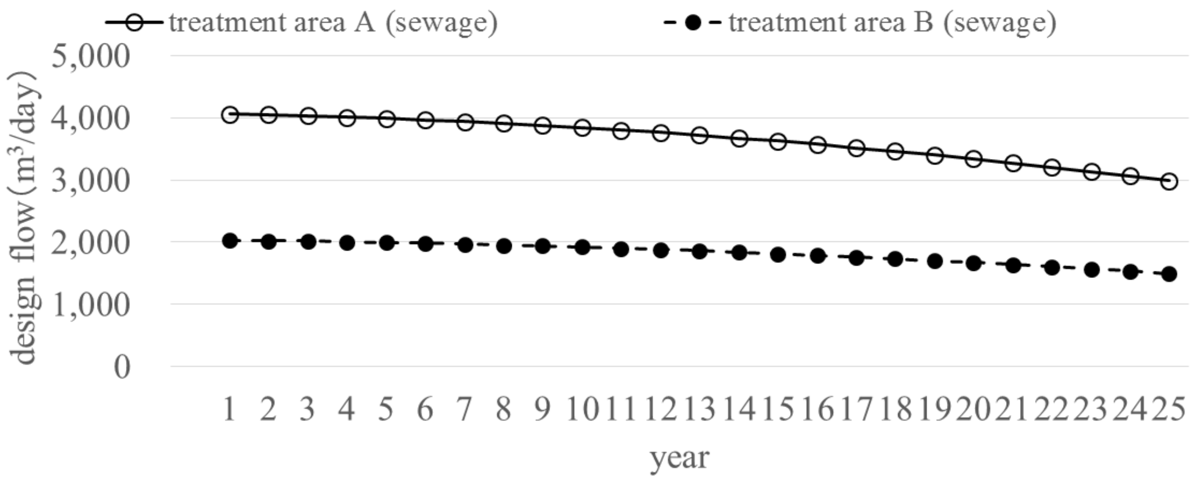


Figure-12 the design wastewater flow (in virtual city)

Table-8 the current facilities capacity (in virtual city)

	treatment plant A	treatment plant B
treatment process	sewerage (CAS)	sewerage (OD)
treatment capacity (m^3/day)	9,000	4,700
current inflow (m^3/day)	4,060	2,030
operating rate (%)	45	43

An example of the trial calculation result is shown in Table-9. The life cycle cost, capacity of sewage pipes and treatment plants, energy consumption and greenhouse gas emissions were also evaluated based on the optimization method. In this example, the approach "Unify treatment area B to A (full integration)" was found to be the most efficient. Considering the renewal schedule of each facility for the selected scenario, an optimum stepwise construction plan was developed as shown in Fig-13.

Table-9 Example of trial optimization result (in virtual city)

Factors		scenario 1	scenario 2	scenario 3
Overview		Downsizing A and B separately (no integration)	Unify treatment area B to A (full integration)	Unify sludge treatment function only (partial integration)
Costs (25years)	Total cost	5,879 million (JPY)	4,368 million (JPY)	5,016 million (JPY)
	Cost per year	235 million (JPY)	175 million (JPY)	201 million (JPY)
Technological		-	the capacity of the pipe etc	the capacity of the treatment plant etc
Environmental (25years)	Energy consumption	120 million(Mega joules)	109 million(Mega joules)	116 million(Mega joules)
	GHG emissions	16,732 (t-CO_2)	15,116 (t-CO_2)	16,144 (t-CO_2)
Evaluation results		△	◎	○

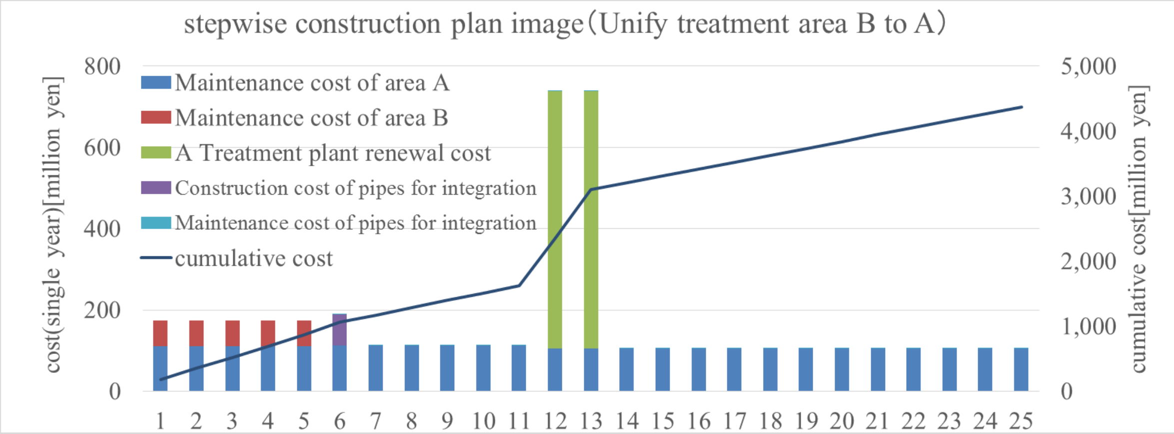


Figure-13 Example of stepwise construction plan (in virtual city)

3.4 The model case study in real cities

The examination about the model case in case of real cities were conducted to confirm the validation and to improve the optimization method. As a result of comparing the examination based on the optimization method and the ones done by the model cities themselves, the selected integration scenario was the same in both methods, even though the used cost function and examination methods had some differences. An example of the model case study is shown in the Table-10.

Table-10 An example of the model case study result (matsue city)

	our method		matsue city	
	(1)No integration	(2)Full integration	(1)No integration	(2)Full integration
Cost (milion yen/year)	36	5	30	15
	Consider the operating rate, also use a new cost function.		*Don't consider the operating rate, use only the past cost function.*	
Technological	–	capacity of treatment,pump,pipe	–	capacity of treatment,pump,pipe
Environmental (per 30years)	Energy consumption 865,300(Mega joules) GHG emissions 167,532(t-CO_2)	Energy consumption 846,703(Mega joules) GHG emissions 163,931(t-CO_2)	–	–
Evaluation results	"(2)Full integration" should be selected.		"(2)Full integration" should be selected.	

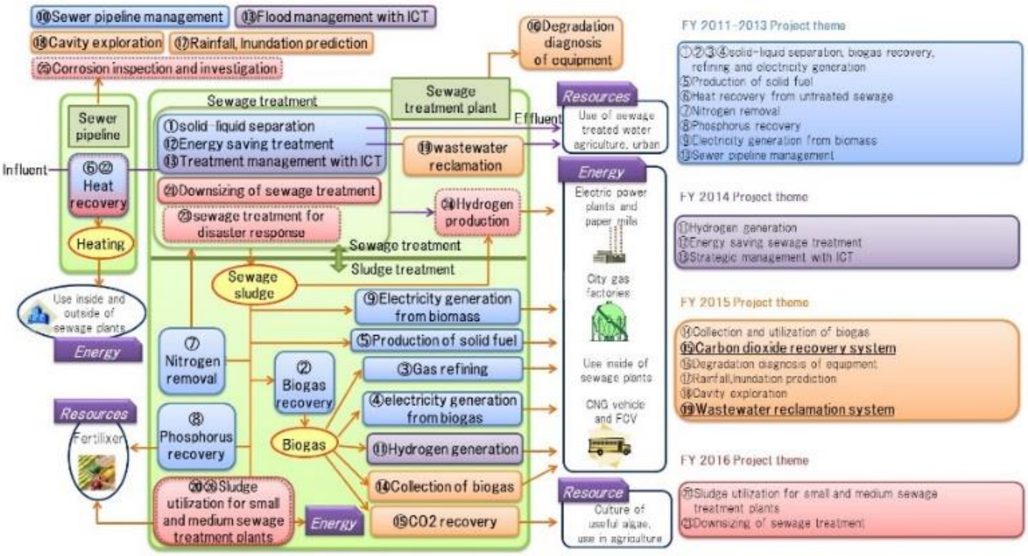
The examination which was done in the model city was also included roughly in the optimization method. Furthermore, the optimization method made it possible to carry out more detailed evaluations such as calculating the cost and energy consumption taking into consideration the operating rate, evaluating technical and environmental, etc.

According to the procedure of this method, the suitable scenario would be able to select, without requiring highly specialized knowledge (for example, local government officials who are unfamiliar with the examination), as in the case of this model case study, It is possible to simply select the optimum integration scenario. In this way, it was confirmed that this method could be a useful tool for establishing an optimal wastewater treatment system for operators such as local governments.

Conclusions

- The relationships between operating rate and power consumption and operating rate and maintenance cost were confirmed.
- The tendency which the unit of power consumption and the unit of maintenance cost increased with the operating rate declines in sewage system, agricultural community effluent and human waste treatment were confirmed.
- The maintenance coefficients were suggested to express the relationships and to estimate the maintenance cost in the future when the operating rate would decrease in the population declining society. These results would be fundamental knowledge for considering the optimization of the overall wastewater treatment systems.
- The optimization method for sustainable wastewater treatment systems was developed based on the above findings, and its validity was examined through a trial optimization in the virtual city conditions.
- The usefulness of the optimization method was confirmed and that of the accuracy was also improved by examination of the real cities.
- These results will be published as technical documents in order to support the local governments to select their suitable approach (for example, "Downsizing separately", “Unify individual facilities", etc.) for the optimization of sustainable wastewater treatment systems in each region from the comprehensive viewpoints including the economical, technological and environmental ones in the population declining society.
- This would contribute to the investigation of optimization of sustainable sewage treatment systems, especially by small local governments, where technical personnel are decreasing. In other words, it will be expected to contribute to the establishment of a sustainable society by promoting optimization study and implementation of wastewater treatment systems in Japan.
- In Japan, there are various other measures to support local governments. (B-DASH project as shown Figure-14 etc.). In order to establish a sustainable sewage disposal system, not only this technical document spread local government and it will be

improved to a better one, in the medium to long term, it is necessary to consider creating a method in cooperation with other works.



Figure

-14 New innovative sewer technology developed through B-DASH project

Are we prepared? Development and Assessment of Emergency Water Supply Preparation Planning

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Abstract: The provision of drinking water, when the performance of water supply system is limited or inoperable, represents a major and increasing challenge to water utilities and municipalities. The proposed emergency water supply preparation planning approach consists of the five steps: preliminary planning, risk management, preventive measures, crisis management and evaluation. The steps are characterized by different elements, such as the determination and update of a risk analysis or practical exercises of inter institutional response. To identify the need for action, the state of emergency water supply planning has been assessed in over 360 German municipalities. The German case reveals that, with focus on urban areas, emergency water supply preparation planning needs to be established in municipalities worldwide to ensure drinking water supply in all phases of emergencies.

Keywords: Disaster Management, Municipality, Water Security

BACKGROUND

The availability of water supply contributes to a high living standard, both in urban and rural environments. In developed nations water supply is meeting the demanding standards of its population under normal conditions, i.e. if the organizational and operational resources selected by the supplier are sufficient. The permanent availability (coverage, quantity, quality and continuity) of drinking water is of high societal relevance (The Sphere Project, 2011). Hence, water supply is considered a critical infrastructure.

Water supply systems in cities are usually centrally organized and linked together with other critical infrastructures, such as the power supply. Natural or man-made hazards can influence critical infrastructures and lead to cascading effects with adverse impacts, for example the unavailability or pollution of drinking water.

If, in the event of an emergency, a limitation or a failure of the public water supply can no longer be avoided, alternative supply measures need to be considered. This can be done, for example, in the form of temporarily laid connecting pipes to receive water from neighbouring utilities, by the use of water transport vehicles or by the provision of packaged drinking water.

To ensure the proper functioning of such alternative supply measures and to ensure the availability of drinking water in the required amount and quality – during any phase of an emergency - municipalities need to provide an emergency water supply preparation planning.

METHODS

In order to maintain drinking water supply in emergencies, the basic structures and processes involving the various stakeholders have to be planned and implemented responsibly (Birkmann et al., 2016). This paper identifies the necessary structures and processes and highlights significant elements in order to provide water in all phases of the emergency.

Additionally the paper presents the state of emergency preparedness planning in the water sector in Germany identified by a survey with a multi-stakeholder participation approach of 360 German municipalities. The stakeholders include public authorities on community up to federal state level, emergency management departures, health

care, as well as water utilities, which are also diversified by small, medium and large enterprises. The aim of the survey was to generate a scientifically founded information basis for the analysis of existing and additionally needed preparation concepts for various actors in the emergency sector from authorities and water supply companies as a basis for successful emergency care planning.

RESULTS

The regarded framework, adapted from BBK (2016), proposes an approach with five steps to address preparation planning in order to provide drinking water in any phase of an emergency (see Figure 1). A thorough preliminary planning creates the prerequisites for the successful implementation and establishment of a risk and crisis management as well as emergency preparedness planning. This includes determination of responsibilities for the implementation process as well as the possible emergencies characterised in scenarios. The generation of risk awareness indispensable, as the acceptance and motivation of all stakeholder, is necessary. The risk analysis, as the second element, is the key element of the emergency preparatory planning. It considers the reasons and causes of hazards on water supply systems, examines the consequences and determines the framework in which these consequences can occur. Crisis management incorporates preparation tasks before an emergency occurs, such as developing arrangements for coordination, stockpiling of equipment and supplies and associated training and field exercises rather than just the operational phase during the emergency.

To assess the state of preparation planning and to identify weak spots, the conducted survey includes the participation of more than 360 municipalities, which embodies over half of the population of Germany. Survey results suggest that concepts and measurements of emergency water supply of the municipalities vary considerably in Germany, especially concerning preventive measures. Not all authorities are aware of the scope of their responsibility, and the preparation for such events is often inadequate.

SIGNIFICANCE OF STUDY

The accumulation of extreme weather events (heavy rain or dry periods), increasing digitization and dependency on power supply and ICT, as well as the current security situation present new challenges to the supply infrastructures. Some potential hazards, such as long-term power cuts, are difficult to be narrowed down spatially and require comprehensive preparation planning.

This paper presents selected results on awareness and improvements, related to emergency water supply preparation planning, which so far have not yet been available and provide basic insights for the development of new strategies for emergency preparation planning in the water supply sector.

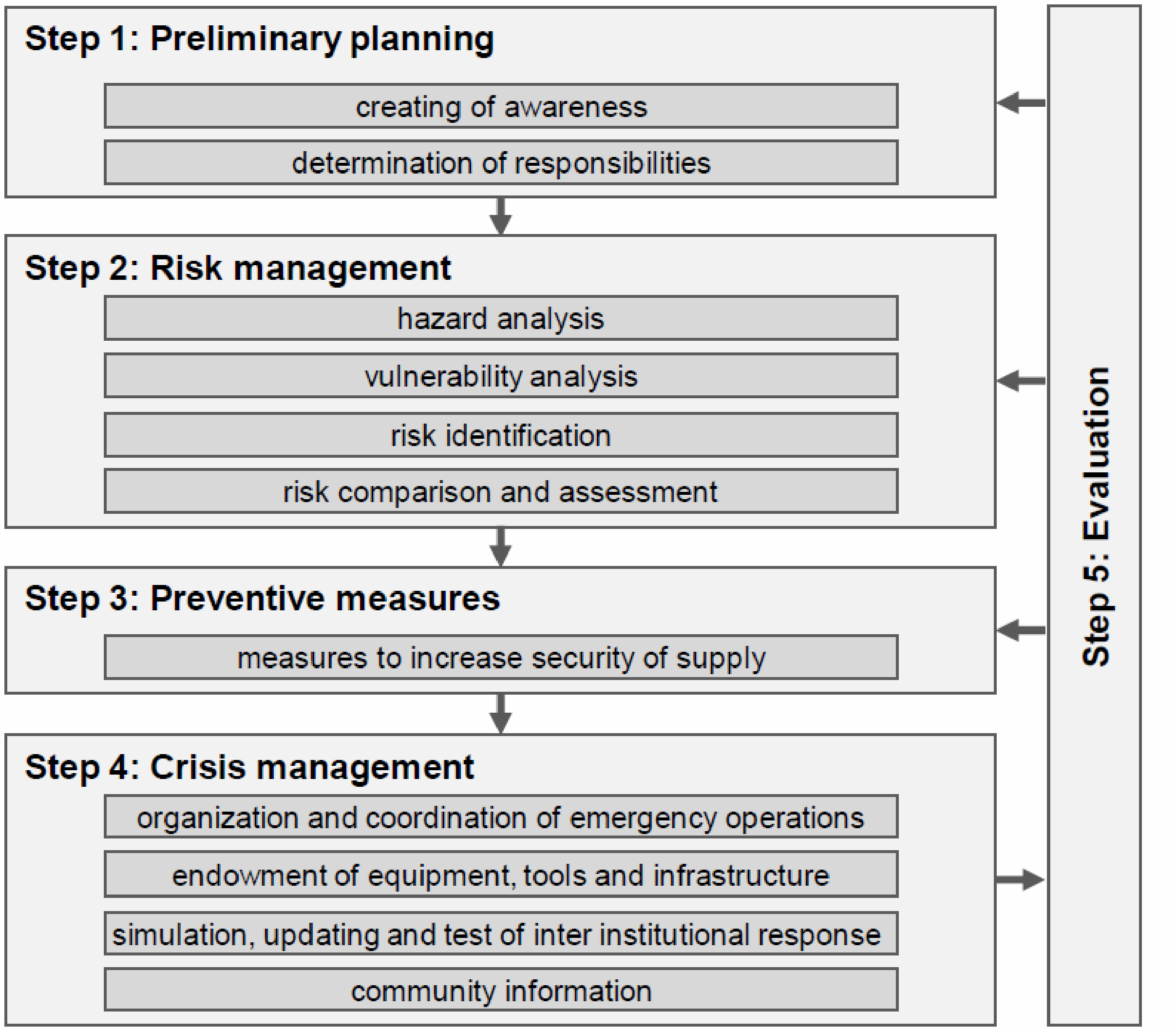

Figure 1: Five steps of emergency water supply preparation planning (adapted from BBK, 2016)

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Resilience adaptation pathways for near-term and long-term management of urban wastewater systems

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Keywords: Adaptation pathways; dynamic assessment, green and grey infrastructure, resilience, uncertainty, urban wastewater systems

Abstract

Stormwater and wastewater drainage are essential services that provide society with urban areas safe from the health risks and material damage derived from inappropriate sanitation and pluvial flooding. Emerging threats and issues (e.g. climate change, population growth, rising environmental standards, lifestyle changes and affordability) and their associated future (large) uncertainties pose an unprecedented challenge to the performance of urban wastewater systems. This consequently become a barrier to accurately predicting and adequately informing decision-making processes to manage urban wastewater systems.

These threats often require approaches that embrace the possibility of failure whilst minimising its impacts and consequences; such views are generally included in the concept of resilience. In other words, urban drainage infrastructure needs to become more resilient to variable future conditions. Additionally, large uncertainties not only require a (clear) long-term vision of potential adaptation strategies, but also entail the need to assess adaptation and resilience of the system in the short-term in order to prevent any maladaptive lock-in.

In this study, a dynamic assessment of compliance and adaptability potential is carried out for a number of green, grey and hybrid strategies in a case study for a period of 35 years (from 2015 to 2050). The assessment approach comprises two sections: (1) Evaluation of the compliance of the strategies with three adaptation targets (sewer flooding, river flooding and CSO spills) for the domain of resilience across four different future scenarios. (2) Evaluation of adaptability potential which is defined as the regret indexes derived from the weighted aggregation of regrets for various performance objectives (I. Sewer Flooding, II. River

Dissolved Oxygen, III. River Ammonia Nitrite Nitrate, IV. Health & Aesthetics and V. River Flooding). It is noteworthy that each scenario consists of 7 epochs (i.e. 5-year transient scenarios) in 2020, 2025, 2030, 2035, 2040, 2045 and 2050.

The results indicate that the compliant domain of large stand-alone green infrastructure options (such as rain garden) was comparable to those of large stand-alone grey infrastructure schemes (such as sewer separation or sewer rehabilitation & centralised storage expansion). **Figure 1** illustrates an example representation of the dynamic assessment of 6 different strategies whilst considering two adaptation targets (sewer flooding and CSO spills). Green infrastructure strategies showed promising performance with low regret levels across scenarios, whilst enhancing the adaptation potential of grey infrastructure strategies applied to the case study.

It can be concluded from the results that by applying such dynamic assessment approaches, short-term actions can be complemented by the long-term components of the assessment, allowing planners to delay decisions and distribute investment efforts, so that the most suitable strategies (or combinations of strategies) are put in place to satisfy the needs of the present whilst being able to adapt to those of the future.

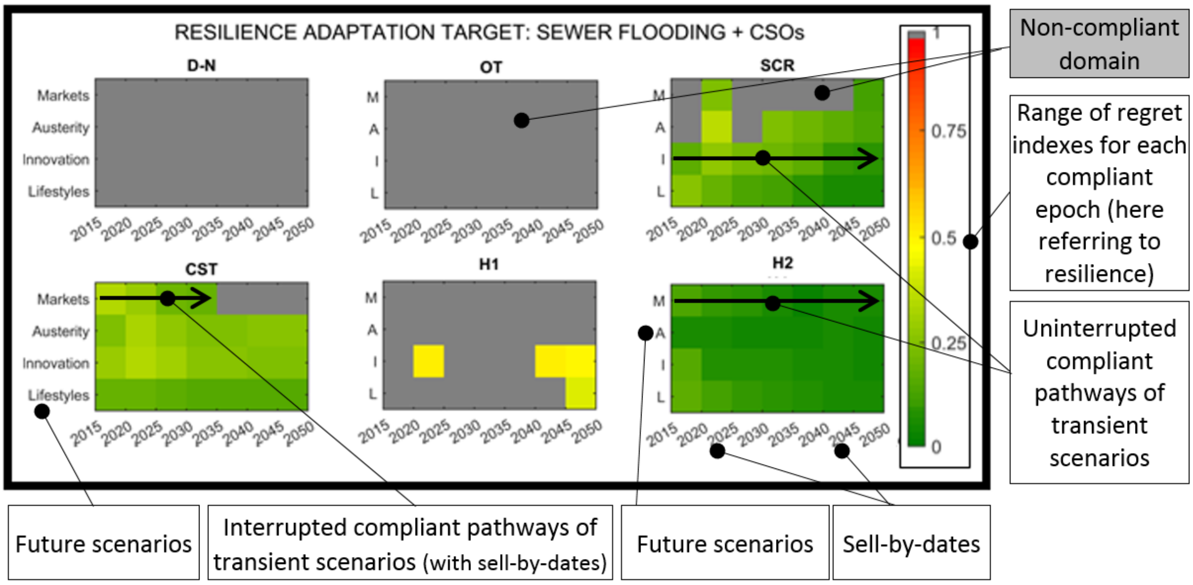

Figure 1: Resilience domains for sewer flooding and CSO adaptation targets of 6 adaptation strategies (D-N: Do-Nothing, OT: On-site Treatment, SCR: Source Control of Roofs, CST: Rehabilitation of Combined Sewer Infrastructure with a New Storage Tank, H1: OT + CST, and H2: SCR + CST). The compliant domain (coloured tiles) is described by resilience

scenario indexes for each epoch, ranging from low (green) to high regret (red). Non-compliant and full-regret epochs are shown in grey.

Wastewater resilience planning

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ABSTRACT

Wastewater Treatment Plants (WWTPs) are typically located at low points in watersheds or coastal and river areas. Many WWTPs have recently undertaken studies to assess vulnerability to more extreme flooding events due to climate change and sea level rise. Powerful storms have inundated WWTPs with storm surge, causing hundreds of millions of gallons of untreated sewage to spill into neighboring waterways. In response, U.S. WWTPs, including California’s 2.0 million gallons per day (MGD, average) Sewer Authority Mid-Coastside (SAM) WWTP, have developed resilience plans and increased infrastructure fortification against floods and storm surge.

The SAM WWTP performed an evaluation of its WWTP and pump stations infrastructure’s reliability against external hazards beyond the control of SAM, including natural hazards, malevolent threats, and failure of critical dependencies, and internal electromechanical failure due to general equipment failure, age and/or lack of redundancy. This evaluation was conducted using an approach that aligns with methodologies recommended by the Environmental Protection Agency for the vulnerability and risk assessment of wastewater treatment infrastructure. The selected methodology assesses risks associated with hazards to, or failure of, critical infrastructure, and identifies, quantifies, and relates a utility’s level of risk and resilience.

In this assessment, risk and resilience, respectively, refer to the likelihood of an asset to withstand an interruption and the ability of an asset to return to service after an interruption. Critical assets and resources were identified and assessed for current conditions and expected performance against their estimated remaining useful life. Hazards and resulting vulnerabilities to these assets were then ranked in terms of how their respective occurrence or failure could impact the functionality of the WWTP and pump stations, herein defined as consequence. Each hazard’s consequence was ranked against the expected likelihood of occurrence, or risk.

The assessment resulted in prioritized recommendations for improving the overall reliability of the WWTP while continuing to treat wastewater safely, reliably, and cost-effectively using the WWTP’s existing processes. Recommendations were made to improve operator and/or public safety were given a higher level of priority. SAM’s vulnerability assessment provides a comprehensive framework applicable to other WWTPs evaluating infrastructure resilience.

1 Introduction

Government bodies, taxpayers, utilities, consultants, and researchers have growing interest in the incorporation of resilience into wastewater management. Recent debates place resilience at the core of sustainability thinking, as systems need to become resilient to overcome future climate-related uncertainty. The concept of resiliency originated in the field of ecology in the 1970s; ecologists defined resilience as the capacity of an ecosystem to survive, adapt, and grow in the face of unforeseen changes. A system’s resiliency measures the system’s capacity to absorb disturbance while undergoing change so as to retain the same function, structure, identity, and response mechanisms [1].

The ecological definition of resilience is applicable to engineered systems. An engineered system is a combination of components that work in synergy to collectively perform a useful function. Such a system can be represented as a set of variables, with a particular structure and relationship. Figure 1 illustrates the conceptual representation of an engineering system within a resilience assessment framework. There are four elements that inform the resilience of engineered systems: stressors, properties, metrics and interventions [2]. A stressor is a pressure on the system caused by human activities, such as increase of pollution, or by natural events, such as occurrence of drought, and is synonymous with other terms used in resilience literature such as threat and hazard. These stressors affect the variables of the system and in turn, the system’s performance. Whereas chronic stressors, such as urbanization and aging of infrastructure, are well-known, recurrent, and can often be estimated, acute stressors, such as natural hazards and attacks, are unpredictable, uncommon, and can have devastating consequences.

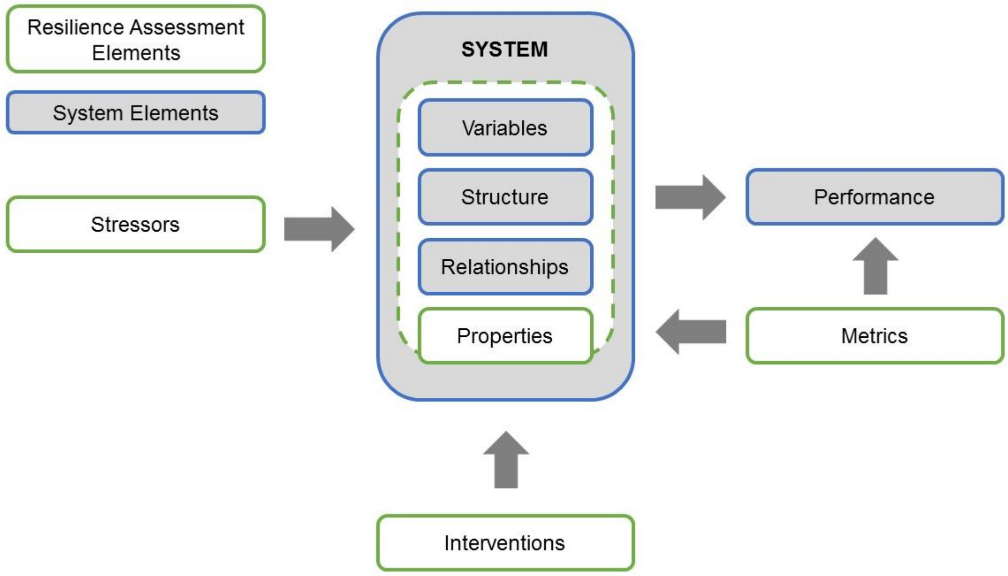

Figure 1: Conceptual representation of an engineering system within a resilience assessment framework.

Source Reference [2].

Resilient engineered systems may possess several properties that allow them to withstand, respond to, and adapt more readily to stressors, including but not limited to robustness, redundancy, resourcefulness and flexibility. These properties may be considered indicators of resilience. Metrics used in resilience assessments, such as recovery time and failure magnitude, relate to the required performance or level of service of the system. Although properties and performance may be quantified by metrics, the ultimate goal of resilience-based design focuses on achieving the required performance. The performance of an engineered system with respect to resilience can be improved by means of interventions which alter its properties, such as replacing aging equipment, installation of spare equipment, introduction of real-time control, or increasing of system capacities.

Vulnerability assessments can be used to identify such interventions and to prioritize a system's available resources for implementing interventions. Vulnerability assessments and emergency response plans are required by the Environmental Protection Agency (EPA) under Public Law 107-188 Title IV (June 2002) for any facility providing drinking water to a population of 3,300 or greater [3]. Although not required, the EPA does recommend that wastewater treatment facilities attain similar assessments because of their criticality to the health and safety of their service community and environment, and because of their storage and use of toxic and explosive chemicals.

The SAM WWTP performed an evaluation of its WWTP and pump stations infrastructure’s reliability against external hazards beyond the control of SAM, including natural hazards, malevolent threats, and failure of critical dependencies, and internal electromechanical failure due to general equipment failure, age and/or lack of redundancy. The purpose of this work was to:

1. Protect public and environmental health, and operator safety;
2. Respond to regulatory concerns;
3. Identify and prioritize the hazards that may affect the WWTP performance;
4. Recommend measures and improvements that would be the most beneficial to the WWTP infrastructure and process reliability; and
5. Embrace a policy of sustainability for the responsible use of existing resources.

1.1 WWTP Expected Performance

SAM owns and operates a WWTP and a sanitary sewage collection system that collects sewage from its three-member agencies: City of Half Moon Bay, Granada Community Services District, and Montara Water and Sanitary District. The WWTP is located on the coast in Half Moon Bay, California where earthquakes, storms and marine events are common. The WWTP currently includes the following treatment processes:

1. Primary Treatment: Influent screening, grit removal, primary clarification;
2. Secondary Treatment: Activated sludge, secondary clarification, chlorination, de-chlorination; and
3. Solids Handling: Anaerobic digestion, dewatering, and landfill disposal.

The performance expected from the WWTP is presented in the Permit issued by the San Francisco Bay Regional Water Quality Control Board Order No. R2-2-12-0061 that governs the discharge of treated wastewater to the Pacific Ocean. The WWTP capacity, expanded in 1999, is designed to handle the influent flows listed in **Fehler! Verweisquelle konnte nicht gefunden werden.**.1.

Tab. 1.1: Maximum Treatment Plant Influent Flows

Source Reference [4].

Flow	Value (MGD)
Average Daily Dry Weather Flow Capacity	4
Peak Wet Weather Flow Capacity	15

The WWTP is required to produce a final effluent that complies with the quality limitations listed in the aforementioned Permit. The WWTP may not be entirely or partially bypassed, unless:

1. Bypass was unavoidable to prevent loss of life, personal injury, or severe property damage; or,
2. There were no feasible alternatives to the bypass, such as the use of auxiliary treatment facilities, retention of untreated wastes, or maintenance during normal periods of equipment downtime [6].

WWTP Operational Challenge

A primary operational challenge for SAM is to maintain complete and continuous use of the WWTP infrastructure while its equipment is reaching or exceeding its useful life. The WWTP design does not include emergency retention capacity, and hence does not allow for any downtime. Staff can only temporarily reduce the influent flow by diverting flow into remote storage structures at two pump stations in the collection system.

Tab. **1.2: Asset Useful Life vs. Current Age**

Source Reference [4, 5].

Asset Type	Useful Life (years)	Current Age (years)
Pipelines	50	32
Structures	30 to 50	16 to 32
Process Equipment	15 to 20	30
Auxiliary Equipment	10 to 15	30

compares the useful life to the current age of each type of asset currently sited at the SAM WWTP, as recommended in the Code of Federal Regulations (CFR), Title 40, Part 35, Subpart E. According to the CFR, an asset’s useful life is defined as the estimated period of time during which a treatment works or a component of a waste treatment management system will be operated. Because the WWTP’s assets are near to or have exceeded CFR useful life limits, risk of asset failure is increasing. SAM’s vulnerability assessment identifies the assets to which immediate improvements are most beneficial to the WWTP performance to alleviate this risk.

Tab. 1.2: Asset Useful Life vs. Current Age

Source Reference [4, 5].

Asset Type	Useful Life (years)	Current Age (years)
Pipelines	50	32
Structures	30 to 50	16 to 32
Process Equipment	15 to 20	30
Auxiliary Equipment	10 to 15	30

2 Methodology

The SAM WWTP vulnerability and risk assessment evaluated the risk level posed to the WWTP by the following two types of hazards:

1. External Hazard: threat to the proper functioning of the treatment plant that is beyond the control of the WWTP and originates outside of the boundaries of the site.
2. Electromechanical Equipment Failure: equipment failure event due to general equipment failure, age and/ or lack of redundancy.

The approach of the assessment of the WWTP’s existing conditions and vulnerabilities to external and electromechanical hazards aligns with the methodologies recommended by EPA for the vulnerability and risk assessment of wastewater infrastructure. The selected methodology assesses and manages risks associated with hazards to, or failure of, critical infrastructure, and identifies, quantifies, and relates a utility’s level of risk and resilience. In this assessment, risk and resilience, respectively, refer to the likelihood of an asset to withstand an interruption and the ability of an asset to return to service after an interruption.

Critical assets and resources were identified and assessed for current conditions and expected performance against their estimated remaining useful life; this step measures the assets' likelihood of failure. Hazards and resulting vulnerabilities to these assets were then ranked in terms of how their respective occurrence or failure could impact the functionality of the WWTP; this step represents the consequence analysis. Each hazard's consequence was ranked against its expected likelihood of occurrence, or risk. The risk analysis estimates the likelihood that the occurrence of a hazard causes the consequences indicated by the consequence analysis. The correlation between risk and consequence can be seen in Figure 2.

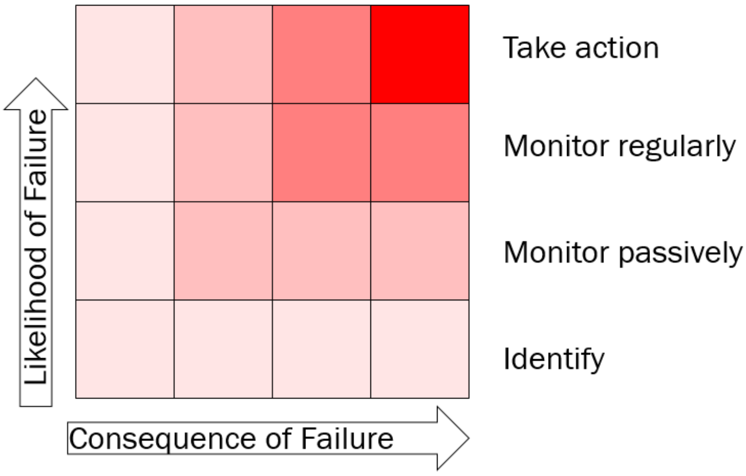

Figure 2: Likelihood of Failure versus Consequence of Failure.

Source Reference [4].

The methodology screens out lower risk hazards, allowing SAM to focus on improving assets or practices that are most critical to the continuity of the WWTP's service. Furthermore, the methodology culminated in the prioritization of unreliable assets or processes for which recommendations are provided to alleviate risk posed to the WWTP. Benefits of risk reduction and resilience enhancement through recommended improvement options were developed and qualified as part of this methodology. The sequence of the steps of the SAM WWTP reliability evaluation are shown in Figure 3.

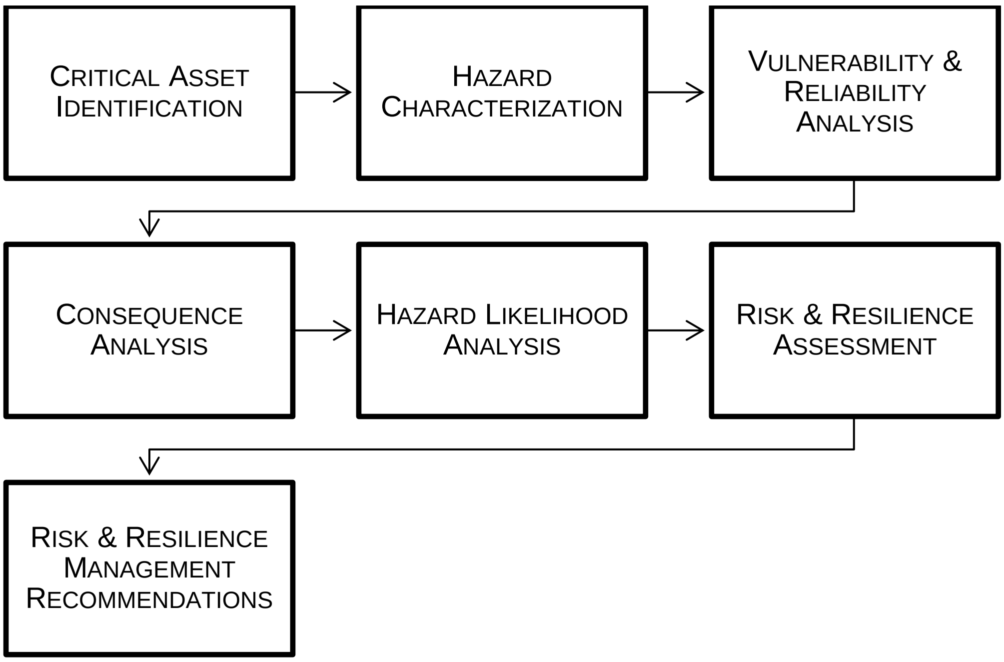

Figure 3: SAM WWTP Reliability Evaluation Approach.

Source Reference [4].

External Hazard Assessment

2.2.1 Hazard Identification

External hazards are either natural or man-made. Natural external hazards applicable to the SAM WWTP are earthquakes, tsunamis, wildfires, floods and landslides. Man-made external hazards specific to WWTPs are power supply outages, absence of key personnel, vandalism/terrorism, and loss of service and supply providers. Service and supply requirements include but are not limited to chemical supply, diesel fuel supply, biosolids removal disruption, spare parts supply and spare parts installation. Using a conservative approach, the consequence of each external hazard was assumed to equally affect each asset of the WWTP and the overall service continuation of the WWTP.

2.2.2 Risk Level

The external hazard risk level (Risk) is defined as the probability of hazard occurrence (Probability) multiplied by the hazard consequence (Consequence).

$$Risk = Probabilty \times Consequence \qquad \textbf{(1)}$$

Probability and consequence ratings are presented in Tab. **2.1: Probability of External Hazard Occurrence Rating**

Source Reference [4].

Rate of Occurrence	Remote (Less than once in 50 years)	Occasional (Once in 5 to 50 years)	Frequent (More than once in 5 years)
Hazard Occurrence Rating	1	5	10

and Table 2.2, respectively. Each external hazard is assigned a consequence score based on the worst reasonable potential destruction or service loss incurred by the WWTP as a result of that external hazard.

Tab. 2.1: Probability of External Hazard Occurrence Rating

Source Reference [4].

Rate of Occurrence	Remote (Less than once in 50 years)	Occasional (Once in 5 to 50 years)	Frequent (More than once in 5 years)
Hazard Occurrence Rating	1	5	10

Tab. 2.2: External Hazard Consequence Rating

Source Reference [4].

Criterion	Relative Weight	Anticipated Consequences		
Public and Personal Health Safety	50%	No injuries or adverse health effects	No lost time injuries or medical attention	Loss of life
Impact on Environment	25%	Full compliance with permits	Violation but no enforcement	Enforcement action with

or Regulatory Compliance		and no impact on environment	action and/or minor impact on environment	fines and/or major impact on environment
Ability to Restore Service	25%	Service restored in less than 2 hours	Service restored in 2 to 24 hours	Not able to restore service for more than 24 hours
Criterion Rating		1 (Negligible)	5 (Low)	10 (Severe)
Consequence Rating	100%	Weighted average of the three criterion ratings		

As shown above, three criteria are considered when evaluating the consequence of external hazard:

1. The public and personnel health and safety;
2. The impact on the environment, liability costs and regulatory compliance; and
3. The ability to restore service, including any penalties for service interruption and repair and replacement costs which may be high due to urgent construction, as applicable.

Each criterion is given a rating and the consequence rating is the weighted average of these three ratings. Public and personnel health and safety is the most imperative criterion and is therefore assigned a weight twice as high as that of other two criteria.

Electromechanical Equipment Failure Assessment

2.3.1 Asset Inventory

Asset characterization is the process by which a utility’s assets are evaluated and chosen for inclusion the reliability evaluation based on each asset’s criticality to the overall service of the WWTP. Criticality is based on the perceived consequences associated with the loss of service of that asset. The purpose of asset characterization is to determine the assets that, if compromised by failure, could result in prolonged or widespread interruption of the service, degradation, injuries, fatalities, detrimental economic impact to SAM or the community, or any combination thereof.

The assessment focuses on the WWTP's most critical system assets as determined from site visits. This reliability evaluation methodology was exclusively applied to assets within the WWTP site and did not include an assessment of SAM's collection and outfall systems. Field investigations were used to gather each asset's technical information and to evaluate each asset's rate of failure occurrence. The assets that were inventoried and evaluated are a total of 421 electromechanical devices (such as pumps, valves, actuators, blowers, etc.) and instruments (such as flowmeters, level sensors, etc.) that are currently being operated at the WWTP. These assets comprise SAM's active infrastructure.

Passive assets such as tanks, structures, or pipelines within the WWTP site and the collection system owned and operated by SAM are not included in this reliability evaluation. Passive infrastructure is not considered because it typically does not experience sudden, unexpected failure under normal operating conditions, provided that they are adequately inspected and preventatively maintained.

2.3.2 Risk Level

The internal hazard risk level (Risk) is defined as the probability of equipment failure (Probability) multiplied by the consequence of equipment failure (Consequence).

$$Risk = Probabilty \times Consequence \qquad \textbf{(1)}$$

The probability of equipment failure is rated based on equipment age and staff experience is rated as shown in Table 2.3.

Tab. 2.3: Probability of Equipment Failure

Source Reference [4].

Rate of Occurrence of Equipment Failure	Once every 10 years	Once every 5 to 10 years	Once every 3 to 5 years	Once every 1 to 3 years	Less than once per year
Probability of Equipment Failure Rating	0.5	2.5	5	7.5	10

The following three criteria were considered when evaluating the consequence of the external hazard:

1. The impact on the WWTP effluent quality;
2. The impact on the WWTP treatment capacity, including existing levels of redundancy; and
3. The ability to return the piece of equipment to service, including staff and resource preparedness.

Each of the three criteria is given a relative weight based on percentage, and an anticipated consequence of failure rating from 1, negligible, to 10, severe, as shown in Table 2.4. The consequence rating is the weighted average of these three ratings. Using Equation 1, risk is calculated by multiplying the overall consequence of failure rating and the probability of failure.

Tab. 2.4: Consequence of Equipment Failure

Source Reference [4].

Criterion	Relative Weight	Anticipated Consequences		
Impact on Effluent Quality	33%	None	Mid-term effluent quality non-compliance	Immediate effluent quality non-compliance
Impact on Treatment Capacity	33%	None	No more redundancy or peak capacity less than 15 MGD	Failed process or average capacity less than 4 MGD
Ability to Return Equipment to Service	34%	Immediate repair/ replacement possible	Repair possible before treatment is impacted	No contingency plan; preparedness uncertain
Criterion Rating		1 (Negligible)	5 (Low)	10 (Severe)
Consequence Rating	100%	Weighted average of the three criterion ratings		

3 Results

External Hazard Evaluation

Fehler! Verweisquelle konnte nicht gefunden werden. summarizes the external hazard evaluation results. SAM staff experience, historical data from government sources (when available), and commonly used construction or geographic standards for hazard risk designations were used to assess the likelihood and consequence for each external hazard identified for the WWTP within this evaluation.

The likelihood of occurrence and resulting consequence for each external dependency hazard, including power supply outage, absence of key personnel, and service provider business failure, were determined based on SAM staff experience. Similarly, vandalism and terrorism threats are assumed very unlikely based on SAM staff experience, the history of adversarial events the WWTP has experienced, the location of the WWTP relative to major urban areas, and already-existing protection measures (such as fencing and access control), despite having potential significant consequences to the functionality of the WWTP.

Earthquakes are of major concern throughout California, and the degree of damage posed to the WWTP is defined by earthquake magnitudes. For the WWTP site, earthquake likelihood was estimated based on the frequency of United States Geological Survey (USGS) recorded earthquakes as listed in the USGS Earthquakes Hazard Program. This Program provides earthquake probabilities based on location, Richter Magnitude and time span. For the WWTP, the likelihood of occurrence of an earthquake with Richter Magnitude of 5.0 or greater is 0.3 (30 percent) over five years. Therefore, the earthquake hazard was assigned the greatest likelihood and consequence threat under this risk assessment methodology.

The occurrence of a tsunami was given the greatest consequence rating under this risk assessment methodology. Since SAM’s WWTP is located within the tsunami inundation area per the California Geological Survey and California Emergency Management Agency Tsunami Inundation Map for Emergency Planning for the Half Moon Bay Quadrangle published in June 2009, the tsunami hazard was given a rate of occurrence of 5 per **Fehler! Verweisquelle konnte nicht gefunden werden.**, considering that tsunamis are possible but are expected not as frequent as earthquakes.

According to the California Department of Forestry and Fire Protection’s Fire and Resource Assessment Program Fire Threat Map (October 2006), the SAM WWTP is located in an area of moderate wildfire threat. A wildfire hazard at the WWTP would have detrimental impacts to the service and environment of the WWTP, and moderate safety impacts. Therefore, the wildfire hazard was assigned the rate of occurrence and consequence ratings shown in 3.1.

Landslides can pose serious hazard to property in the hillside terrain of the San Francisco Bay region. Per the USGS 1997 San Francisco Bay Region Landslide Folio Summary Distribution of Slides and Earth Flows San Mateo County Map, the WWTP site is located on flat land with little or no potential for the formation of slumps, translational slides or earth flows. A rate of occurrence score of 1 was therefore assigned to the landslide hazard for the WWTP, despite the high consequence associated with potential foundation and structural destruction upon occurrence.

None of the WWTP’s critical assets are sited within a designated Flood Emergency Management Agency (FEMA) Special Flood Hazard Area. The site falls within FEMA’s Flood Insurance Rate Map (FIRM) Panel 0255E; FEMA flood maps are used to rank an area’s potential flood damage based on flooded land areas and water depth on a defined storm recurrence interval. The land in and around the WWTP is labeled as type Zone X signifying that the area is outside of the 0.2% annual chance (500-year) floodplain. Flood insurance purchase is not required within this zone type. A flood at the WWTP is therefore considered unlikely except in the very specific instance of an earthquake-triggered tsunami, or possibly in the case of an internal flood caused by equipment malfunction. The risk of internal flooding due to equipment malfunction is measured in the electromechanical hazard risk.

Tab. 3.1: External Hazard Evaluation Summary

Source Reference [4].

External Hazard	Rate of Occurrence	Consequences				Risk Level
		Safety 50%	Environmental 25%	Service 25%	Rating	
Earthquake	10	10	10	10	10	100
Power Supply Outage	10	1	10	10	5.5	55
Absence of Key Personnel	10	1	10	10	5.5	55
Service Provider out of business	10	1	10	10	5.5	55

Tsunami	5	10	10	10	10	50
Wildfire	5	5	10	10	7.5	37.5
Vandalism, Terrorism	1	10	10	10	10	10
Flood	1	10	10	10	10	10
Landslide	1	10	10	10	10	10

Electromechanical Equipment Failure Evaluation

Table 3.2 summarizes the electromechanical equipment failure evaluation results. The following three facilities at the SAM WWTP handle sewage treatment byproducts and were designed with no redundancy:

1. Belt filter press with main sludge conveyor;
2. Dewatering screw grit conveyor; and
3. Biogas flare.

These assets have the highest risk levels as their failure is considered fairly likely and could cause significant adverse effects. All devices ranked with a risk level of 54 or lower have been designed and are being operated with some level of redundancy. Their sudden failure is therefore less detrimental to the WWTP. These devices are still considered a priority for the WWTP since, upon failure, the WWTP would function under a precarious mode of operation with no redundancy.

Tab. 3.2: Failure Risk Ratings by Treatment Process - Source Reference [4].

Unit Process	Equipment Unit	Failure Probability	Consequences				Risk Level
			Effluent Quality 33%	Treatment Capacity 33%	Service Ability 34%	Rating	
Sludge Dewatering	Belt Filter Press	10	5	10	10	8.4	84
	Dewatered Sludge Main Conveyor	10	5	10	5	6.7	67
Grit Removal	Grit Washer	10	1	10	10	7.0	70
Sludge Digestion	Biogas Flare	10	1	10	10	7.0	70
	Mixing Pumps 1 & 2	10	1	5	10	5.4	54

	Sludge Recirculation Pumps 1 & 2	10	1	5	10	5.4	54
	Sludge Transfer Pumps 1 & 2	10	1	5	10	5.4	54
Disinfection	Chemical Metering Pumps 1&2	10	5	1	10	5.4	54
Headworks	Screening Conveyor	10	1	5	10	5.4	54
Influent Pumping	Influent Pumps 6, 7 & 8	10	1	5	10	5.4	54
Primary Treatment	Chain and Flight Mechanisms 1 to 3	10	1	5	10	5.4	54
Secondary Treatment	Scraper Mechanism 1 & 2	10	1	5	10	5.4	54
Effluent Pumping	Effluent Pumps 1, 2 & 3	10	1	5	10	5.4	54

4 Recommendations

The following recommendations intend to reduce the risks calculated herein, enhance resiliency and reliability, and add value to the SAM WWTP within a reasonable level of cost. Recommendations which improve operator and/or public safety were given a higher level of priority.

External Hazard Recommendations

Table 4.1 lists the proposed mitigation measures for all external hazards with a risk level exceeding 50 per Tab**. 3.1: External Hazard Evaluation Summary**

Source Reference [4].

External Hazard	Rate of Occurrence	Consequences			Rating	Risk Level
		Safety 50%	Environmental 25%	Service 25%		
Earthquake	10	10	10	10	10	100

Power Supply Outage	10	1	10	10	5.5	55
Absence of Key Personnel	10	1	10	10	5.5	55
Service Provider out of business	10	1	10	10	5.5	55
Tsunami	5	10	10	10	10	50
Wildfire	5	5	10	10	7.5	37.5
Vandalism, Terrorism	1	10	10	10	10	10
Flood	1	10	10	10	10	10
Landslide	1	10	10	10	10	10

3.1. This list includes a mitigation measure for all external hazards that are certain to occur over the WWTP service life (i.e., a rate of occurrence of 10).

Tab. 4.1: Mitigating Measures for External Hazards

Source Reference [4].

External Hazard	Existing Mitigation Measures	Recommended Mitigation Measures	Priority Level
Earthquake	Existing facilities probably designed per current seismic requirements at the time of their construction	Perform a structural analysis to determine whether the WWTP complies with current seismic regulations	High (Hazard is potentially life threatening)
Tsunami	Unknown	Get updates from Pacific Tsunami Warning Center and establish evacuation plan and procedures	High (Hazard is potentially life threatening)
Power Supply Outage	Back-up generator	Upgrade as needed	High (Potential WWTP wide shut down)
Absence of key personnel	Not Applicable	Establish a matrix of the core competencies needed to adequately operate the WWTP and verify that all of them are covered by at least two staff members	Moderate

Electromechanical Equipment Failure Recommendations

Failure avoidance/mitigation measures, listed in Table 4.2, were recommended for each critical piece of equipment with a risk level of at least 70. These measures address SAM's WWTP equipment which is designed and operates with no redundancy.

Tab. 4.2: Mitigation Measures for Electrotechnical Equipment Failure

Source Reference [4].

Equipment	Recommended Measure	Priority Level
Belt Filter Press & Main Sludge Conveyor & Dewatering Screw Grit Conveyor	Establish a contingency plan describing the steps to take following a failure of the equipment. Contingency plan could consist of renting temporary dewatering equipment or temporarily hauling digested sludge off site. If no contingency option reveals satisfactory, install new redundant dewatering equipment.	High (Potential sitewide impact)
Bio Gas Flare	Renovate the biogas piping system to the flare to avoid condensate accumulation and SCADA alarms.	Moderate

5 CONCLUSIONS

The SAM WWTP infrastructure vulnerability and risk evaluation against external hazards and electromechanical equipment failure resulted in prioritized recommendations for improving the overall resilience of the WWTP which allow the continued treatment of wastewater safely, reliably, and cost-effectively using the WWTP's existing processes. SAM has implemented some recommendations, including:

1. Replacement of the failing ductile iron force mains with HDPE and improved hydraulics;

2. Upgrade of traditional pumps with grinder pumps;
3. Construction of additional storage capacity in the collection system;
4. Improvement of pump performance, service life, and maintenance by installing the "deragging" system at pump stations; and
5. Installation of VFDs on aeration blowers to reduce wear on equipment, save energy and associated costs, and improve biological performance with more dissolved oxygen (DO) control.

SAM can use this assessment framework to re-evaluate the WWTP's resiliency after the listed and planned improvements are completed. Additionally, this assessment framework can be applied to other WWTPs evaluating infrastructure and process resiliency and evaluating the allocation of resources for improvements and the risk reduction and resilience benefit of such improvements.

6 Literature and Source References

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[4] SRT Consultants, Inc. Wastewater Treatment Plant Reliability Evaluation Study, April 2015.

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