3 WATERS RESILIENCE ASSESSMENT GUIDELINE AND OPPORTUNITIES FOR IMPROVEMENT

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ABSTRACT

Water supply, wastewater, and stormwater systems are often collectively referred to as the 3 waters systems in New Zealand. The 3 waters systems are of importance in supporting community's basic needs. The 3 waters are vulnerable to natural hazards (e.g., earthquakes, flooding) and may suffer both structural (physical) damage and/or non-structural (equipment) damage. Damage could lead to reduced functionality or the entire shut-down of the 3 waters systems, with failure impairing the community's wellbeing. Consequently, this could have considerable impact on the daily functioning of the whole society.

In response a resilience assessment guideline is developed for 3 waters systems for the New Zealand context by Beca. This was commissioned jointly by the University of Canterbury Quake Centre, Water New Zealand and IPWEA. This guideline aims to promote wider understanding of network resilience and the costs and benefits of potential strategies for improving the resilience of pipe networks, to inform pipe network intervention strategies. The guideline aims to assist with developing evidence and a knowledge base for improving system resilience in preparation for natural hazards. The guideline provides tools and strategies enabling asset owners to make rational and strategic decisions for asset management and urban planning of 3 waters systems. This guideline will fit into a wider framework of guidance being developed to set national good practice in asset management in 3 waters with particular emphasis on pipe renewals.

This paper presents the definition of 3 waters resilience in the context of New Zealand. Furthermore, examples of the underlying philosophy for improving 3 waters resilience and the key considerations when assessing system resilience for 3 waters facilities are discussed. Lastly, the potential benefits of integrating resilience assessment in the process of asset management are presented.

KEYWORDS

3 waters systems, resilience assessment, strategical decision making

PRESENTER PROFILE

Melanie is a Civil Engineer working for Beca, with a speciality at 3 waters resilience. Melanie completed her PhD research at the University of Canterbury. The focus of her research was "Decision Support Framework for Post-earthquake Restoration of Sewerage Systems" in the context of the Canterbury earthquakes. This work can underpin decision making on system restoration after a seismic event and also support system maintenance and upgrade by guiding system rehabilitation and monitoring system behaviour during business-as-usual time.

1 INTRODUCTION

Water supply, wastewater, and stormwater systems serve the basic needs of their local community. These systems are often collectively referred to as the 3 waters in New Zealand. Territorial authorities are responsible for providing quality and cost-effective 3 waters systems and regulatory services in both business-as-usual times and emergency situations.

Seismic events both transient ground motion and permanent ground deformation can induce physical damage to the 3 waters networks, limiting or impeding the operability of the whole system. On the other hand, reliable and resilient 3 waters systems can boost the community's confidence and facilitate post-event recovery.

Examples of partial or total loss of functionality for 3 waters systems following natural hazards can be identified worldwide. The moment magnitude (Mw) 7.4 Turkey earthquake (Izmit, Oct. 19. 1999) had serious impact on the Izmit wastewater system, which used to have capacity of 10,500 litres per second but reduced to 30,000 litres per day due to the seismic effects (Erdik, 2001). Tohoku earthquake (Mw= 9.0) and Tsunami in 2011 damaged 63 sewerage treatment plants. It was estimated that 1.52 million households suffered water outage (Eidinger and Davis, 2012). After the 1994 Northridge earthquake (Mw= 6.7), about 450,000 people lost water supply service for, in some cases, a week or more (Schiff 1995). The Canterbury earthquake sequence (CES) 2010-2011 caused significant damage to the 3 waters systems in Christchurch. As of January 2014, 659 km of sewer pipelines, accounting for 41% of the total reticulation network, and 136 pumping stations (83%) were identified as damaged to a varying extent (Liu et al., 2015c). 125 (57%) of water pump stations or reservoirs experienced earthquake-induced physical damage. Two months after the February event, the Christchurch wastewater treatment plant was operating at 30% of its normal capacity, and the wastewater system was leaking 40 million litres per day into backyards and water courses due to earthquake-induced damage to pipes (Tang 2016).

The New Zealand National Infrastructure Plan (NIU, 2011) states: "By 2030 New Zealand's infrastructure is resilient and coordinated and contributes to economic growth and increased quality of life". In the plan, resilience is defined as the concept that is wider than natural disasters, and covers the capacity of public, private and civic sectors to withstand disruption, absorb disturbance, act effectively in a crisis, adapt to changing conditions, including climate change, and grow over time. Furthermore, 3 waters resilience has been identified as a key stream for local, regional, and national asset management planning and land development policy.

The University of Canterbury Quake Centre (UCQC), together with IPWEA and Water New Zealand (Water NZ), have launched the Evidence Based Investment Decision Making process for the 3 Waters Pipe Network Programme (Pipe Renewals Guidelines Programme). The programme aims to develop guidance documents and tools to assist New Zealand's water organisations to make nationally consistent, evidenced-based decisions relating to the management and renewal of their 3 Water Pipe Networks. The programme covers inspection, maintenance and renewal strategies for pipework in potable water, wastewater and stormwater systems. This programme comprises 11 themes and is expected to take about 10 years to complete.

The theme of system resilience has been identified as one of the key areas to be included in the programme with the purpose of promoting wider understanding of the susceptibility of 3 waters networks. Towards that, this paper presents a 3 waters resilience guideline embedded in the Pipe Renewal Guideline Programme. This 3 waters resilience guideline aims to provide guidance on the system resilience of buried piped 3 waters networks in New Zealand.

This paper presents the definition of 3 waters resilience in the context of New Zealand. Section 3 introduces the underlying philosophy for improving 3 waters resilience. Key considerations when assessing system resilience for council-owned 3 waters facilities are discussed in Section 4, followed by the potential benefits of integrating resilience assessment in the process of asset management in Section 5. The conclusions are drawn in Section 6.

2 DEFINING THREE WATERS RESILIENCE IN NZ

2.1 3 WATERS RESILIENCE IN NZ CONTEXT

In line with the concept defined in the NIU plan (NIU, 2011), 3 waters resilience in the context of New Zealand is defined as *the capability of 3 waters systems that can* ***mitigate the risk before hazards, contain the effects if hazards occur, provide services in a compromised way after hazards but minimise the consequence caused by hazards, restore the services in a timely manner*****.**

Four dimensions of resilience that have been widely recognised include: technical, organisational, social, and economic (Bruneau et al. 2003). Specifically, technical resilience refers to the capability of physical components, structures, and systems to sustain disastrous effects while providing 3 waters service in an acceptable manner immediately after hazards occur. In the post-event recovery stage, less recovery time and cost could indicate a stronger position in the technical dimension of system resilience. The 3 waters resilience in the organisational dimension focuses on the ability of asset owners and Territorial Authorities (TA) to respond to hazards and to make decisions as well as take actions on continuous provision of 3 waters service during and after the critical time. The social dimension of resilience is designed to measure the ability of reducing the social consequences of impaired 3 waters systems on the community and governmental jurisdictions in the aftermath of the event. The economic dimension of resilience can be used to measure the economic losses (direct and indirect losses), as a result of damaged 3 waters systems and affected service post-event.

These four dimensions of 3 waters resilience can be applied for assessing 3 waters resilience in the New Zealand context. They can act as measures for asset owners to evaluate the ability of 3 waters facilities containing the consequences and minimising the losses caused by natural hazards.

Four principles of resilience should be considered when assessing 3 waters resilience:

- Robustness
- Redundancy
- Resourcefulness
- Rapidity

Robustness refers to the ability of 3 waters systems to withstand a given level of hazard-induced stress without suffering degradation or loss of functionality. Redundancy is the availability of alternative assets inbuilt in 3 waters systems that can be functioning when needed in the event of natural hazards. These assets are expected to perform in lieu of the damaged system facilities. Resourcefulness is defined as the capability of TAs, as the operators and managers of 3 waters systems, to transfer and allocate necessary resources and services during the natural disasters. Rapidity represents the time required for 3 waters systems to return to full system functionality and serviceability and, where possible, the betterment introduced in the process of post-event restoration.

These four principles need to be taken into account when assessing 3 waters resilience in New Zealand. It could enable territorial authorities to have a thorough understanding of the system resilience in the face of the four principles.

3 UNDERLYING PHILOSOPHY FOR THREE WATERS RESILIENCE ASSESSMENT

3.1 MAXIMISING THE VALUE OF EXISTING ASSETS

Improving 3 waters resilience presents both opportunities and challenges. The opportunities are for asset managers to upgrade the system facilities and enhance system resilience through repairing/replacing the system components of concern. The challenges are to make rational and informed decisions on the selection of components to be repaired/renewed within the time and budget constraints with the purpose of optimising 3 waters resilience.

Although the 3 waters facilities in New Zealand are aging, most of them are still in a largely functional state. In some cases, renewal or replacement is not necessarily the most cost-efficient solution. To achieve higher levels of 3 waters resilience does not necessarily mean more investment; instead, maximising the value of existing assets also has the potential to improve resilience while using programed renewals budgets. This can help reduce the need for additional capital investment. This requires TAs to better understand their 3 waters systems and identify the weaknesses within their networks. Strategic approaches can be taken towards mitigating the risk and reducing the system weaknesses.

3.2 HIGH LEVEL STRATEGIC MANAGEMENT

TAs are responsible for the daily maintenance of 3 waters facilities. However, when assessing or enhancing 3 waters resilience, it is not enough to solely consider specific 3 waters facilities or individual assets, but to treat the wider network, including community needs as a whole (IPWEA, 2015). A holistic approach should be implemented where a variety of factors are involved (Liu et al., 2013). Among other factors, ground conditions, hazard risk analysis, interdependency between 3 waters and other systems should be considered in resilience assessment (Gibson & Newby, 2015). Furthermore, due to geological proximity, the functionality of the 3 waters underground systems can be directly affected by the roading networks above the ground and vice versa. Moreover, local telecommunication systems assist in transferring and collecting data in relation to the status-quo of 3 waters system serviceability for both business-as-usual operation and post-event inspection. All in all, TAs need to think of the big picture when providing business-as-usual system maintenance and post-event recovery.

3.3 INTEGRATING SYSTEM RESILIENCE AT THE PLANNING STAGE

Identifying the best strategies to increase resilience to the largest extent while using the minimum expense within budget is challenging yet achievable. Integrating system resilience at the planning stage is one of the keys. During the early stages of asset planning and construction, TAs have more flexibility to choose the most cost-efficient actions to be undertaken while considering all factors involved in the big picture. The earlier TAs integrate system resilience into the asset planning, the less it will cost. After networks are built, it is expensive to make further changes prior to the end of asset life than for example, at the design stage.

3.4 APPLYING DIFFERENT LEVELS OF SOPHISTICATION FOR ASSESSMENT

Resilience assessment can assist TAs in understanding the vulnerability of 3 waters systems and identifying strategies to enhancing system resilience through some pre-defined procedures. The procedures should have the potential to be tailored and modified, depending on, for example, the different scales of community served and the level of resilience required. A three-level resilience assessment approach is recommended herein:

- Simplified assessment
- Intermediate assessment
- Advanced assessment

The simplified resilience assessment approach is best suitable for small sized networks and communities. It is conducted in deterministic fashion where the risk of the potential hazards are measured as low, medium, and high, without any uncertainty for consequence considered. The intermediate assessment approach is applied for medium sized of networks for inspecting the technical, organisational, social dimensions of 3 waters resilience. The advanced approach for assessing 3 waters resilience is to holistically consider four dimensions and principles of resilience for a large community, using probabilistic simulation and connectivity analysis. Asset managers in charge of system planning should determine the appropriate level of assessment approach to use, depending on the sizes of community and network as well as level of asset management details required.

4 KEY CONSIDERATIONS FOR 3 WATERS RESILIENCE ASSESSMENT

4.1 DATA DOCUMENTATION AND MANAGEMENT

The asset data on the 3 waters systems are of critical importance for resilience assessment and, consequentially, decision making on 3 waters asset management (IPWEA, 2015). Data play a fundamental role in understanding the current situation of 3 waters facilities, risks and forming the knowledge base to inform the actions TAs take. To ensure that 3 waters systems can be properly evaluated, the data should therefore include the characteristics of the assets (e.g., diameter, material), installation information (e.g., depth, date), failure history (e.g., failure mechanism, repair time and operation) and other information of interest. It is essential also to capture the asset information relating to spatial distribution relative to urban populations, because this affects the criticality of individual components. Special attention is needed on the connections between assets, especially between pipes and structures, in the light of the evidence on the extensive earthquake-induced damage observed during the Canterbury earthquake sequence in 2010-2011.

In addition to factual and accurate data themselves, asset taxonomy, data format, failure classification should be standardised in advance of data documentation process. As part of day-to-day maintenance operations, it is imperative to standardise and unify data documentation and management systems. The Metadata Standard has been developed exclusively for 3 waters assets in New Zealand (Treasury, 2016). It aims to establish a specification for asset data collection, entry, storage and consequently, enable analytical capabilities to make evidenced-based investment decisions. Specifically, the standard promotes a common understanding of the meaning or semantics of asset data, and ensures the correct and proper use and interpretation of the data for all stakeholders. It can be applied to both capital and operating environments. Furthermore, the standard recognises various levels of sophistication in the data and provides relevant data attribute guidance in this regard. Accordingly, the standard will benefit 3 waters asset managers in terms of funding and investment priorities; research and research investment; policy development and national, regional or local reforms; national, regional or local reporting and benchmarking; shared services and inter-organisational collaborations.

4.2 UNDERSTANDING OF GROUND CONDITIONS

The majority of 3 waters facilities are buried under the earth. For the stand-alone structures, such as pump stations, their foundations are built within the ground. Therefore, sufficient understanding of factual ground condition is of importance in terms of the identification of potential geotechnical hazards. Furthermore, understanding the interaction between the ground and 3 waters facilities can assist in predicting physical and functional damage to 3 waters components, thereby facilitating the resilience assessment process for 3 waters.

4.3 UNDERSTANDING OF PIPE MATERIAL AND FAILURE MECHANISM

In order to maximise the level of resilience achieved, it is important to understand the advantages and disadvantages of pipe materials, including the modern materials, such as PVC and PE. Although the evidence collected from the CES shows that these ductile materials performed well during the earthquakes, they can suffer failure mechanisms which are uncommon for other pipes, for example, chemical break down. Also, manufacture quality and installation process are factors, among others, that can significantly affect the overall performance of 3 waters assets. For the modern pipe materials, where to install them and how much to install are also critical, considering the cost and potential failure mechanisms. With capital works and asset renewal budgets that are generally limited, understanding pipe failure mechanisms and wisely choosing materials at the location where they are most needed and the facilities nearby are critical. For example, where there are waterways that could lead to lateral spread or flooding, hospitals, and schools, modern ductile pipe materials should be preferentially considered and installed. All in all, pipe failure mechanisms need to be considered during the decision making process for modern ductile pipe materials.

4.4 IDENTIFYING ASSET VULNERABILITY SPATIALLY AND COMPREHENSIVELY

3 waters serve community, interact with surrounding soil and the ecological environment, and underpin the daily operation of the entire society. It is important to examine the vulnerability of 3 waters systems spatially and comprehensively, for instance, how the disaster-induced physical damage affects the performance, functionality and serviceability of 3 waters systems (Liu et al., 2015a). A wastewater pipeline, for example, suffered moderate physical damage after an earthquake. However, it may still be functional and conveying wastewater, to some extent, with cracks leaking untreated sewage into the environment. Although it is still able to provide some levels of serviceability, the adverse effects of the leaking sewage on social and ecological aspects of system performance need to be taken into account. The factors, such as the number of households and public facilities affected, the number of complaints received, the volume of direct wastewater

discharged into waterways, and the direct and indirect economic cost occurred, are matters to evaluate when assessing wastewater system resilience.

4.5 IDENTIFICAITON OF ACCEPTABLE LEVEL OF SERVICE

In accordance to the selected dimensions and principles of 3 waters resilience, asset managers need to establish the desired levels of system resilience, in consultation with the community (Liu et al., 2015b). It is important to determine the targets in advance, so that TAs can evaluate whether their 3 waters system resilience match the pre-defined targets. There are many ways to measure resilience in qualitative and quantitative terms. It is for asset managers to decide which approach is appropriate while remaining consistent and coherent. Based on the status-quo of 3 waters system performance, and considering the community's expectations on 3 waters service, the desired levels of system resilience can be formed and assessed.

4.6 RECOVERABILITY

After a natural disaster, the time required to recover 3 waters services to the pre-event levels of service might be very long. The duration of the recovery process varies depending on, among others, the severity of the natural hazard, the robustness of the system components, the identification and implementation of effective recovery strategies, and funding and resources available to implement the strategies (Liu et al., 2016). There are two tiers of recoverability, namely, short-term and long-term recovery. Short-term recovery aims to return the service to community as quickly as possible by whatsoever means. Common methods include, for instance, portable toilets and water tank vehicles to provide temporary services. Long-term recovery involves the development of permanent reinstatement plans and the implementation of the plans. It is intended to restore the service to the pre-disaster level and, if possible, to accomplish a more robust and resilient 3 waters systems.

Time is a key measure for the recoverability of 3 waters systems. In addition to this, issues of recoverability lie on how to allocate and systematically manage available construction crew and equipment at a time at a time of high demands on these resources. Therefore, fast recovery means high resilience in terms of 3 waters systems as well as the management organisations. Pre-defined emergency management and contingency plans are of value in preparation for natural disasters.

5 BENEFITS OF RESILIENCE ASSESSMENT APPROACH IN ASSET MANAGEMENT

Resilience assessment of the council-operated 3 waters systems is needed in preparation for natural hazards. It equips TAs with evidence-based understanding of 3 water systems to facilitate asset management and planning.

With the help of resilience assessment, decision makers can:

- Gain full knowledge of the current status of 3 waters systems
- Identify the strengths and weaknesses of the systems in terms of system resilience
- Determine strategies to systematically improve system resilience and performance in the direction towards more robust 3 waters systems

- Make rational and informed decisions on operational investment relating to asset upgrade and/or renewal, capital work projects, and future land development

Resilience assessment should be considered as both a pro-active approach, which is intended to evaluate the current and future condition of 3 waters system following the completion of renewal plans, and a re-active method that can be used to guide the formation of recovery plans in the aftermath of natural disasters with the purpose of developing resilient systems. The use of resilience assessment methods after disasters should be integrated into the post-event decision making, in line with the overall recovery schemes.

6 CONCLUSIONS

TAs are responsible for the daily maintenance of 3 waters systems. Natural hazards can severely damage 3 waters facilities. TAs need to make informed decisions on asset upgrade and recovery after natural hazards, where possible, integrating system resilience into post-event restoration process. A resilience assessment guideline for 3 waters systems in New Zealand is under way. Some concepts to establish resilient networks are presented in this paper. Firstly, 3 waters resilience can be defined as the capability of 3 waters systems that can mitigate the risk before hazards, contain the effects if hazards occur, provide services in a compromised way after the event but minimise the consequence caused by hazards, restore the services in a timely manner.

Four underlying philosophy for 3 waters resilience assessment are:

- Maximising the value of existing assets
- High level strategic management
- Integrating system resilience at the early stage
- Applying different levels of sophistication for resilience assessment appropriate for the community

Key factors should be considered when assessing 3 waters system resilience are:

- Data documentation and management
- Understanding of pipe materials and potential failure mechanisms
- Identifying asset vulnerability spatially and comprehensively
- Identification of acceptable level of service pre and post event
- Recoverability

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