greater WELLINGTON
REGIONAL COUNCIL
Te Pane Matua Taiao

Whaitua te Whanganui-a-Tara

An overview of the Wellington City, Hutt Valley and Wainuiomata Wastewater and Stormwater networks and considerations of scenarios that were assessed to improve water quality

Image courtesy of Wellington Water Limited – Moa Point Wastewater Treatment Plant

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Executive summary

Within an urban environment, the influence of the stormwater and wastewater network on receiving freshwater and coastal water quality can be a significant factor affecting ecological health, contact recreation and cultural values.

Whaitua te Whanganui-a-Tara covers both rural and urban land uses, and this report provides an overview of the urban stormwater and wastewater networks only. Cost assessments were undertaken on two modelled scenarios considered by an expert panel; Improved and Water Sensitive. These looked at increasing amounts of rural and urban mitigations (including wastewater pipe repair and water sensitive design) to improve water quality and ecological health, which the Whaitua Committee will use to help guide freshwater quality objective setting.

Legacy issue

A legacy issue is prevalent, where historical network designs focussed on the rapid transfer of stormwater to the coast to reduce flooding (with minimal consideration of treatment for water quality) and the conveyance of wastewater away from densely populated urban areas for health purposes. It was only in the 1990's that Wellington began to treat its wastewater prior to discharging this to the ocean.

Management and expenditure

Wellington Water manage the three waters network for a number of councils who own the assets. The annual expenditure on infrastructure is linked to the proportion of funding received from the various stakeholder councils and long term and strategic planning. Consideration of the 2018 and 2019 stormwater and wastewater capital expenditure (CAPEX) per property against other cities in New Zealand shows Wellington falls below national averages, and when compared to our nation's largest city (Auckland), Wellington Water (managing its various stakeholder councils infrastructure) spent 2.6 - 3 times less.

Water quality and ecological considerations

In recent years, there has been an increased awareness and focus on improving water quality and ecological health, driven by a range of central and local government policies. Subsequently, the management and objectives of water infrastructure is changing to have greater emphasis on reduced environmental impact and water sensitive design, to help cater for population growth and future climate pressures. This requires adaption from Wellington Water and its stakeholder councils away from traditional infrastructure approaches.

Current state of wastewater infrastructure

Wellington region's public wastewater network is old, with pipes of average age ~53 years. Over 32% of this network is likely to be in poor or very poor condition (grades 4 and 5), contributing to leakage and overflows into the environment. In addition, these aging pipes also suffer from increased infiltration of both groundwater and salt water (in low lying areas), reducing capacity to convey and treat waste. Stormwater inflow to the wastewater network (for example from residential downpipes being directed into wastewater gully traps) contribute to large peaks in the wastewater network during rainfall events, which then leads to wastewater overflows

(where wastewater discharges into the environment often through constructed fail safes in the network to prevent backflow).

Constructed overflows

Over 2 years (2018 and 2019), ~304,000 m^3 of untreated wastewater overflowed from monitored locations into the receiving environment (and an unknown volume from un-constructed, not monitored sites). This represents ~0.64% of the average annual volume of wastewater that was treated prior to discharge to the coastal environment, from three wastewater treatment plants in the Whaitua.

When considering the volume and frequency of wastewater overflows, the three most problematic sub-catchments are Hutt River Valley, Wellington City and Wainuiomata, with one single discharge point (Silverstream storage tank) to the Hutt River making up >60% of all the monitored wastewater discharged through 2016-2019. Within this Whaitua, fixing the grade 4 and 5 pipes in the network and providing localised storage to reduce constructed overflows to ~one per year has been indicatively estimated by Wellington Water to cost between $1.83 - 2.23 billion (including 30 years of growth).

Cross connections

Illegal cross connections (wastewater directly connected to stormwater) can direct waste into the aquatic environments during both dry and wet weather. These are often small in volume, but can lead to ongoing human health risks. New cross connections are still occasionally occurring, despite building compliance requirements to certify connections. A number of simple solutions exist to reduce the chance of a cross connection occurring, which include proving the connection (with flush or dye tests or photographs) or simple modifications to wastewater pipe infrastructure (pipe diameter, marking, labelling or colouring pipes). Detecting historical cross connections will require more detailed investigations, which Wellington Water are already responding to through roving crews and sanitary survey investigations. Complete identification of all cross connections would require significant investment.

Private wastewater laterals

A large ‘unknown’ of the wastewater network is the privately owned laterals connecting dwellings and buildings on private properties to the public network. Little data exists on their condition and subsequently risk to the environment. Repairing the public network would only solve part of the environmental, social and community issues with discharge of wastewater to the environment. Consideration of how private laterals can be repaired and replaced over time is of importance to improving water quality, and may require innovative approaches such as plumbing inspections/certification at the point of a property sale. Roving crews also can initiate requests to private landowners when their investigations trace the source of a wastewater issue. Wellington Waters high level indicative estimates for the identification and repair of cross connections and leaking private wastewater laterals is between $250 – 350 million .

Overview of traditional stormwater infrastructure

The stormwater network has a complicated management and ownership framework, where there are hard and natural ‘assets’ ranging from pipelines and pump stations to open channels, streams and rivers that are collectively owned or managed by various district councils, a regional council and Wellington Water. Most of the traditional design advice for stormwater has focussed on engineering solutions to meet a level of service linked to a 100-year average recurrence interval storm. The infrastructure has focussed on the rapid conveyance of stormwater out of the urban environment to reduce flooding and improve public health. It has had limited focus on water quality treatment of potentially entrained contaminants.

The traditional stormwater infrastructure approach has also led to community disconnection, as streams have been piped (out of sight, out of mind), engineered (straightened channels with poor ecological health) and public access often minimised for both maintenance and safety reasons.

Wellington Water hold a five year interim year global stormwater consent that is focused on monitoring and reporting of the quality of stormwater discharges to fresh and coastal waters. The purpose of this interim consent is to develop a stormwater management strategy, which seeks to improve the management of adverse effects of stormwater discharges on ecosystem health, mahinga kai, contact recreation and Maori customary use.

Water sensitive design

The transition of stormwater infrastructure design from the traditional approach to that of water sensitive design (WSD) principles will help enhance community connection to the freshwater and marine environment and lead to improvements in water quality and ecological health. WSD is the principle of incorporating the natural water cycle and the subsequent management of this into stormwater design and aims to improve resilience of cities and communities.

Whilst the agglomerated "*Regional Standard for Water Services. Version 2.0*" (compiled by Wellington Water from various stakeholder councils) recommends WSD as the preferred approach to managing stormwater, there remains a number of barriers to WSD implementation for developers, local councils and Wellington Water.

Auckland Council has developed a suite of WSD planning and design documents to help guide developers, consultants and contractors, which could be used to help guide Wellington Region. Wellington Water are beginning to implement some regional guidance documents, and have recently produced a design guide for four types of water sensitive designs considered as 'green infrastructure'. However, a number of work packages are still underway or in some cases have not yet been started, including:

- Planning guidelines for different councils that incorporate site assessments and outline objectives for WSD. This will help inform designs in both greenfield, infill and brownfield developments.

- Ownership, operational and maintenance approaches for WSD green infrastructure. A draft document is being prepared by Wellington Water, which considers who will own the assets, how they may be vested to councils and ongoing maintenance responsibilities.

- Further design documentation for WSD green infrastructure, as the 2019 design guide only covers wetlands, swales, rain gardens and permeable paving.

- Industry education and compliance, which is necessary to ensure quality design and construction of WSD green infrastructure to reduce the risk of ongoing liabilities (relating to retrospective repairs or maintenance).

To integrate WSD into the Wellington Region, a number of these barriers will need to be addressed, and where possible should look at utilising/adapting previously documented material from other cities in New Zealand.

Stormwater scenario costs and total cost estimate

Assessment of the 50 year life cycle costs (including annual maintenance) relating to two scenarios are presented below. Costs presented include low to high ranges, which incorporates some uncertainty and sensitivity in costs for various WSD green infrastructure.

Life Cycle Cost estimates (LCC) for urban stormwater scenarios in Whaitua Te Whanganui-a-Tara (excluding all roof replacement costs[1] and wastewater renewals or repairs).

Urban stormwater scenario	**Total Life Cycle Cost over 50 years ($)**	
	Low	**High**
Improved	$596 million	$816 million
Water Sensitive	$1.83 billion	$2.73 billion
	Proportioned LCC ($/dwelling/year)[2]	
Improved	$83	$114
Water Sensitive	$255	$380

The direct costs presented above for implementation of WSD green infrastructure will have wider social, cultural and economic benefits. The costs needs to be considered with the estimates of repairing and replacing parts of the wastewater and potable network[3].

The total cost estimates for the scenarios (assumed to occur over 50 years) when the wastewater and stormwater mitigations are considered together, range from $2.7 – 3.4 billion for the Improved scenario, to $3.9 – 5.3 billion for the Water Sensitive scenario.

[1] Replacement of roofs at a rate faster than attrition over 50 years would incur much greater costs, which currently hasn't been accounted for in this assessment. Roof replacements primarily target heavy metal load reductions in the receiving environment.

[2] Only residential dwellings (~143,500) have been used to estimate annual LCC costs per dwelling. Commercial and industrial activities (and their business premises) would also contribute to LCC costs, meaning the values presented could be lower. Additionally, this assumes equal proportioning of costs across existing and new dwellings, when in reality, new builds may carry a greater cost burden.

[3] An assessment of potable network, population growth, water supply constraints and expert panel ecological flow scenarios has been considered in Blyth and Williams (2020).

Contents

1. Introduction

1.1 Background and objectives

This report is intended to provide an overview of the stormwater and wastewater network and their various issues and challenges within Te Whanganui-a-Tara Whaitua. The primary audience for this report is the Whaitua Committee, whom can utilise this information to help develop recommendations.

Stormwater and wastewater make up two components of the 'three waters' and are inherently interconnected. Both are integral for enhancing wellbeing within an urban environment, however also have an impact on water quality, human and ecological health and mana whenua values. Subsequently to achieve improvements, these systems should be considered jointly, not independently. The subsections below provide high level summaries on the main challenges these networks face, including aspects such as the condition of pipes, wastewater overflow locations and volumes, growth, common faults (cross connections, broken private laterals, gully traps) and investment comparative to other regions.

Finally, the report considers the feasibility of achieving some of the Whaitua Freshwater Quality and Ecology (FWQE) Improved and Water Sensitive Scenarios. These scenarios were considered by an Expert Panel and examined the effect on water quality and ecology, through increasing adoption of mitigations from Water Sensitive Design (WSD) implemented in many locations, fixing cross connections and significantly reduced wastewater overflows.

2. Overview and Connectivity of both networks

2.1 Overview

The wastewater and stormwater networks are two systems serving different purposes, however they do affect one another through historical direct and in-direct connections. The wastewater pipe network's purpose is to move wastewater from residential, industrial and commercial properties to plants for treatment and discharge to the environment. The network is predominantly underground, and made up of:

1. Publically owned wastewater assets such as treatment plants, underground wastewater mains (pipes), storage tanks and pump stations. The maintenance, operation and renewal of these assets are funded through rates, and managed by Wellington Water.

2. Private wastewater 'laterals' are smaller diameter pipes that connect wastewater from a residential dwelling or commercial premises to the publically owned assets (i.e. the wastewater main running down a street or in back yards of properties). These are owned by the property title holder (see Section 3.7.4 for more detail).

Whilst not included as part of Wellington Water's network, privately owned septic tanks are also wastewater management systems that require maintenance and repair. These are generally found in peri-urban (urban/rural fringe) and rural areas and are no longer permitted in urban areas.

The stormwater network is made up of natural assets such as streams, modified watercourses and overland flow paths and built assets that include gutters, sumps, pipes and pump stations. The built network's primary intent is to convey rainfall runoff to reduce standing water and flooding risk in urban environments, which aids public health and protects both people and their property, while allowing for ongoing development and a functional city. Generally, (through historic design principles focussing on water conveyance) little treatment of stormwater occurs in the built assets (limited to collection of sediment and litter in sumps) before discharge to the environment, except where Water Sensitive Design (WSD) has been implemented. The wastewater network is primarily underground, while the stormwater network is both above and below ground through overland flow paths and piped stormwater, often conveyed to open streams/water courses. Many small urban streams are modified by being entirely or partially piped, from the headwaters to the outlet at the coast. The network is primarily made up of:

1. Road corridor associated assets that include sumps, gutters and culverts that are typically managed by the Council Roading Departments or NZTA.

2. Publically owned built stormwater assets such as manholes, pipes, constructed wetlands, raingardens, and pump stations (where gravity flow is insufficient) managed by Wellington Water

3. Private stormwater 'laterals', which connect from a residential household or commercial premises to the publically owned assets (e.g. the stormwater main running down a street). These are owned by the property title holder.

4. Natural network such as streams, rivers, wetlands and modified watercourses are typically maintained or managed by the adjacent land owners which can include the local councils and Greater Wellington Regional Council.

5. There are also other owners and managers of stormwater assets such as very large industrial/commercial sites (such as airports).

2.2 Connectivity

Water and contaminants move between wastewater and stormwater networks in a number of ways. Some of these pathways are described below.

Infiltration from groundwater and salt water (in low lying city areas with tidal fluctuations) occurs into underground pipes that have leaking joints or are cracked or broken, and is worse over winter with higher water tables. This contributes to dry weather flows in stormwater and wastewater pipes (during periods of no rainfall) and increases overflow risk in the wastewater network. The earthenware pipes in Wellington were generally laid with mortar joints until about 1960 when rubber ring joints became standard.

Inflow from surface runoff occurs during storm events. By design, this would be through the stormwater network, however runoff can enter the wastewater network through:

- Residential faults such as low gully traps or direct connection of downpipes to gully traps. A gully trap receives wastewater from a kitchen, bathroom and laundry before it is emptied into the wastewater lateral. See Figure 1.

- Direct connections of stormwater pipe to a wastewater pipe, resulting in considerable inflow increases in the wastewater network during rain events.

- This excess inflow to the wastewater network is what causes overflows to occur into the natural environment. Inflow (from stormwater) and infiltration (from groundwater/seawater) are the primary reasons untreated but diluted wastewater ends up in our freshwater and marine environments, and in much greater volumes than direct wastewater cross connections.

Figure 1. Inflow from a residential property where the down pipe has been routed to a gully trap (connecting to the wastewater network). Image courtesy of Steve Hutchinson, Wellington Water.

Wastewater cross connections occur through direct connection of residential, commercial or industrial premises wastewater laterals to the stormwater network, resulting in discharge of human waste to the natural environment under both dry and wet weather flows. Cross connections are infrequent (anecdotally, most city councils detect <10 per year) and generally small in volumes compared to constructed overflows (with overflows occurring due to both inflow and infiltration and dry weather blockages). They can however impact the receiving water body over long periods and increase risks to human health during dry weather, which could be exacerbated if the receiving environment has small flow rates. See Figure 2.

Figure 2. While shocking, this is the reality of an illegal cross connection in Te Aro (Wellington City) from a private residence, where their waste was being routed to a stormwater main. The next rainfall event would transport this to Wellington Harbour. Image courtesy of Steve Hutchinson (Wellington Water).

Wastewater constructed overflows are installed by design (i.e. are not a deliberate or neglectful cross connection) to prevent wastewater backflows from pipe or pump station failures due to emergency conditions or over-loading. This can be through a direct opening in a wastewater main, which would overflow into a nearby stormwater main, manhole, stream or coastal environment to avoid wastewater spilling onto private property or public areas. The greatest volume of wastewater discharged to the receiving environment is through constructed overflows, which results from a combination of issues including lack of capacity, blockages, inflow and infiltration.

Wastewater un-constructed overflows occur through backflow of wastewater out of low-lying manhole lids or gully traps. These present a higher risk of public health risk. These are difficult to measure and quantify and can mix wastewater with floodwater in surface flooding situations. Again, these are caused through a combination of issues including lack of capacity, blockages, inflow and infiltration. See Figure 3.

Figure 3. Un-constructed overflow occurring from a manhole lid. Image courtesy of Steve Hutchinson, Wellington Water.

Exfiltration (leakage) from wastewater network to stormwater, through cracked or broken pipes or leaky joints. This exfiltration can enter groundwater and stormwater pipe networks, eventually making its way to the environment, although some treatment can occur along the way (through natural biological processes). Further details on exfiltration, inflow, infiltration and cross connections and solutions to resolve some of these issues has been detailed in Section 3.7.

3. Current state of wastewater network

3.1 Historical network development

The wastewater system has traditionally been focused on the prevention of transmittable disease by drainage of wastewater from properties. Recent decades have seen a shift to incorporate cultural and environmental aspects in the conveyance, treatment and disposal of wastewater.

The development of the wastewater network (dating back to the 1872 Health Act) has been described in the Whaitua Committee Meeting 8 Notes (Wellington Water Limited 2019a). Development of the network started as far back as 1890. Basic treatment in Wellington began in the early 1980's, with milliscreening of larger solids. By 1998, Moa Point wastewater treatment plant was constructed, with an 1800 m ocean outfall to the south coast.

At Karori, the outfall to the south coast was constructed in 1930, with a septic tank also built to provide some settling of solids before discharge. The current wastewater treatment plant was constructed in 1996.

Hutt Valley has developed in stages, with some sewers in Petone dating back to 1895, while the main Hutt Valley and Wainuiomata wastewater networks were installed between 1940 and 1960. An 18 km outfall sewer from Seaview running to Bluff Point (past Pencarrow Lighthouse) was constructed in 1962, with some grit removal and maceration before discharge to the coast. Fine screening was installed in 1984 and a modern treatment plant was commissioned at Seaview in 2002, with Wainuiomata wastewater also being pumped to this treatment plant around the same time (rather than being treated and discharged to the Wainuiomata River).

3.2 Ownership and management structure of the network

3.2.1 Historical framework

Prior to the establishment of Wellington Water Limited and its predecessor Capacity Infrastructure Services, the wastewater and stormwater networks were both owned and managed by local authorities (councils), using their own internal staff and contractors to ensure the networks were operational. Funding was through rating payments, and investment into infrastructure was focussed on repairs and replacements where necessary, primarily based on asset age or condition or subsequent failures, with major infrastructure such as treatment plants required by resource consents.

In Wellington City, wastewater laterals connecting residential/commercial premises to the network were managed by the City Council between 1992 and 2005 for the section from the property boundary to the main. By 2005, Wellington City council passed a policy (The Lateral Policy 2005) which transferred ownership and responsibility of those sections of wastewater laterals back to the property or title holder (see Section 3.7.4 for more detail on private laterals).

Significant investment into wastewater treatment plants occurred in the 90's and early 2000's, and shortly after the completion of the Seaview wastewater treatment plant, Capacity Infrastructure Services ('Capacity') was created (2004).

Capacity was established as a shared service council controlled trading organisation, jointly owned by the Hutt and Wellington city councils. Capacity took over the management of the three waters infrastructure and strategic planning, on behalf of the local councils who maintained ownership of the assets. Between 2008 and 2013, Capacity expanded to incorporate the Porirua and Upper Hutt city councils as equal shareholders.

In 2014 Wellington Water Limited was formed as a result of a merger between Capacity and Greater Wellington Regional Council's water supply group. The equal ownership now extends to Hutt, Porirua, Upper Hutt and Wellington City Councils, South Wairarapa District Council and Greater Wellington Regional Council.

3.2.2 Current framework

Within this Whaitua, Wellington Water manage and operate the three waters network across four stakeholders; Hutt, Upper Hutt and Wellington City Councils and finally, Greater Wellington Regional Council. Outside of this Whaitua, Porirua City Council and South Wairarapa District Councils are also shareholders in Wellington Water. Wellington Water's 2018/19 annual report provides a detailed summary of the operations and purpose (Wellington Water Limited 2019). A proportion of local council rates are allocated to Wellington Water annually, in addition to revenue that is received from occasionally charging third parties for work performed. In 2018 and 2019 the total revenue was ~$154 Million and ~$136 Million, respectively (Wellington Water Limited 2019).

There was a decrease in revenue and operating expenses in 2019 (from a budgeted revenue of ~$152 Million) due to a number of large council capital expenditure projects (CAPEX) which were delayed.

Operational works (OPEX) are conducted through an Annual Work Programme, developed from the long-term plans of councils, which is delivered on a financial-year basis. Wellington Water enters into contracts with contractors to perform the work and manages the programme. CAPEX work is determined through an Annual Work Programme that is jointly agreed with councils. Wellington Water is responsible for the procurement process, including the selection of contractors and contract pricing, and enters into contracts with contractors who perform the work (Wellington Water Limited 2019).

Under this funding framework, some of the following strengths and weaknesses have been identified for consideration by the Committee.

Strengths:

- Wellington Water can integrate strategic planning across three waters, particularly important for stormwater and wastewater

- Regionalisation enables a centre of knowledge for water management otherwise not viable in smaller councils

Weaknesses:

- Land-use planning in territorial authorities a split from catchment management planning (i.e. source protection) at Wellington Water. This is a constraint across all three waters networks, but particularly for stormwater management.

- Wellington Water cannot change the funding regime to increase performance, OPEX or CAPEX programmes. Wellington Water are limited to making recommendations on funding levels and approaches and then strategically planning these with the various council stakeholders.

3.2.3 Three waters reform

Central government are currently undertaking a ‘three waters review’, which is looking into the improvement of the regulation and supply arrangements of drinking water, wastewater and stormwater (DIA 2020). This is led by the Minister of Local Government and began in mid 2017. The review is ongoing, however at the time was running in parallel to the Havelock North Inquiry, where a campylobacter outbreak in drinking water resulted in up to 5500 people being ill and potential four deaths.

The review considers three essential aspects of the three waters (DIA 2020):

- Health and safety: safe drinking water, safe disposal of wastewater and effective stormwater drainage

- Prosperity: adequate supply of cost effective three waters services for housing, businesses and community services

- Environment: well managed extraction of drinking water, and careful disposal of wastewater and stormwater

The current three waters environment puts onerous constraints on small towns and rural regions who have limited staff and ratings base to achieve the high quality standards of treatment and discharge required under various national regulations. Pressures on smaller providers has been exacerbated by the amended drinking water standards (Ministry of Health 2018) which were revised following the Havelock North outbreak.

The review will consider new service delivery mechanisms that may result in agglomerations of councils within and potentially across regions, which is proposed to occur over a 5 year period (from 2020). Currently, the exact distribution and nature of these new service delivery groups is evolving through direct council to council correspondence, however the government may help facilitate or recommend certain arrangements. The potential benefits of such an arrangement would allow for a larger rating base to cross-share infrastructure investment around regions (Mahuta 2020).

The government also has developed a new bill (Taumata Arowai – Water Services Regulator Bill), which seeks to create an independent three waters regulator whom will regulate and check compliance (primarily relating to drinking water) for the various service delivery arrangements that are yet to be finalised.

Wellington Water Limited is a good example of what these service delivery mechanisms may look like around the country, where an agglomeration of local councils will collectively contribute rates to a management and operational entity.

3.3 Effects of wastewater in the environment

The makeup of wastewater has been described in Wellington Water Limited 2019a. Essentially, wastewater is made up of tradewaste (from commercial premises), blackwater (faeces, urine and sanitary products) and greywater (taps, washing machines, showers). The highest microbial and nutrient loads come from blackwater.

The impacts of untreated wastewater in the environment are highly dependent on factors such as:

- How diluted an uncontrolled discharge is (for example, a wastewater overflow occurring during a storm event may be diluted by a factor of 1:10, and then be flowing into a stream environment with high flows for additional dilution).

- How much volume a direct cross connection could be delivering (for example, where wastewater is connected to stormwater and discharging to the environment with no treatment).

- The volume of water in the receiving environment at the time of discharge

- Whether the receiving environment is popular for contact recreation of Mahinga kai gathering

Treated wastewater (see Section 3.7.7) is discharged to the coast and is treated to a standard where there is no significant environmental impact beyond the mixing zone, which varies between 100 and 200 metres for the main treatment plants (see Figure 4 as an example).

Figure 4. Moa point outfall discharging treated wastewater (image courtesy of Wellington Water, video available https://www.youtube.com/watch?v=9fKpdZVDIzc)

The impact of wastewater in the aquatic environment can be highly variable, but generally have greatest impact when discharge is untreated and/or uncontrolled. Generally, wastewater can have impacts on:

- Microbial pathogens (bacteria, viruses and protozoa) which are measured by a bacterial indicator *E.coli* in freshwater environments, or *enterococci* in coastal environments. This can cause illness through contact recreation and food gathering, and is the basis for the NPSFM swimability attribute states (ranging from A to E).
    - Most urban streams often measure as an E attribute state (unsafe for contact recreation), due to lower stream flows (less dilution) and inputs from human, and to a lesser extent animal (from faecal inputs from pets and, farmed and wild animals) wastewater. The levels of E.coli can be highly variable, particularly in regard to rainfall.
- Oxygen availability within the aquatic environment. The effects of wastewater is primarily measured through Biochemical Oxygen Demand (BOD_5), which shows how much oxygen bacteria require to break down the organic component of wastewater over a 5 day period.

- Untreated wastewater can have a BOD_5 concentration of 200–300g/m^3, while the BOD_5 for a healthy aquatic ecosystem would be less than 5 g/m^3 (Ministry for Environment 2003).

- The impact of wastewater discharge on the receiving environment is therefore dependent on its naturally occurring dissolved oxygen levels (DO). Higher DO concentrations (i.e. > 8 g/m^3) may mean greater oxygen is available for bacteria to break down wastewater, while providing oxygen for fish and macroinvertebrates. This is highly variable, with impacts during uncontrolled overflows likely to be less than dry weather cross connections of wastewater entering a stream. Lower DO concentrations and wastewater discharge can result in an anaerobic environment that may kill some aquatic fauna, but this is rarely observed.

- Nitrogen (in all forms, including nitrate and the toxic sub-species, ammonia) and phosphorus. Inputs from untreated wastewater can be significant for an aquatic body, where nitrate-nitrogen and dissolved phosphorus concentrations can be around 30 g/m^3 and 10 g/m^3, respectively.

  - These inputs can lead to eutrophication at quite low concentrations, and toxicity to aquatic life at higher concentrations. Eutrophication arises from excess periphyton (algae) and macrophyte growth, which can reduce light penetration and oxygen levels in water, and smother streambed habitat.

  - Ammonia, primarily created through urine, can have toxic effects at low concentrations on aquatic fauna.

3.4 Wastewater pipe condition

3.4.1 Extent and condition

Table 1 provides an overview of the structural condition assessment grades applied to wastewater and stormwater pipes, following the WaterNZ Pipe Inspection Manual. This has been adapted from Appendix B of the report 'Potential Implications for Upper Hutt to meet the 2017 NPS-FM E. coli Objectives' (Wellington Water Limited 2019b).

Figure 5 presents the network extent, condition and 2018/19 overflow locations.

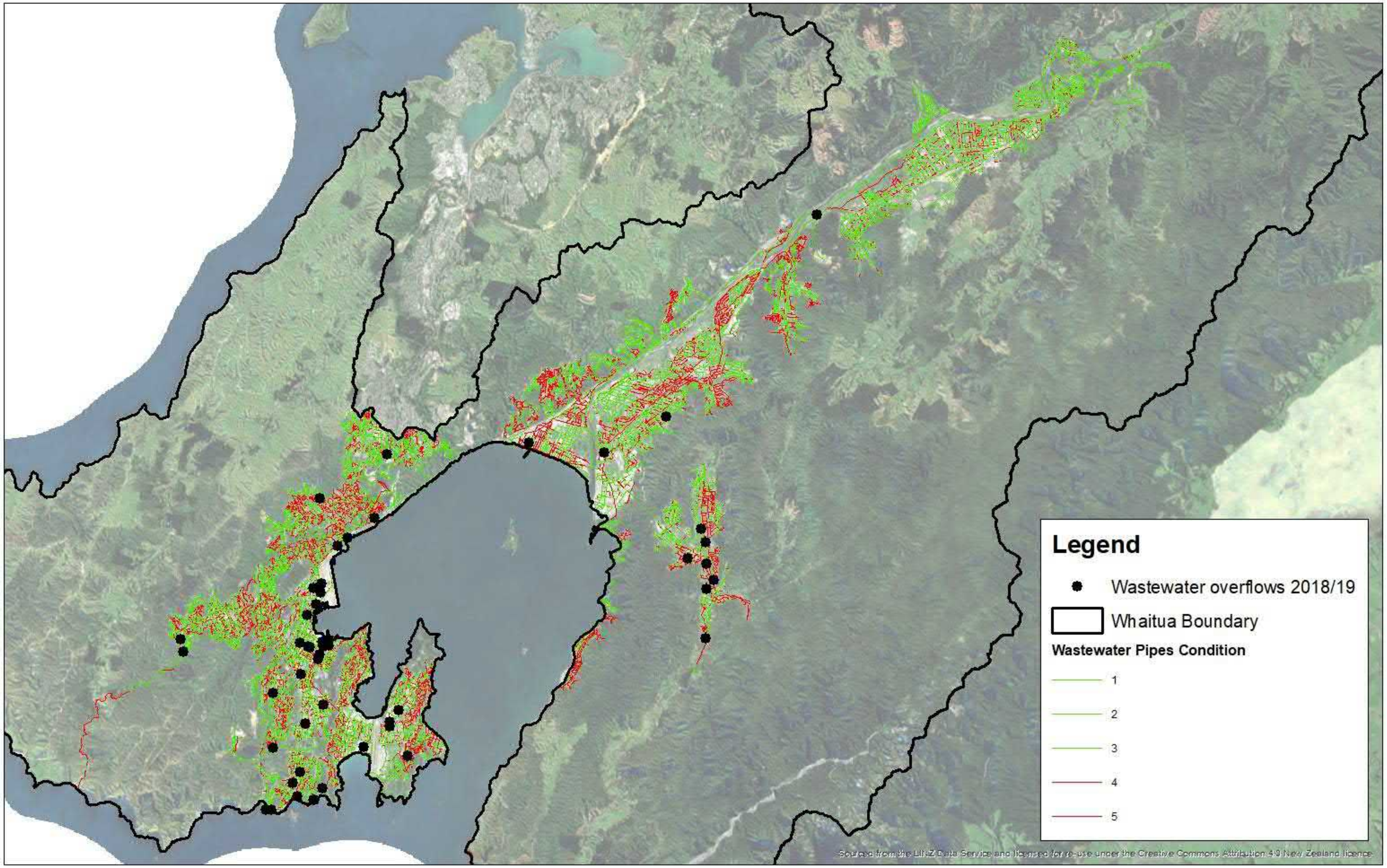


Figure 5. Wastewater pipe condition (green = condition 1 to 3, red = 4 to 5) and locations of monitored overflows in 2018/19

Table 1. Pipe condition glossary

Condition Grade	Classification	Description and action
1	Very good	New or near new condition. No action required.
2	Good	Minor damage or deterioration, includes most repaired assets. Monitor to see if there are changes.
3	Moderate	Needs some attention but is still working, may need repair. Consider specialist assessment.
4	Poor	Either not working or working poorly from damage or deterioration. Structural integrity in question. Undertake a specialist assessment.
5	Very Poor	Needs attention. Replace or repair.

Appendix B presents a figure of the subcatchments assessed within this Whaitua, and the larger expert panel assessment units (which were agglomerations of subcatchments used to assess general water quality trends and responses to scenarios).

Table 2 documents the length of the wastewater network for different pipe conditions within the subcatchments. This is supported by Figure 6, which breaks down the subcatchments into the worst condition pipes (grade 4 and 5), as a proportion of the total pipe length. It should be noted, some catchments have small network lengths due to their delineation in GIS, such as Te Awa Kairangi lower mainstem (which represents the main river channel only).

Asset condition is determined primarily through video inspection. In many cases where pipes have not been recently inspected, condition has been extrapolated from other similar age and materials. These conditions therefore represent an approximation of the state of the public wastewater network and should be used as an indicative guide only. No data is readily available on the private laterals which extend from each house to the public main.

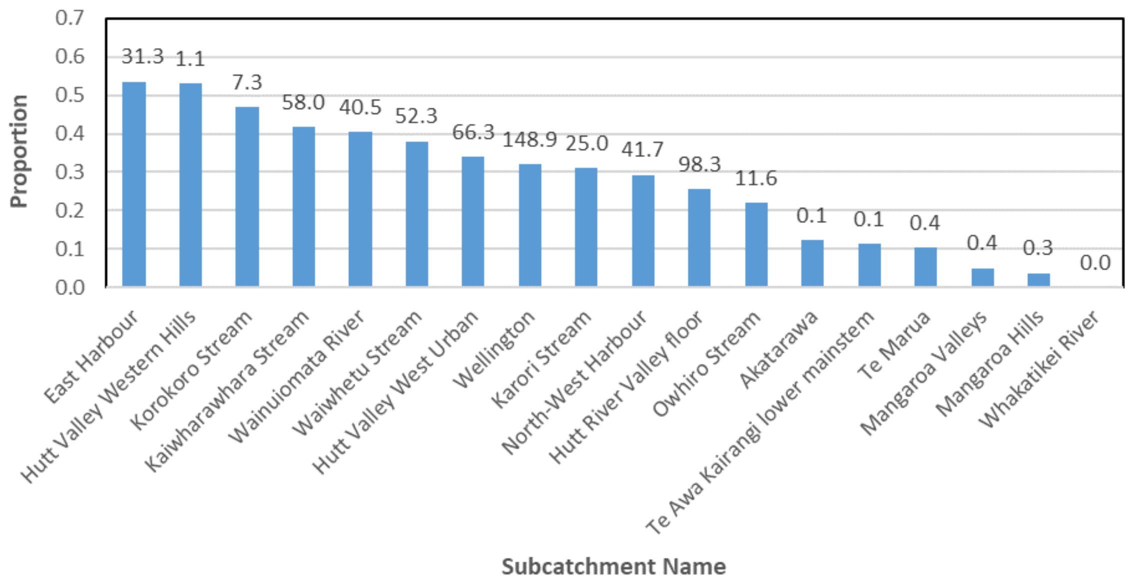


Figure 6. Proportion of poor/very poor (grade 4/5) wastewater pipes relative to total length, by subcatchment. Lengths (km) of 4/5 pipe are presented above the bars.

Table 2. Length of public wastewater pipe by condition rating and subcatchment within Te Whanganui-a-Tara Whaitua.

Subcatchment Name	Condition					Total Length (km)
	1	2	3	4	5	
Wellington City	126.9	102.1	85.1	36.3	112.6	463.0
Hutt River Valley floor	126.6	67.1	91.1	44.5	53.8	383.1
Hutt Valley West Urban	49.0	24.9	55.4	17.1	49.2	195.7
North-West Harbour	38.3	30.8	31.4	22.6	19.2	142.2
Kaiwharawhara Stream	28.7	26.0	26.5	11.9	46.1	139.2
Waiwhetu Stream	41.5	21.0	22.6	31.3	21.0	137.4
Wainuiomata River	30.1	19.5	10.3	23.3	17.2	100.4
Karori Stream	19.6	19.0	17.1	15.5	9.6	80.8
East Harbour	18.6	1.2	7.7	1.3	30.0	58.7
Owhiro Stream	21.5	12.6	7.2	3.9	7.7	53.0
Korokoro Stream	4.5	0.6	3.1	6.5	0.8	15.5
Mangaroa Hills	4.8	1.5	0.8	0.1	0.2	7.4
Mangaroa Valleys	6.1	0.7	0.2	0.2	0.2	7.4
Te Marua	2.4	0.6	0.5	0.2	0.2	3.9
Whakatikei River	2.9	0.0	0.0	0.0	0.0	2.9
Hutt Valley Western Hills	0.3	0.3	0.4	1.1	0.0	2.1
Te Awa Kairangi lower mainstem	0.1	0.6	0.0	0.1	0.0	0.8
Akatarawa	0.4	0.0	0.2	0.0	0.1	0.8

Table 2 and Figure 6 show:

- The total estimated length of public wastewater pipes within the Whaitua is ~1,794 km.
- The estimated length of grade 4 and 5 (poor/very poor condition) pipes in the Whaitua is 583 km, ~32% of the total wastewater network.
  - 20.4% of the total wastewater network is considered grade 5 (very poor condition), in need of attention.
  - Wellington City (148.6 km), Hutt River Valley Floor (98.3 km) and Hutt Valley West Urban (66.3 km) contribute 53.7% of the grade 4 and 5 pipes for the entire Whaitua.
- East Harbour (Eastbourne) has the highest proportion of poor/very poor condition wastewater pipes, at ~53% of the catchments network, or 31.3 km (see Figure 6).
- The Kaiwharawhara and Waiwhetu Streams also have high proportions of poor/very poor condition wastewater pipes (~42% and 38% respectively) with greater lengths than East Harbour (58 km and 52.3 km, respectively).

3.4.2 Age

A regional breakdown of wastewater pipe ages are presented in Figure 7. The condition assessments presented above are generally reflective of pipe age, where older pipes that are subject to decay and damage (for example, from ground movement and tree roots) are likely to have a poorer condition rating (grade 4 and 5). Age does not always reflect condition however, as new pipes can still fail unexpectedly due to manufacture and installation defects (see Section 3.7.7).

The Water Performance Report (Water New Zealand 2020) provides an overview of pipeline age, with the wastewater network averaging 53 years old. Similar age pipes exist in Auckland, with an average of 45.3 years. Within some Whaitua suburbs, there are significant lengths of wastewater pipes that were installed as far back the early 1900's (for example, an estimated 130 km of wastewater pipe in Wellington City is likely to have been installed between 1900-1920).

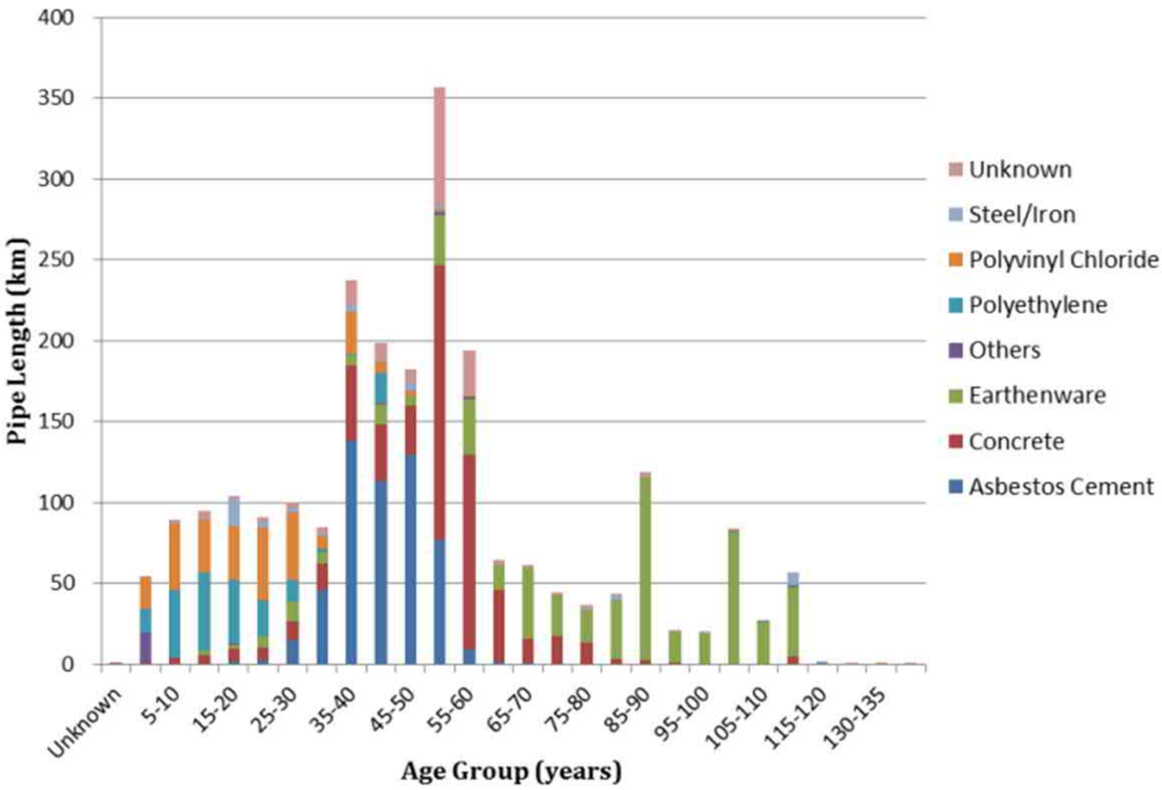


Figure 7. Regional wastewater pipe age profile (Hutchinson 2018).

3.5 Wastewater pipe overflows

Wellington Water have been documenting overflows through the network using telemetered flow meters at ~50 constructed overflow locations (some of which are presented in Figure 5). This is required as per the Global Stormwater Consent (GHD 2017). Not all overflow locations are monitored under this consent, and there are undocumented constructed overflows that are still being identified and added to the network. Without monitoring at all locations, the total volume and frequency of wastewater overflows cannot be determined with confidence, as an unmonitored site may in fact be significant in terms of environmental impacts. Wellington Water run hydraulic models of the wastewater network to identify problem areas and potential overflow locations, which help fill in monitoring gaps, coupled with operational staff and public identifying overflow locations.

Wastewater overflows occur at both unconstructed and constructed overflow locations, the latter are put in place as emergency fail safes to prevent uncontrolled discharge of wastewater to private property or publicly accessible locations. These overflows generally occur during wet weather events (heavy rainfall) and result in wastewater spilling into the natural environment (streams, including modified watercourses, the coastal marine area, or in some cases the Hutt River). Dry weather overflows occur periodically due to blockages, broken pipes or pump failures (Wellington Water Limited 2019a) but are generally short in duration and are often contained before they reach aquatic environments. Lack of capacity in the network (for example where a pipe is undersized or has no additional capacity during wastewater peaks) is also a significant driver for overflows. The most common causes for overflows have been described in Section 2.2. Figure 8 shows the constructed overflow at Silverstream on Te Awa Kairangi (the Hutt River).

Figure 8. Silverstream weir and constructed overflow. Image courtesy of Shearer (2017).

3.5.1 Number and volume of overflows in 2018 and 2019

Wastewater overflows from 1 January 2018 to 12 January 2020 are presented in Table 3 for the subcatchments within te Whanganui-a-Tara Whaitua. These are based on monitored overflow events recorded by Wellington Water and does not capture all overflow locations and their associated overflow volumes, or the discharge volumes related to unplanned dry weather events (from blockages or pump failures). Subsequently, the volume of wastewater discharged would be higher than presented in Table 3. Also note that these overflows are from the network only. Bypasses of partially treated wastewater from the treatment plants are not included.

The volume of wastewater that overflows is difficult to measure, as often the sites where overflows occur (in wet wells) have not been designed for accurate flow measurements. Overflows are highly variable across different years, depending on climate (wet or dry years) and where localised storm events occur. Subsequently, the outputs in Table 3 and Appendix A are a guide only to indicate that there are additional problematic sites distributed across the network.

In 2018 and 2019, the greatest estimated volume and frequency of overflows occurred in the following subcatchments:

1. Hutt River Valley Floor (specifically at Silverstream) – 194,598 m^3 over 2 years, with an average of 6 overflow events per year.

2. Wainuiomata – 88,637 m^3 over 2 years, with an average of 20.5 overflow events per year.

3. Wellington City – 17,799 m^3 over 2 years, with an average of 24.5 overflow events per year.

By contrast, in 2016/17, the estimated highest volumes of overflows occurred in the following subcatchments:

1. Hutt River Valley Floor (specifically at Silverstream) - 243,480 m^3 in 1 year

2. Wellington City - 70,288 m^3 in 1 year

3. Wainuiomata – 60,740 m^3 in 1 year

Table 3. Number of overflows and estimated volumes per subcatchment from 1/1/2018 until 13/1/2020 (~2 years).

Sub Catchment	No. of recorded Overflows	No. of overflow locations	% (whole Whaitua)	Overflow Volume Estimate (m^3)	2018 Events	2019 Events	Avg /year
Wellington	156	51	57%	17,799	19	30	24.5
Wainuiomata River	82	14	30%	88,637	18	23	20.5
Owhiro Stream	5	3	2%	104	0	4	2
North-West Harbour	4	3	1%	2	2	1	1.5
Karori Stream	8	2	3%	678	2	3	2.5
Kaiwharawhara Stream	2	2	1%	-	1	1	1
Waiwhetu Stream	6	2	2%	2,596	3	2	2.5
Hutt River Valley floor	12	1	4%	194,598	9	3	6
Hutt Valley West Urban	0	0	0%	-	0	0	0

The ‘top 10’ wastewater overflow assets by volume and frequency for the 2018 and 2019 years have been presented in Appendix A – Wastewater Overflows.

3.6 Wastewater Network Design Standards

Wellington Water has agglomerated a number of the various councils stormwater, potable water and wastewater standards in the document "*Regional Standard for Water Services"* (Wellington Water 2019e). This sets out the levels of service required for wastewater infrastructure.

The performance criteria requires designs for wastewater infrastructure to have a nominal operational and structural design life of 100 years and be designed in a way that minimises renewal and maintenance costs, and any adverse effects on the environment.

In situations where the existing network is affected by a development, upgrades shall meet the following minimum standards (which may need to be assessed in the wastewater model):

- Overflows at unconstructed locations shall not be made worse (volume or frequency)
- Detention, if approved by Council, should provide storage for 24 hours average dry weather flow for non-pumped systems.

Residential wastewater pipe designs must account for peak wet weather flows (PWWF), which includes a proportion of inflow and infiltration that could or will occur at some point of the pipes lifespan. Wastewater pipes ideally should gravity drain, however where this is unfeasible, pump stations would be designed to continue wastewater conveyance to treatment plants. The network is intended to be designed to account for future development within a catchment, however in some situations network capacity may be exhausted.

In new or re-developments (i.e. greenfield and brownfield) where the receiving network capacity could be affected from additional wastewater, some privatisation of wastewater assets can occur. This may mean the development of wastewater storage tanks within a subdivision that can attenuate peak flows, wastewater pumping stations and even onsite treatment and land discharge (on rare occasions). In these situations, the developer and eventually the residents of the development will be responsible for the maintenance of this asset, which may be funded through body corporate arrangements. There is generally limited monitoring or compliance checks of these private assets by Wellington Water or various council stakeholders. In other cases the assets are built by the developer and "vested" to Council for Wellington Water to manage, operate and maintain.

3.7 Wastewater network considerations

This section describes some common faults and ongoing problems in the wastewater network while also providing information on available funding and potential solutions. It is not intended to provide a comprehensive overview of the many technical solutions available, but is intended to identify some areas for further discussion within the Whaitua Committee.

3.7.1 Replacement of pipes

Currently, replacement and repair of pipes by Wellington Water is undertaken on an as needed basis, with strategic planning also undertaken on assets through a risk-based approach. This is driven by operational budgets (determined by the allocations from local council stakeholders contributing to Wellington Water) and priority locations, where pipes that have failed or near failure (grade 5 and 4) will be of the first priority over those that are still functioning but are potentially leaking or damaged (verified through CCTV inspections).

The Water Performance Report (Water New Zealand 2020) details the various infrastructure costs for the three waters networks annually. Over two years (2018 and 2019), the average capital expenditure for the wastewater network per property has been reported in Table 4. This is a snapshot in time, with some cities having higher growth than others, which may affect the comparisons.

Table 4. 2018 and 2019 average wastewater capital expenditure per property around New Zealand (data sourced from Water New Zealand 2020).

City	Average $/property	Difference (from 2 year average)
Tauranga	571	40%
Auckland	553	36%
2 year average (from presented cities)	408	-
Hamilton	380	-7%
Christchurch	355	-13%
Wellington Water	180	-56%

Through 2018 and 2019, Auckland has spent over 3 times the CAPEX amount (per property) on wastewater than Wellington Water (as governed by its various shareholders). The cost to replace the grade 4 and 5 wastewater pipes within this Whaitua has been estimated by Wellington Water (Wellington Water Limited 2020b) at $1.4 - 1.7 billion (see Section 5.3 for more detail on the assumptions and limitations of this assessment). The priority of which replacements are undertaken could be driven by a risk based approach of critical infrastructure, identifying which are the assets that pose the greatest risk (currently, or during a failure) and would have the greatest social, environmental and economic impact.

There are many suburbs that have poor condition pipes of varying extents. Determining which suburbs are the priority over others to begin targeted asset renewals may require guidance from the Whaitua Committee, if this differs from undertaking a risk based assessment.

3.7.2 Identifying and fixing cross connections

Cross connections have been described in Section 2.2. This section considers the direct connection of wastewater into stormwater (often accidentally or by neglect). Wellington Water has an active programme of monitoring to identify cross connections. This has been through sanitary surveys (visually), public observations and complaints and a water quality sampling programme, where high *E.coli* concentrations >10,000 cfu/100 mL triggers additional investigations.

Wellington Water has initiated a ‘roving crew’ option for council shareholders that want to undertake more proactive detection of cross connections. Porirua City Council (PCC) is the first council to adopt these extra measures, and are allocating an additional $250,000 per annum to the investigations (Campbell 2020). The roving crew will undertake proactive measures to identify cross connections and leaking laterals, rather than reactively responding to trends in water quality or reports from contractors and the public. This will help identify historic cross connections that may have been occurring for long periods, but are hard to detect due to infrequency of wastewater discharges.

Currently, the framework of roving crews is still being setup and decided upon, including the total number of full time employees needed. It is likely that to assess the extensive private network across many catchments (which also requires seeking landowner permissions) will take many years, assuming a budget of $250,000 per annum. Future assessments on the amount of testing completed over a year of roving crew work will help determine the effort and time needed to assess the entire Whaitua (if this is considered an option worth pursuing).

Communication with local councils, drainlayers and inspectors has identified common themes relating to the ongoing occurrence of new cross connections in Wellington. These are described below and could be resolved with some simple solutions.

1. Surveyors/design companies wrongly identify “as-built” drawings (stormwater versus wastewater pipes). Drainlayers/plumbers then undertake the works on new dwellings and may not verify the connection to the correct network (through lifting manholes, flush tests or smoke/dye tests).

    a. Wellington Water signs off new subdivision connections to the existing or future public network (not beyond the private boundary). However ‘tie ins’ for private property laterals (which may occur sometime later) are signed off by the local council inspectors as part of a building consent process.

    b. On private property, private lateral connections and plumbing in new buildings are signed off by local council inspectors, with council compliance certificates (CCC’s) issued on numerous items, with plumbing/drainlaying often a single line item of many on the CCC. The inspector takes assurance from the drainlayers design drawings, accreditation, and certification of works.

2. There is no requirement in the Building Act or national standards for different diameter or coloured wastewater and stormwater pipe. Often 100 mm PVC pipe is used for both stormwater and wastewater, as it makes it easier for the drainlayer as limits the number of fittings required (i.e. a quicker process).

3. While plumbing works are covered by a 10 year period of liability (as well as some of the as-built design drawings by appropriate companies), the level of detail required to verify or prove the connection is often limited. For example, there is no requirement for photographs or no way to record if a flush or dye test has been conducted.

Some recommendations to help reduce the number of new cross connections could include:

1. Requirement for all new connections to be proved, through photographs of the connection point and/or physical testing (flushing water or dye testing). For existing dwellings that may have a historic cross connection, smoke testing and dye testing can be conducted. Smoke testing cost estimates from Hutt City Council were ~$1000 for 14 dwellings. CCC and drainage permits would only be issued if this information was provided.

2. Consideration of different size or coloured pipe for wastewater, however this may require changes to national and regional standards.

a. While the standards vary through councils, there is often a requirement for drainlayers to mark the wastewater pipe. This maybe through spray-painted end caps, duct tape or pegs in the ground. Potentially this could be standardised across all councils, with a similar method required that would identify a wastewater connection. Consultation with the industry would help identify their most preferred option. This would help in situations where different drainlaying companies undertake connections.

Wellington Water have identified a number of reasons for cross connections occurring and are taking steps to address these through education and communication with the industry, changes to regional standards, and if possible contributing to changes to national standards.

Correcting cross connections may not always result in a significant improvement in stream health as ongoing all weather leakage of wastewater (if the pipes are in poor condition) or overflows may continue to release significant levels of contaminants into the receiving environment. This is because of the high pathogen concentration of raw wastewater, with E.coli levels that can exceed 1,000,000 cfu/100 mL (Metcalf and Eddy 2014). A single cross connection that isn't identified could also have ongoing environmental and health implications, however is dependent on the receiving water body (i.e. small urban stream versus a dynamic coastal environment).

Illegal cross connections (from residents or unlicensed practitioners undertaking their own wastewater connections) anecdotally do occur, albeit infrequently (from anecdotal discussions with councils and plumbers). However, these are often relating to sinks, wash basins and occasionally showers, rather than toilet connections. Subsequently, this can increase greywater into the natural environment.

3.7.3 Reducing Inflow and Infiltration (I & I)

Inflow & Infiltration (I & I) into the wastewater network from groundwater and stormwater can significantly reduce the ability of a pipe to convey waste during winter, high tides (for coastal infrastructure near sea level) and storm events. Prior to the Local Government Act in 1974, which was amended in 2002, there was little legal requirement to keep stormwater out of the wastewater network, with older residential dwellings able to connect their downpipes to gully traps. This can have significant impacts in some older suburbs which haven't had active campaigns to reduce I & I.

Figure 9 shows what can happen if there is excess I & I, in this case leading to an un-constructed overflow.

Figure 9. Un-constructed raw wastewater overflow discharging to the environment. Image courtesy of Steve Hutchinson, Wellington Water.

Significant investment in Waiwhetu (Lower Hutt) has occurred since 1999 on wastewater and stormwater infrastructure, including private laterals. Stormwater was overloading the wastewater system during storm events, resulting in overflows into the environment, and particularly into the Waiwhetu Stream. Wastewater mains were CCTV inspected and pressure tested. Over $8 m was spent on network improvements between 2004 and 2010, which resulted in the repair and replacement of ~7 km of wastewater pipe. Overflow storage tanks were also installed at a number of locations, to contain some of the overflow volume during events, which can then gravity feed back into the wastewater network as the flow subsides (Beachen 2015). Repairs of cross connections and broken/damaged private laterals were the responsibility of the owner, who is required to undertake the repairs through a Hutt City Council policy (Beamsley 2009).

An assessment of 2,422 properties found that over 1,328 (54.8%) had private laterals that did not pass a basic water pressure test (Beamsley 2009). Repairs to these lateral (and associated) costs were the responsibility of the owner and not included in the $8 M network cost mentioned above, although HCC paid for the inspection and arranged contractors where property owners requested. Following completion of these upgrades, assessments in 2009 and 2015 showed that rainfall inflow (from stormwater cross connections) reduced 90% over summer and 60% over winter, significantly reducing wastewater overflows to the environment (with a return period of 5 years and 2 years for summer and winter, respectively) (Beamsley 2009 and Beachen 2015).

Wellington Water have estimated the cost to reduce overflows in this Whaitua through storage of events up to 0.5 year average recurrence interval (ARI) would be ~$430 – 530 million

(Wellington Water Limited 2020b). See Section 5.3 for greater detail on the assumptions and limitations of this assessment.

Active campaigns to reduce stormwater inflow into the wastewater network through property inspections would help to identify and resolve some of the capacity issues. Gordon George (Hutt City Council) advised that over 36,000 properties have been inspected since 1999 in Porirua, Upper Hutt and Hutt City districts (personal communication 4 May 2020). The inspections are undertaken as discrete projects ranging in size where a batch of dwellings may be inspected and inflow issues resolved. Some of these projects are outsourced to consulting firms. In addition, the suburb of Karori over the last 12 months has had a smoke testing programme to trace stormwater and wastewater connections.

Figure 10. Smoke testing indicating presence of stomwater connections to the wastewater network. Image courtesy of Wellington Water (https://www.wellingtonwater.co.nz/faqs/wastewater/smoke-testing/)

Infiltration (from groundwater and sea water) requires significantly more investment as it is linked to leaky pipes and asset renewal, repair and replacement (see Section 3.7.1). In low lying areas, sea level rise is and will continue to impact on wastewater pipes that are prone to leaking and infiltration, particularly where tidal movements can force groundwater and salt water back into the network. This requires ongoing pumping efforts (increasing operational costs) to maintain the network and also additional treatment issues with salt water at the treatment plants.

3.7.4 Private laterals

Section 3.4.1 details the condition of the public wastewater network, however little information is available about private lateral connections. It is likely that most private laterals that have not been repaired or replaced (due to a failure) have had little to no maintenance since a property was constructed and the older ones will have generally had mortar joints used in construction. Subsequently, many are likely to now be leaking.

Wellington Water have estimated the cost to replace private laterals in this Whaitua at $250 – 350 million (Wellington Water Limited 2020b) (see Section 5.3 for more detail on the assumptions and limitations to this assessment). In some situations, local council investigations has resulted in private lateral upgrades that may be undertaken by council arranged contractors and paid off through rates (see Section 3.7.3 in regards to Waiwhetu Stream and Beamsley 2009 for more detail). However, across various councils, the management of private laterals differs (for more detail, visit https://www.wellingtonwater.co.nz/faqs/wastewater/lateral-blocked/).

- In Hutt City, private laterals are privately owned beyond the property boundary to the council main, however if a blockage or damage occurs to the lateral outside of the property (that isn't the owners fault), Hutt City will repair this.

- Within Upper Hutt City, laterals are a mixture of entirely privately owned (to the council main) and private/publically owned (with the public section considered to be outside of the property boundary as per Hutt City).

- In Wellington City, private laterals are also privately owned beyond the property boundary to the council main (like Hutt City), however owners are generally liable for any damage to or replacement of that lateral outside of their property boundary beyond a single tree root clearance.

In a situation where the council does not own the lateral through the road reserve and has no responsibility to repair this, it could mean a property owner may have their lateral damaged by tree roots or service activities (see Section 3.7.5) that may not be evident for some time. When a fault is identified, it could then be up to the owner to repair and replace this lateral at significant cost (as it may involve digging up footpaths and the road itself, with traffic management requirements).

Another problem is that, when there are upgrades of new wastewater mains within a street, there may be no requirement for the council to upgrade or work with private owners to repair or replace existing private laterals (meaning 50+ year old laterals could be connected to a new wastewater main).

Subsequently, Wellington Water have to work across various local council policies that are not always consistent. Having a universal policy across councils would help reduce complexities and allow for greater strategic planning. Some policy options could include:

- Pass ownership and responsibility to the council (and subsequently Wellington Water) for private laterals within road corridors to a private property boundary,

- Encourage private lateral repair/replacement when wastewater mains are being repaired or replaced

- Investigate the opportunities for a plumbing inspection or 'warrant of fitness' to be required prior to a house sale, except under special circumstances where it may not be practical. This inspection would need to verify the condition of the laterals to confirm they are water tight, determine no cross connections exist, inspect septic tank volumes and condition and verify stormwater inflow is not occurring (through low gully traps or direct connections).

- Whether this would solely be a condition assessment or if there is a requirement to undertake repairs would require further investigation.
- This approach would help reduce overflows and cross connections through the private sector being responsible for their assets, while increasing awareness of water quality.

3.7.5 Strikethroughs

An often unknown but increasingly common fault in the wastewater and stormwater network can be strikethroughs from service providers, such as telecommunications lines. Unpressurised wastewater mains and private laterals could have a strikethrough occur without any knowledge of this until a fault develops (such as a blockage or obvious leak).

This often occurs through direct push and directional/horizontal drilling, which may penetrate through underground pipes. If this happens in road reserve areas where laterals are not the responsibility of the council (for example, Wellington City), a private owner could end up responsible for the repair (if they are unsuccessful in identifying the fault in a suitable timeframe to have the contractor fix it).

Further investigation into how to reduce strikethroughs may be necessary, which could potentially include a requirement for a CCTV inspection from a manhole near where drilling crosses wastewater and stormwater infrastructure.

Figure 11. Strikethrough CCTV image within a wastewater pipe. Image courtesy of Steve Hutchinson, Wellington Water

3.7.6 Monitoring of overflows

As described in Section 3.5, monitoring isn't occurring at all constructed overflow locations. The majority of the monitoring network is currently outsourced to an external contracting company. Increased monitoring would improve the understanding of the magnitude of constructed overflow volumes and identify the most problematic sites (if they are not being monitored already); however, they will come at increased cost should more instrumentation be installed and then managed.

3.7.7 Pumps/treatment plants

Pumping Stations are located at low points in catchments to lift the wastewater into more elevated locations in the gravity system (through rising mains, which are pressurised pipes). Routine inspection of the pumping stations occur monthly. A major inspection and maintenance activity, including checking of pumps occurs annually under operational contracts.

Pumping stations are necessary in areas of low topographic gradients. In some locations, they may be working for prolonged periods to pump groundwater or salt water that has infiltrated into the network (additional to wastewater). As new development occurs, additional load is placed on the wastewater pipe network, including at pumping stations. Subsequently, pump stations may need to be periodically upgraded or new stations installed, however this is dependent on the location and capacity constraints, particularly in dense urban areas where infill or commercial development is occurring (such as new office or apartment blocks) on low lying land.

Rising mains are very difficult to inspect and often require excavation and sampling of the pipe material. Subsequently, most data is collected only when they fail and are repaired, to help inform knowledge and risk related to similar age and material pipe. Constructed overflows are often located near pumping stations, as a fail safe should pumping cease (such as through electrical faults, blockages or pipe failures), however this often only under extreme circumstances as they often have redundant storage and alarm systems.

The three wastewater treatment plants within this Whaitua (see Section 3.1) discharge treated water to the ocean through ocean outfalls at Wainuiomata/Pencarrow, Moa Point, and Karori Stream (on the south coast). Condition assessments have been occurring regularly. The Moa Point ocean outfall is subject to an annual dive survey to check their exterior condition and for breaks. Assessment of the internal condition of the ocean outfall has not been undertaken as there are limited technologies available for inspection. The Hutt Valley outfall (Wainuiomata/Pencarrow) has had periodic condition assessments of the on-land portion since it came into service in 1962, including several visual internal condition inspection and one electro-magnetic condition inspection in 2013. The Hutt and Karori outfalls on-land portions have had leaks from time to time and been damaged by landslide or tree falls before entering the ocean, resulting in repairs as necessary.

Overflows (also termed bypasses) can occur at treatment plants under situations of extensive network load (through excess inflow and infiltration). Each plant has a failsafe built in that would result in the discharge of treated or untreated (but screened for solids) wastewater into the receiving environment. Table 5 details the WWTP specifications and general functions of wastewater discharge during wet weather events. Reducing the network load at the source (starting at private dwellings) and upgrading the network and treatment plant capacity over time will help minimise overflow risk, leading to greater wastewater treatment. The amount and frequency of bypass overflows at the treatment plants has not been incorporated in this report due to time limitations.

Unplanned failures can occur, even on relatively new infrastructure (although the probability is less). Moa Point has been in the media over the last 4 months due to the pipeline failure which stopped the pumping of sludge to the southern landfill. This pipeline was installed in the mid 90's and the failure is likely to be from a defect, despite the pipe being designed for an asset life of up to 80 years (Wellington Water Limited 2020). Trucks have been transporting sludge through residential areas 24 hours a day, 7 days a week for the last few months and the estimated repair costs could be up to $16 M.

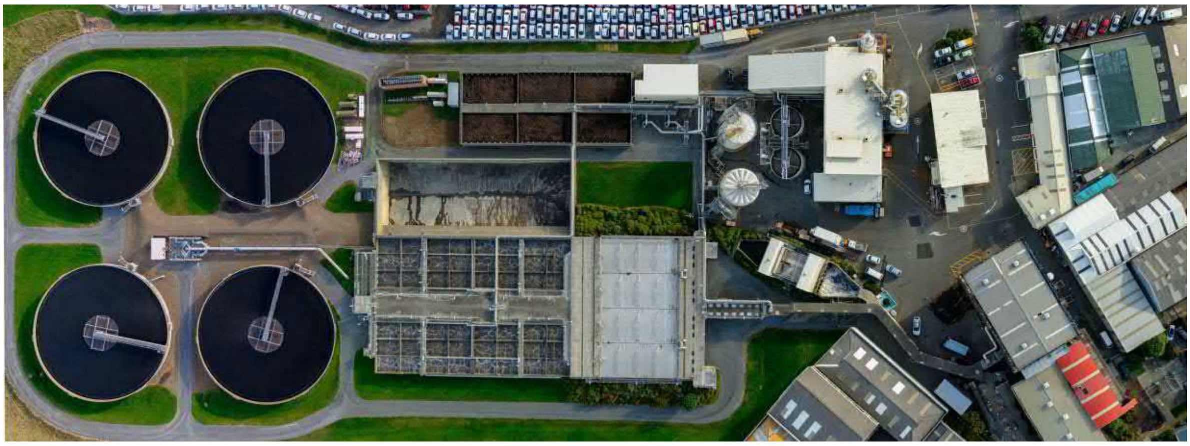


Figure 12. Aerial image of seaview WWTP. Image courtesy of Wellington Water Limited.

Table 5. WWTP specifications, treatment process and function during wet weather flows

Treatment Plant	Average inflow (L/s)	Design Treatment rate (L/s) before overflow	Average Faecal Coliforms effluent (cfu/100mL)	Average BOD5 effluent (mg/L)	Treatment Process	During Overflow
Karori (Western WWTP)	54 L/s	200	14	6	Secondary treatment with UV Screening - Screening, contact stabilisation through aeration (for sludge breakdown) and clarification, sludge/water separation, sludge disposal, UV treatment of water, discharge	When excess water >design capacity occurs leading to overflows, treated WW is preferentially directed to overflow into Karori Stream, while screened untreated water is sent down the discharge pipe to the coast. Only during extreme events do untreated overflows occur to Karori Stream (last occurring 2013/14) and are heavily diluted when this does occur
Moa Point	820 L/s	3000	68	6		When excess water >design capacity occurs leading to overflows, treated WW up to 3000 L/s and the residual untreated (but screened) wastewater is discharged simultaneously through the outfall pipe to the coast. Subsequently, the untreated wastewater is diluted to a degree.
Seaview	630 L/s	1560	177	11		When excess water >design capacity occurs leading to overflows, treated WW is discharged to the ocean outfall with excess to the Waiwhetu Stream near Seaview. A wet weather storage tank at Seaview helps to reduce the frequency of treated overflows to Waiwhetu except under large events, which happens ~4 times per year

4. Stormwater network

4.1 Historical development

Stormwater infrastructure has been installed in Wellington from as early as 1860, with streams being piped and runoff diverted to ensure development can occur without the risk of flooding (Wellington Water Limited 2019c). The primary objective had historically been focussed on the rapid transfer of regular rainfall out of the city, rather than on treatment of contaminants or coarse waste removal that is subsequently entering fresh and coastal waters. An effective stormwater network also helps reduce human health risks, as less standing water means less disease transfer and drier, less damp, housing.

Wellington Water Limited manages a stormwater pipe network of over 1700 km in length. It is not currently tasked with managing the natural stormwater network of streams, including highly modified watercourses, except where they interact with the built network such as at intakes. There is increasing public awareness and desire for the stormwater network to expand from a water quantity and conveyance infrastructure to one that also undertakes treatment and improves public health when undertaking contact recreation and mahinga kai gathering in fresh and marine receiving environments.

However, to achieve these goals requires a significant change to the 'status quo' of stormwater development for new (greenfield) developments, and considerable investment, planning and thought relating to how the current aging network can be improved or retrofitted over time.

4.2 Ownership and management structure of the network

Stormwater in New Zealand has largely remained the responsibility of local councils (Mahuta 2020), where other infrastructure entities (for example Watercare in Auckland) may manage the wastewater and drinking water components of the 'three waters'. Wellington Water Limited takes a unique role, managing the entire three waters network across a number of councils. This creates a greater magnitude of work and responsibility, but also provides an opportunity to constructively plan the three waters infrastructure collectively.

Ownership of the stormwater assets remains with the representative council stakeholders. Further breakdown of the responsibilities of stormwater include:

- Private homeowners and businesses own and are required to maintain their stormwater laterals, which connect to the public 'mains'.

- Council and central government roading departments (i.e. NZTA) maintain the road side stormwater infrastructure, including sumps, culverts and gutters.

- Large commercial entities such as Wellington Airport and CentrePort have an extensive stormwater network that is managed internally before discharge to the environment.

Stormwater discharge is often consented for commercial and industrial areas that have a larger footprint and potentially greater impact on the receiving environment in terms of water quantity and quality. Resource consents need to be obtained from Greater Wellington Regional Council. Wellington Water secured a 'Global Stormwater Consent' in 2018, which consented the entire stormwater network they were managing, and included setting objectives and monitoring requirements for water quantity and quality in certain locations (GHD 2017).

The global consent secured by Wellington Water is for a five year period, subsequently requiring renewal in 2023. The consent has to meet requirements of the legislation identified below, indicating the complex nature of stormwater management and discharge (GHD 2017):

1. Building Act 1991
2. Health Act 1956
3. Resource Management Act 1991, and policy and plans including:
    a. New Zealand Coastal Policy Statement (NZCPS)
    b. National Policy Statement for Freshwater Management (NPSFM 2017)
    c. Regional Policy Statement for the Wellington region
    d. Proposed Natural Resources Plan (PNRP)
    e. Operative Regional Plans (at the time of the consent), being the Coastal Plan, Freshwater Plan, Discharges to Land Plan

Management of the stormwater network by Wellington Water is limited to ‘built assets’, which in this case refers to the concreted and piped infrastructure. These assets convey water to receiving bodies, such as rivers, streams, groundwater aquifers (where stormwater infiltrates) and the coast (see Figure 13 as an example). Collectively, the receiving water bodies and various parks could be termed ‘natural assets’, and are owned and managed by the adjacent land owners which can include the various councils (described in Wellington Water Limited 2019c). Streams within urban areas can have hundreds of adjacent land owners. This creates a management mosaic which requires strong communication to ensure appropriate stormwater management and maintenance is occurring. However, in many instances, property owners are not aware of their responsibilities and are confused when Wellington Water or its client council will not act to carry out maintenance. The multiple landowners and interfaces with the stormwater network creates significant complexity for operations and management.

Figure 13. Dry weather discharge from a stormwater culvert draining to Te Awa Kairangi (the Hutt River), likely from groundwater infiltration or leakage from the potable network.

It is also this complicated arrangement that poses future challenges in retrofitting of stormwater infrastructure, due to the range of stakeholders and their associated interests/objectives.

The requirements of the NPS-FM and current public attitudes suggest that improving receiving water quality will also become a function that Wellington Water must deliver on behalf of its client councils, although this is not currently within Wellington Water's service level agreements with its client councils. It is likely that the existing management system will present barriers to Wellington Water's ability to be effective in improving stormwater quality, namely that:

- Wellington Water can only make recommendations to its client councils on land-use, funding mechanisms and funding levels for stormwater quality, that compete against other council initiatives and activities.

- Wellington Water or its client councils do not have delegated authority to regulate the users and/or polluters of their networks for the purposes of stormwater quality under the RMA.

- Current stormwater bylaws in Wellington region do not have stormwater quality provisions (except PCC regarding car washing) and are only enforceable by prosecuting individuals through District Court.

4.3 Water quality effects of stormwater on the environment

The impacts of stormwater in the environment (relating to water quality and ecology) vary depending on landuse, asset condition, treatment and hydrological flows. As described in Section 3.3, stormwater can contribute to wastewater overflows resulting in contamination to the receiving water body.

The majority of stormwater contaminant loads are driven by rainfall, where dry weather results in little to no flow (unless a cross connection is present or groundwater is inflowing to a pipe). The highest load and subsequently concentrations occur during the 'first flush' (Wellington Water Limited 2019c). This is where contaminants (such as metals from car brake pads, or sediment from bare earth) build up on surfaces during dry periods. The first significant rainfall event that leads to runoff mobilises these contaminants to the receiving freshwater/coastal environment, while ongoing rainfall (i.e. lasting many hours or days) and its associated runoff is likely to have decreased concentrations of contaminants thereafter (except for where wastewater overflows may be occurring).

The Contaminant Load Model (CLM) was developed by Auckland Council from a range of monitoring studies, and estimates yields and loads that can be generated from various landuses which would enter the freshwater or coastal environment through stormwater. This has been adapted for the Wellington Region by NIWA and Jacobs during Te Awarua-o-Porirua Whaitua process (Moores *et al.* 2017). Some of the specific water quality contaminants that can arise from stormwater are described below (GHD 2017), and associated yields have been detailed within Moores *et al.* 2017 where applicable.

- Metals such as copper and zinc. These are common in industrial and commercial landuses, roads (generating metals through brake pads and vehicle emissions) and residential areas, where old galvanised roofs can leach zinc into rainfall and subsequently, stormwater.
    - Metals can have a number of effects on the receiving environment, however the most common are acute (from short term exposure during the 'first flush') and chronic toxicity (long term accumulation) effects on aquatic life. Untreated stormwater can accumulate metals in the environment over time (in deposited sediment), which leaves lasting environmental legacy issues that take time to dissipate. Metals are known to accumulate in shellfish and at high levels can be harmful to human health.

- Sediment, which can carry contaminants (i.e. metals and nutrients), can be mobilised from numerous locations, including bare earth (i.e. cleared gardens) through to construction sites. Inadequate sediment/erosion control practices would result in large scale runoff through the stormwater system, particularly during short but intense rainfall events.

  - Sediment can reduce clarity, increase turbidity and deposit locally within receiving water bodies (smothering habitat).

- Hydrocarbons can also be found in stormwater runoff, with numerous sources located in urban environments. The effects of hydrocarbons on the environment varies depending on the type of hydrocarbon, how concentrated the runoff is, and whether it is ongoing and accumulating within deposited sediments.

- Microbial pathogens are present in stormwater, not only related to wastewater but also from direct inputs from avifauna, farm animals and pets. Pet faeces in parks or private dwellings can be washed into stormwater or generate ongoing loads of microbes through numerous events until they are decomposed.

  - These pose risks to human health, particularly through any contact recreation (swimming) or Mahinga Kai gathering in both the marine and freshwater environments.

- 'Other' contaminants can include paint, paint thinners, oil and automobile fluids, herbicides and fertiliser. In addition there are a number of emerging contaminants, such as perfluorooctane sulfonate (PFOS) which is associated with many industrial practices including fire retardant foams, that may have entered the environment through stormwater runoff over decades of use (Environmental Protection Authority 2020).

  - The effects of these are wide ranging and quantifying their impact is challenging without site investigations. For example, the impacts of a one-off paint dump down a stormwater drain may be acute to the aquatic life, but not have ongoing chronic effects.

- Hydrological effects on receiving environments, including a more flashy regime dominated by rapid surface overland flow due to a lack of infiltration, which also reduces baseflow into small streams and rivers during drier periods as less water is stored in unconfined shallow aquifers. This can lead to erosion, sedimentation (stream bank instability) and habitat modification.

- Temperature changes can occur in receiving environments due to stormwater runoff from urban landuses, where higher temperatures have the ability to affect ecological health in some situations.

- Litter from around the city is also transported through the stormwater network, although litter traps and sumps can reduce the volume. The presence of litter within the receiving environments can then negatively influence community views and their connection with particular freshwater and coastal environments.

Traditional stormwater design in an urban environment generally conveys water from impervious surfaces through a piped network to a receiving freshwater or coastal waterbody. Subsequently, little treatment occurs of the contaminants. Water Sensitive Design (WSD) utilises practices that aim for hydraulic neutrality (flows similar to an undeveloped landscape) with numerous mitigations and treatments in place to reduce contaminant loads and their effects on the environment. This is described in Section 4.6.

Whilst not covered in this report, stormwater devices (from natural to built assets) can also be important ecological habitats and corridors, and in some instances can represent significant barriers to headwater connectivity. See Figure 14 as an example of fish passage design in a culvert.

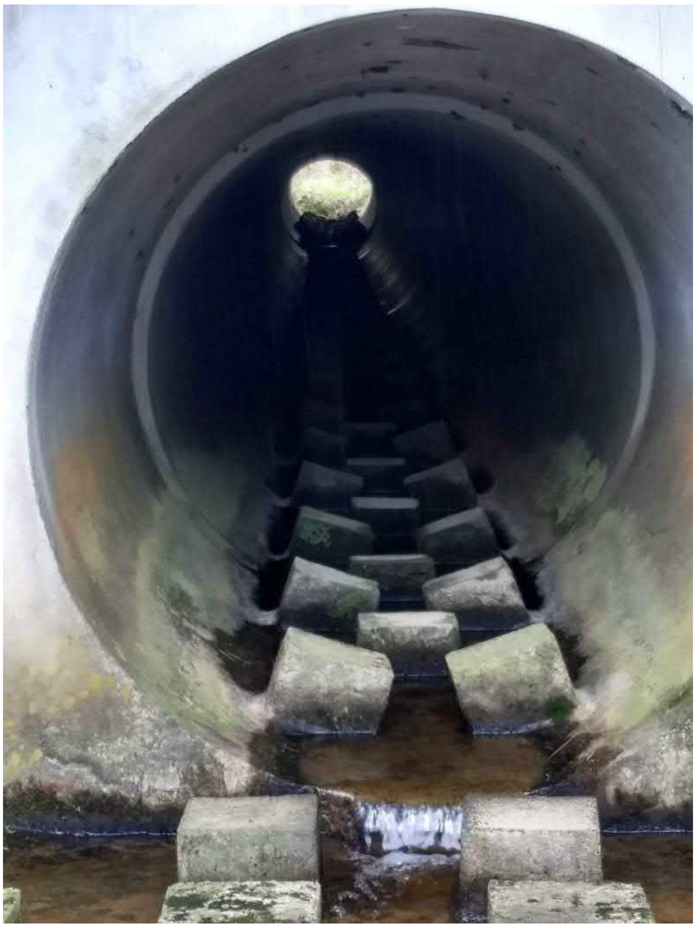


Figure 14. Culvert providing fish passage. Stormwater structures can also act as ecological barriers when fish passage hasn't been considered, or erosion and hydrological modification has happened over time.

4.4 Asset overview and expenditure

The extent of the Whaitua Te Whanganui-a-Tara stormwater network is well described in the Global Stormwater Consent (GHD 2017). Section 4 of the global consent existing environment report (an addendum to the consent application) breaks down the stormwater infrastructure by catchment, including significant streams such as Owhiro and Kaiwharawhara, Hutt River and Waiwhetu streams. This includes historical information about the stormwater infrastructure, its length, age and catchment characteristics that could be contributing contaminants. Due to the quantity of information, this has not been re-presented in this report, with a focus on high level summaries of the stormwater infrastructure only.

The known stormwater networks from Wellington Water's Whaitua based council stakeholders totals ~1,365km in length, while the wider network (including Porirua) is ~1,640 km. The total network encompasses 38.5 km of channels, seven detention dams and 21 pump stations (GHD 2017). The length of the stormwater network owned by each local authority is identified in Table 6.

Table 6. Length of stormwater network in Whaitua Te Whanganui-a-Tara (adapted from GHD 2017).

Council	Length of Network (km)
Wellington City	688
Hutt City	526
Upper Hutt City	151
Totals (km)	1,365

Over two years (2018 and 2019), the average capital expenditure for the stormwater network per property has been reported in Table 7.

Table 7. 2018 and 2019 average stormwater capital expenditure per property around New Zealand (data sourced from Water New Zealand 2020).

City	Average $/property	Difference (from 2 year average)
Tauranga	306.5	64%
Auckland Council	235.5	26%
Christchurch	204	9%
2 year average (5 towns)	187.3	-
Hamilton	101	-46%
Wellington Water	89.5	-52%

Whilst this is only a short snapshot in time and CAPEX projects can take years of planning before large expenditures occur on construction, over the last 2 years Auckland and Tauranga City Councils have spent 2.6 and 3.4 times more on stormwater than Wellington Water (and its various council stakeholders). Both these cities have however experienced large amounts of growth which may affect their CAPEX.

4.5 Business as usual stormwater development

Traditional stormwater design focuses on the capture, conveyance and in some cases storage and attenuation of stormwater prior to discharge to the environment. The "*Regional Standard for Water Services"* (Wellington Water 2019e) sets out the levels of service required for stormwater and wastewater infrastructure as defined by a design storms annual exceedance probability (AEP), and varies depending on the planned infrastructure (i.e. roads, residential or commercial developments).

The focus for land use development and practices currently follows hydrological and hydraulic designs for standardised stormwater infrastructure, including (but not limited to) pipes, stormwater attenuation tanks, soakage pits (for Upper Hutt gravel terraces), sumps and open water courses.

Section 4.2.12 of this standard refers to water sensitive design as the recommended design approach for stormwater management. The project scoping and site assessment phase indicates early discussions with Wellington Water land development team and reference to Auckland City Councils GD04 (Lewis *et al.* 2015). GD04 is described further in barriers to water sensitive design, Section 4.7.1.

4.6 Water sensitive design

4.6.1 Purpose and objectives

Water Sensitive Design (WSD) is the principle of incorporating the natural water cycle and the subsequent management of this into stormwater design. WSD aims to improve resilience of cities and communities through the adoption of design techniques that promote a more naturalised stormwater system, including less impermeable areas, greater infiltration and green spaces and the removal of contaminants through both source and sink treatments. For example, roof replacements to materials that yield less zinc (source), to constructed wetlands or rain gardens treating and attenuating runoff (sink). See Figure 15 for an example of a rain garden. At the same time, adoption of WSD seeks to deliver a low risk and higher return for both the land developers and property owners (Wellington Water 2019d).

WSD also has the potential to deliver many other environmental and social co-benefits, such as the preservation of natural soils; terrestrial habitat for native biodiversity; supplementary water supplies and improved health and wellbeing deriving from the use of green infrastructure (Moores & Batstone 2019).

The NPSFM (2017) recognises te mana o te wai (the integrated and holistic well-being of water) and sets out objectives and policies that direct local government to manage water in an integrated and sustainable way, while providing for economic growth within set water quantity and quality limits (Wellington Water 2019d). The adoption of WSD supports te mana o te wai, and Wellington Water have developed local design guidelines to help land developers, consultants and contractors implement WSD in retrofitting and greenfield projects within the region. This document is titled “Water Sensitive Design for Stormwater – Treatment Device Design Guideline” (Wellington Water Limited 2019d).

Section 4.6 and 4.7 will not discuss each of the various WSD mitigations or approaches, which has been detailed in numerous technical reports and design guides, but will focus on the adoption of WSD in Wellington and challenges faced with undertaking these stormwater designs.

Figure 15. Raingarden treating road runoff.

4.6.2 Greenfield and brownfield developments

New developments (greenfield) provide a good opportunity to implement WSD, if proposed land use patterns are considerate of this approach and has robust support and guidance from government and the private sector. Brownfield re-developments may be constrained by existing infrastructure and limited land area and availability to implement WSD, subsequently resulting in innovation in spatial planning and design selection when retro-fits are considered. WSD is new in Wellington, and will take time to become standard practice, while currently it would be considered best practice.

Studies have shown that residential property values often increase when they are located in close proximity to green infrastructure and also when they have views of this infrastructure, including any water (i.e. streams, rivers or wetlands) (Ira 2017). Australia and New Zealand showed an average house price increase of ~ 8% and 6% respectively when near green infrastructure, albeit when it was poorly maintained or degraded could result in a decrease in property value (Ira 2017).

Moores & Batstone (2019) document some of the key outcomes and benefits for adopting WSD, which includes:

- A more natural hydrological regime similar to that of an undeveloped catchment (rather than a flashy catchment with minimal infiltration and high runoff common in traditional BAU design). This is supported by Ferguson (2018).

- Improved water quality, through both sink and source treatment and mitigations, targeting concentrations similar to that of the undeveloped catchment.

- Better ecosystem connectivity and ecological/natural character throughout the urban centre that promotes life and brings a sense of community connection to nature.

- Increased contact recreation from reduced risk to human health. This comes through reduced stormwater inflow into wastewater (preventing overflow) and greater uptake of internal water re-use (greywater recycling) before discharge.

- Increased provisioning for harvesting of food (such as shellfish), through reduced contamination

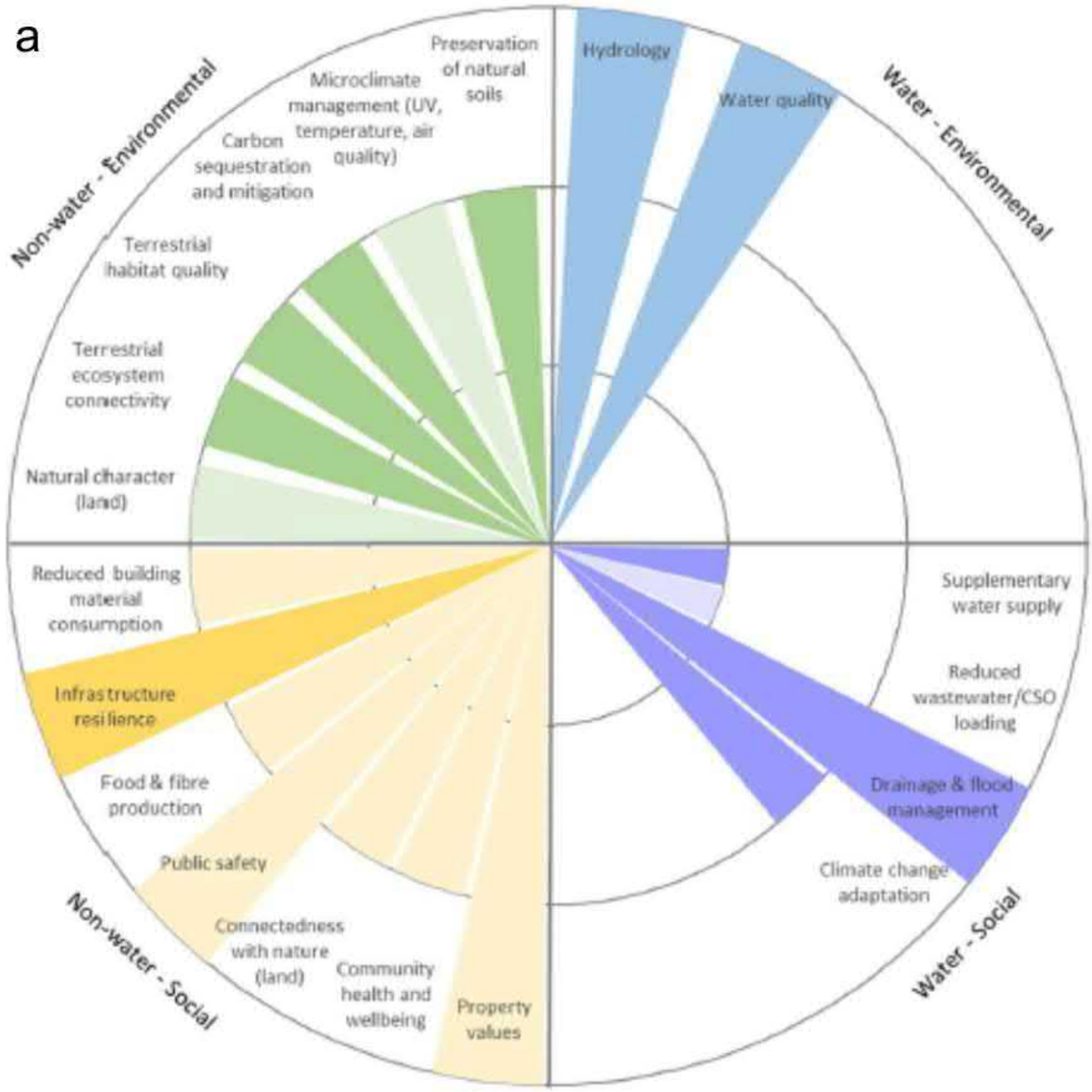
- Supplementary water supplies for emergency (which adds resilience in an earthquake prone location like Wellington)

- Climate change adaptation and flood management enhancement, which promotes working with the natural function of stream and river flows, preventing encroachment from the built environment.

The benefits and costs of implementing WSD in new and existing developments can also be graphically presented, through the 'More Than Water' tool that was developed by the Activating WSD research team (Moores *et al.* 2019). The tool is qualitative and can present a range of co-dependent benefits and costs of WSD versus traditional developments in a simple manner. This tool can be downloaded from the Manaaki Whenua (Landcare Research) website (https://www.landcareresearch.co.nz/science/living/cities,-settlements-and-communities/water-sensitive-urban-design/more-than-water-mtw-assessment-tool).

An example from Moores *et al.* 2019 has been presented in Figure 16. The level of a benefit is reflected in the ***length*** of its sector from the centre of the chart; the importance of a benefit is reflected in the ***width*** of its sector; and the reliability of the qualitative assessment of a benefit is reflected in the ***intensity of the colour*** of its sector.

Further case study examples has been provided in Appendix C.


a
Non-water - Environmental
Water - Environmental
Non-water - Social
Water - Social
Preservation of natural soils
Microclimate management (UV, temperature, air quality)
Carbon sequestration and mitigation
Terrestrial habitat quality
Terrestrial ecosystem connectivity
Natural character (land)
Hydrology
Water quality
Supplementary water supply
Reduced wastewater/CSO loading
Drainage & flood management
Climate change adaptation
Reduced building material consumption
Infrastructure resilience
Food & fibre production
Public safety
Connectedness with nature (land)
Community health and wellbeing
Property values

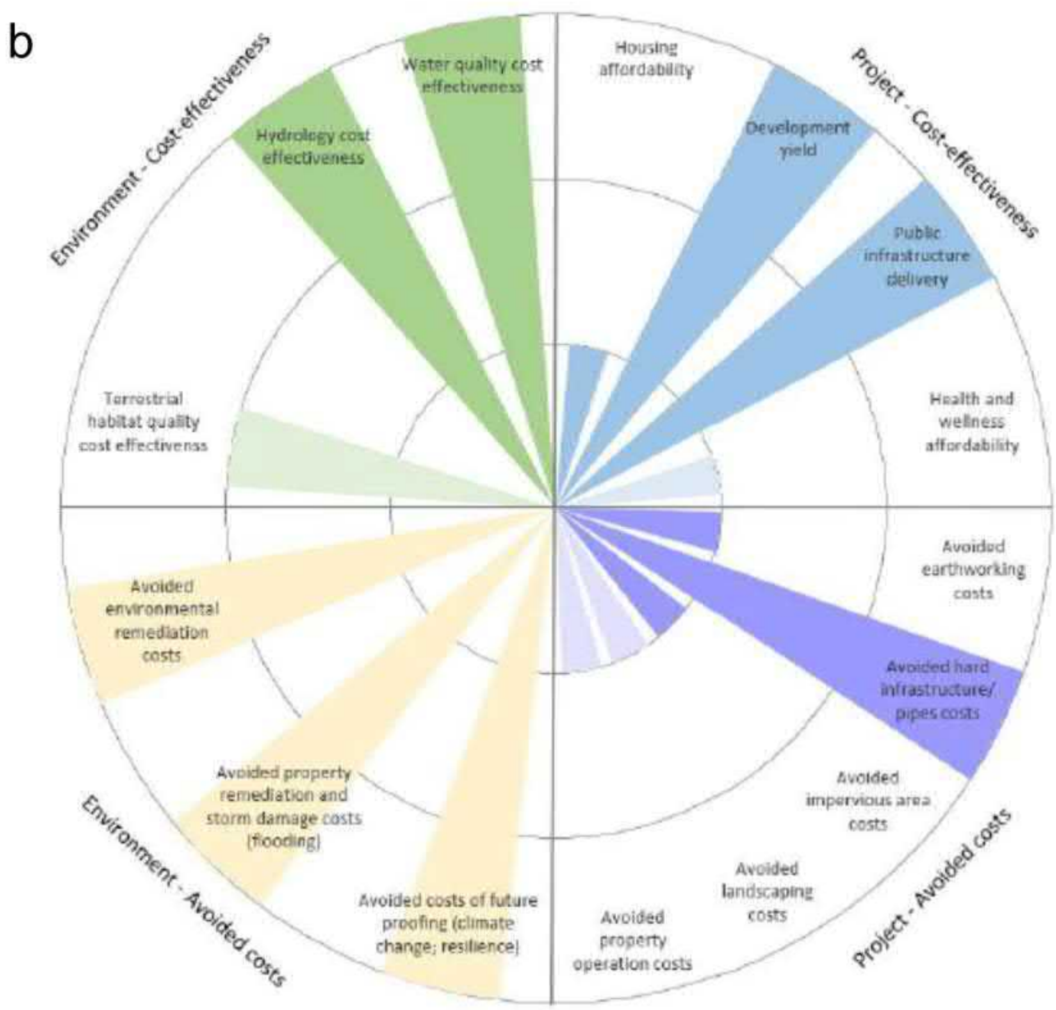


Figure 16. Greenfield Kiromiko Park development in Wanaka, and an overview of the environmental benefits (a) and cost benefits (b) of undertaking WSD using the More than Water tool (Moores *et al.* 2019).

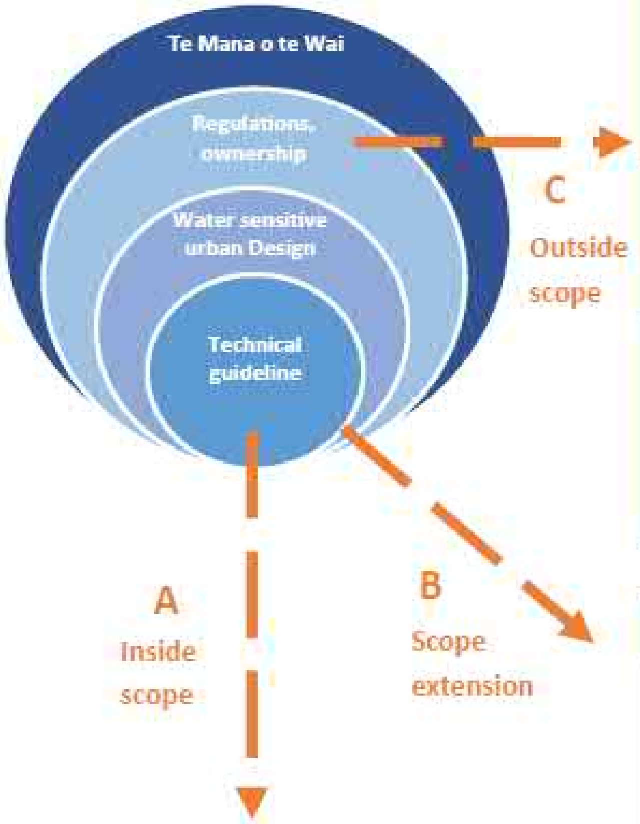
4.7 Barriers to water sensitive design

4.7.1 Wellington Water work streams

Wellington Water have identified a number of barriers to WSD in the region (see Figure 17). Some of these are being addressed through various work streams over the next five years which will help increase the adoption of WSD for green infrastructure (GI) within the region. Greater detail about barriers to WSD (independent from Figure 17) are provided in sections 4.7.2 to 4.7.6. It should be noted, Figure 17 was prepared when it was thought that the Ministry for the Environment (MFE) would be producing a WSD guidance for planning and land development, which is no longer occurring.

Water Sensitive Design Guideline Project Update

1 Aug 2019



Parallel project streams

	Scope	Schedule
Policy and planning	• Water Sensitive Design guidance for planning and land development (Ministry for Environment)	2020/2021
	• Planning provisions for stormwater treatment (PCC)	2019/2020
	• Alignment of Regional and District Plans on WQ	TBC
Asset management	• Recommendation on ownership and management framework for green infrastructure	2019/2020
	• Operational funding model and business case for LTP	2019/2020
People and capability	• Standardised operations and maintenance procedures	TBC
	• Update to land development approvals process	TBC
	• Training and development across supply chain	TBC

Technical practice notes

Technical guidance in interim (to be scheduled)
• Quantity management using WSD and hydraulic neutrality for water quality
• Grey water re-use and potable water reduction through WSD
• WSD case studies from Wellington region
• Acceptable solutions for on lot treatment

Water Sensitive Design for Stormwater: Treatment Device Design Guideline

August 2019	Sept 2019	Sept 19 —Mar 2020	March 2020 onwards	2024/25
Secondary consultation complete	Public Release with Draft PCC District Plan Update	User info sessions through land development forum	Implementation through PCC District Plan and WWL work streams	Cyclical review

Figure 17. Wellington Water WSD update (August 2019)

4.7.1 Planning guides

Designing and constructing water sensitive green infrastructure (GI) is only one link in the chain of WSD, and requires sound planning to ensure the GI is appropriate and beneficial to the environment and community. In order for GI to be incorporated into new developments, and retrofitted into existing urban environments, an understanding of the planning requirements are necessary for both the agents that design development proposals and councils.

The reasons planning guides are needed can include:

- To provide an understanding on the objectives of WSD in different sites around a city, where the focus may shift from stormwater attenuation to water treatment. The Whaitua Committee will provide recommendations and objectives for various freshwater management units, which will help guide future WSD.

- To inform and consider design options at an early stage of a development, which will help in landscape functionality and improve effectiveness of the GI, whilst working with developers to ensure returns on their investment.

- To detail policies and rules for GI, stormwater attenuation and treatment including the activity status (i.e. permitted, controlled, discretionary).

Currently, there is limited planning guidance for WSD for the majority of the Wellington Region. Porirua City Council (PCC) with Wellington Water has initiated a planning guide for stormwater infrastructure with their plan change, title ‘Planning provisions for stormwater treatment’. Wellington Water has identified a need to align district and regional plans for water quality in Figure 17, however this is yet to be initiated. Alignment of district and regional planning provisions should also consider stormwater planning for GI, where there may be potential for a single stormwater planning guide for the entire region.

As an example, Auckland Council has developed a number of stormwater planning and design guides as part of the Unitary Plan process. Their main planning document is titled ‘*Water Sensitive Design for Stormwater (GD04)’* (Lewis *et al.* 2015). This is a comprehensive document which details:

- Principles of WSD
- Statutory and land development processes
- Objectives and solutions for GI
- Site assessment and analysis for appropriate GI selection
- Concept design process

Site selection and assessment to inform concept designs is of particular importance during the planning stage, as each site may vary in terms of its objectives. For example, a steep urban development with poor soil infiltration rates may require different GI than a brownfield redevelopment in a flat central CBD location, or a greenfield subdivision with adequate area to incorporate larger assets such as constructed wetlands.

The development of a regionalised tool that could work through site objectives and design considerations (including climate, slope, soil types, infrastructure constraints and land footprint) and then recommend potential GI design options would be useful for both councils, Wellington Water and developers. This would provide some preliminary steps to selection of appropriate GI for the site that can feed into concept design selection, and potentially reduce repeat conversations that may be occurring for every new development considering WSD.

Investigation into how GD04 could be used to help develop planning guides for the Wellington Region could aid in speeding up implementation of GI, and prevent 're-inventing the wheel'.

4.7.2 Education

Public awareness of water quality and environmental health is growing, however ongoing works needs to be undertaken to truly educate the community about the connections of stormwater from the rain falling on their property or workplace through to its discharge to streams and eventually the coast.

In its current state, most of the stormwater network is not visible in dense urban areas as it is piped and underground, only discharging into open channels at certain locations. Many of these stormwater channels have not been designed for aesthetics or water sensitive principles, but instead for water conveyance and flood management, and may hold little value to the communities living nearby. Implementing water sensitive design will go a long way to improving education, as the community can see and feel the GI within their own living spaces and workspaces. Daylighting streams (where streams are piped) or naturalising streams where they are a modified open channel, offer opportunities in some suitable locations to further educate, including promotion of continuous stream corridors (Lewis *et al.* 2015).

4.7.3 Retrofitting for water sensitive devices

Retrofitting GI into existing urban areas can be a greater challenge than in a greenfield site, as the original intent of that site's stormwater design was to convey water rapidly to reduce flooding, while during a greenfield development, appropriate planning can begin at an early stage. GI can be incorporated into the existing landscape, however may have to be adapted to suit the site conditions. A retrofit may not always achieve all the objectives of water sensitive design, including hydrological neutrality, treatment and ecological enhancement as physical and infrastructure constraints may remain.

Re-development is often required on road verges and existing stormwater and building infrastructure to incorporate aspects such as rain gardens, swales, green roofs/walls, stream daylighting and wetlands (Lewis *et al.* 2015). Undertaking these works in developed areas often leads to additional challenges, such as contaminated land, limitations on premium land availability, traffic and parking considerations and business/residential disruptions, however if undertaken correctly can provide enhanced ecological values, a greater social connection to the environment and improved water management and treatment.

A good example of a large brownfield re-development is Auckland's Wynyard Quarter near the CBD, which features a variety of GI's implemented amongst a new residential and commercial hub, developed from an area that had significant contaminated land from decades of marine activities, including oil and fuel storage sites (Wynyard Quarter 2020).

4.7.4 Design Guides

Wellington City Council (2015) published a water sensitive guidance document, titled "Water Sensitive Urban Design Guide – A guide for WSUD stormwater management in Wellington". This document provides a greater overview of a range of water sensitive infrastructure that can be implemented at different sites, the benefits of these devices and provides some context around planning that may be required for the implementation. No specific design advice is incorporated in this document (unlike Farrant 2019).

Wellington Water has taken steps in recent years towards developing an initial design guide for the region. This document was released in 2019 and is titled "*Water Sensitive Design for Stormwater: Treatment*" (Farrant 2019).

The key purpose of this document is to provide design guidelines for four treatment types:

1. Constructed Wetlands (see Figure 18)
2. Vegetated Swales
3. Bioretention (rain gardens)
4. Permeable paving

The design document is comprehensive and aims to provide best practice design and build advice to ensure assets will be working as intended and will not become a liability for a private or public (i.e. council) owner. The ownership of the assets after they are designed and built has not been included in this design guide (see Section 4.7.6). The design guide is also intended for new developments, and does not focus on retrofitting WSD. In addition, any other water sensitive infrastructure (such as rain tanks, green roofs/walls, or filter media) that aren't included in Farrant (2019) would need to be discussed with Wellington Water as the development occurs, to ensure they are fit for purpose.

Currently, this design guide (Farrant 2019) is being integrated into the Porirua City Council Plan Change with planning guides on stormwater infrastructure.

For comparison, Auckland Council has developed GD01 (covering nine devices) titled "*Stormwater Management Devices in the Auckland Region (GD01)*" (Cunningham *et al.* 2017). This document has been developed for Aucklands geology, climate and receiving environments, so while many of the design concepts are general enough to be applied elsewhere in New Zealand, local conditions and planning regulations need to be taken into account. GD01 was used by Farrant (2019) to help guide Wellingtons designs.

In summary, comprehensive design guides have been developed and internationally peer reviewed in other cities around New Zealand (such as Hamilton and Auckland), and Wellington Water now has its own design guideline, although limited to only four types of water sensitive infrastructure. Ongoing development and review of the design guide (planned for the year 2024/25) will look to incorporate a greater range of infrastructure designs. Until then, the use of other GI will require specialist design skills (such as provided from engineering consultants) on an ad hoc basis, at the discretion of developers to then be agreed upon by Wellington Water and the various local councils.

Figure 18. Belmont constructed wetland, draining to Te Awa Kairangi (the Hutt River). Image courtesy of GWRC.

4.7.5 Industry standards and compliance

As detailed in the examples of water sensitive GI at Talbot Park and Koromiko subdivisions in Appendix C, and identified in the People and Capability section of Figure 17, ongoing work is needed within the industry to develop standards, train professionals and undertake compliance assessments relating to GI design and construction.

Currently there are no work streams underway within Wellington Water to support the industry in this regard. Whilst design consultants maybe familiar with GI, some of the contracting companies undertaking the construction of a device may be less familiar. In the case of Talbot Park (see Appendix C), 10 of 14 rain gardens that were constructed had flaws that effected their performance, which then required workshopping and retrospective fixes to rectify the issues. In some situations, poorly designed and constructed GI has been vested over to councils and become a significant liability, due to challenges with operation and maintenance (see Section 4.7.6).

It is likely that as water sensitive GI becomes increasingly dominant as a stormwater management approach, design and contracting companies will also upskill. Consideration of independent compliance checks or inspection during construction may be necessary from Wellington Water or its respective stakeholder councils, particularly where the asset ownership may be vested to the public.

4.7.6 Ownership and maintenance

The ownership and maintenance throughout the life of water sensitive GI is a challenge that has not yet been resolved in the Wellington Region. Poor design and construction of devices which are then handed over to client councils has led to a number of examples where these councils now have a liability due to the significant maintenance or retrofit costs necessary to improve their function. Private developers are faced with conflicting messages and unclear expectations over GI. Environmental regulation is pushing GI devices into developments, but without guidance as to what types of devices may be vested to Council and how these should be deployed. Moreover, the devices that are built may have no ultimate owner due to a lack of agreement between Wellington Water and its client councils for the ongoing management and maintenance of devices.

Cunningham *et al.* 2017 (GD01) details the vesting of assets to Auckland Council from private developers. The key requirement is that it can be demonstrated that a significant flow from the public stormwater network discharges to the proposed GI asset. A number of detailed criteria are outlined for a developer to follow, however the most important is that any discussions about asset vesting need to begin early on in the resource consenting phase. Any assets that aren't vested will remain in private ownership, and in the case of private developments with private roads, may be managed through body corporates and conditional agreements on property titles.

Wellington Water are currently developing a document that will provide recommendations towards the ownership and maintenance of GI assets within the Wellington Region, across its various council shareholders. Currently, the lack of a clear and dedicated GI operator and maintainer has meant there is increasing risk that water sensitive GI infrastructure becomes poorly maintained and a greater liability to the public.

Key areas that need to be agreed upon are:

- Public and private ownership criteria,
- Asset management responsibility,
- Operations and maintenance responsibility, and
- Implementation strategy

Whilst the report is still being developed, it will provide a number of recommendations to councils about ownership and maintenance of water sensitive GI. Once this has been deliberated, reviewed, updated and finalised, the outcome will help in improving the adoption and promotion of GI across the region.

5. Improved and Water Sensitive Scenarios

5.1 Overview of scenarios and their WSD treatments

Te Awarua-o-Porirua (TAoP) Whaitua Committee developed freshwater quality and ecology scenarios with various stakeholders. These scenarios considered 'mitigation packages' that looked at increasing levels of treatment of water quality (and also flow) through the adoption of both source and sink controls.

The three scenarios were:

- Business as Usual (BAU) – which is an improvement from the current state by assuming all rules in the Natural Resources Plan are adhered to at best practice

- Improved – which incorporates a number of WSD treatments and some source controls of heavy metals (for example roof replacements) in urban areas, and various rural mitigations such as land retirement.

- Water Sensitive – enhances on the improved scenario and implements numerous mitigations across an extensive rural and urban area.

The scenarios were 'packages' that were run through a daily hydrological and water quality model, with the results used to compare to the 'current state' (Jacobs 2019).

Te Whanganui-a-Tara Whaitua used the same scenarios, TAoP results and other relevant investigations to assess the likely consequences of different management regimes on surface water quality and ecology in Whaitua te Whanganui-a-Tara. These assessments have been made by a panel of water quality, ecological engineering and aquatic ecology experts (Greer, 2020).

The panel first made assessments of the magnitude of likely changes to a range of attributes (such as copper and zinc concentrations, or the macro-invertebrate index score) through implementation of the scenarios.

These assessments were then applied to current state estimates to provide advice on the expected water quality and ecological conditions. These are presented relative to NOF attribute states where appropriate (for example, Nitrate-nitrogen B attribute state may improve to an A state under the Water Sensitive scenario).

Table 8 provides an estimate of the number of current and future dwellings within the urban landuse area of the Whaitua that forms the background data used by the Expert Panel to help inform decisions. Table 9 details the urban mitigations that were assumed to be implemented in the Improved and Water Sensitive scenarios and has been linked to the number of dwellings where appropriate (to provide an idea of the 'scale' of infrastructure required). Table 9 also provides context on the level of WSD that has been considered in modelling and by the freshwater panel. Rural mitigations have not been considered within this stormwater and wastewater report.

Table 8. Estimated numbers of dwellings within the Whaitua under current and future growth scenarios.

Scenario	No. of dwellings	Comment
Current residential homes in the Whaitua	119,100	These dwelling estimates are based off the landuse mapping data for residential areas from the Contaminant Load Model (CLM) and assumes and average property size of ~700 m^2. This Includes Wellington City, which was not assessed by the Expert Panel (subsequently the dwelling numbers presented to the panel are slightly different than in this report). This excluded all rural areas in the Whaitua (i.e. Makara, Mangaroa and Pakuratahi, Hutt Valley Western Hills). Quality checks with the 2018 Census data estimated the total number of occupied and un-occupied dwellings for this Whaitua in 2018 was 128,391 and 7,887 respectively (Statistics New Zealand 2018).

		Between 1994 and 2018, 28,898 new residential buildings were constructed within the Whaitua territorial authorities (Statistics New Zealand 2018).
Future development (including infill and greenfield)	24,400	Growth information was used by the Expert Panel to understand future contaminant loads additional to the current state. Information presented represents estimates of combined infill and greenfield developments across the entire Whaitua, analysed from Housing and Business Development Capacity Assessments (Housing and Business Assessment 2018). This data is an estimate of the next 28 years (i.e. to 2048 only) and includes Wellington City. Growth projections can be highly variable and the ramifications of COVID-19 may influence future development.

Table 9. WSD treatments in the Improved and Water Sensitive Scenarios for urban areas

Treatment or Control	Description	Improved Scenario	Water Sensitive Scenario
Rainwater tanks	Rainwater tanks on some existing and new dwellings, with increased amounts of internal and external water re-use[4]	• 50% of new greenfield and infill dwellings (~12,200) • 10% of existing dwellings (~11,910) • 2,000 L tanks • No internal reuse • 15% outdoor reuse	• 100% of new greenfield and infill dwellings (~24,400) • 50% of existing dwellings (~59,550) • 10,000 L tanks • 40% internal reuse • 500 mm/year outdoor reuse
Bioretention of road runoff	Unlined bioretention systems (such as rain gardens) that capture and treat road runoff, with infiltration to ground.	• 40% of road area draining for treatment (~136 ha) • Bioretention devices make up 2% of catchment area (assuming catchment is the	• 90% of road area draining for treatment device (~305 ha) • Bioretention devices make up 2% of catchment area (assuming catchment is the road surface

[4] Described in more detail in Ferguson (2018).

	Only applied in *new* infill and greenfield areas, not to existing roads.	road surface area, equivalent to ~2.7 ha of devices)	area, equivalent to ~6.1 ha of devices)
Constructed Wetlands	Treatment in *new* infill and greenfield developments of paved and roof runoff with wetlands sized for a catchment.	• All new paved and roof surface runoff in greenfield and infill development areas (~918 ha of roof and pavement) • Wetland makes up 3% of catchment area (~27 ha of constructed wetlands)	• All new paved and roof surface runoff in greenfield and infill development areas (~778 ha of roof and pavement, area reduced by permeable paving) • Wetland makes up 3% of catchment area (~23 ha of constructed wetlands) • Water re-use of 500 mm/year (i.e. irrigation to parks).
Media filter	Treatment of runoff in *existing* paved commercial and industrial areas, and also existing roads (Improved only)	• 50% of runoff from existing paved commercial and industrial areas (assuming equal runoff generation rate per unit area, equivalent area of ~273 ha) • 50% of runoff from major existing roads (assuming equal runoff generation rate per unit area, equivalent area of ~70 ha)	• 100% of runoff from existing paved industrial areas (assuming equal runoff generation rate per unit area, equivalent area of ~355 ha)
Bioretention of commercial	Treatment of runoff from *existing* commercial paved surfaces	N/A	• 100% of existing paved commercial areas (area equivalent to ~192 ha). Assuming a 2% catchment area,

			bioretention devices would be ~3.8 ha in commercial landuses.
Constructed Wetlands	Treatment of runoff from *existing* major roads (greater WQ reduction than media filter used in Improved scenario)	N/A	• 50% of major roads (assuming equal runoff generation rate per unit area, equivalent catchment area of ~70 ha). Subsequent wetland area needed for treatment at 3% of catchment size would be ~2.1 ha.
Permeable Paving	Treatment of stormwater runoff at source to reduce volumes using permeable paving promoting infiltration. Applied to *new* infill and greenfield only.	N/A	• 50% of paved surface in new greenfield dwellings and 25% of infill dwellings (~103 ha of permeable paving)
Roof Replacement	Replacement of *existing* high yielding Zinc roofs in commercial, residential and industrial areas. Low yielding zinc roofs have been available since 1994 (MRM 2020).	• 50% of existing residential, commercial and industrial roofs (~32,472 dwellings for *residential only*, after removing new builds built after 1994 - See Table 8)[5]	• 100% of existing residential, commercial and industrial roofs (~64,945 dwellings for *residential only*, after removing new builds built after 1994 - See Table 8) [5]

[5] Kingett Mitchell 2003 assessed the proportion of roof types in four Auckland suburbs, identifying that on average, ~64% were galvanised iron roofs, with another 20% galvanised decromastic tile roofs. Corelogic data utilised in Porirua Whaitua determined that ~72% of residential and industrial roofs and 40% of commercial roofs were galvanised (including decromastic tiles). Galvanised roofs are the highest yielding zinc roofs which would be 'replaced' under Improved and Water Sensitive scenarios (with greater yields from poor or unpainted roofs). For costing assessments, the total roof area of residential, commercial and industrial landuses were corrected by the appropriate proportion of galvanised roof and the amount considered to be replaced under each scenario (50% for Improved and 100% for Water Sensitive).

Table 10. Wastewater mitigations considered by the Expert Panel in the Improved and Water Sensitive scenarios

Treatment or Control	Description	Improved Scenario	Water Sensitive Scenario
Wastewater Network Improvements	Repair/replace grade 4/5 pipe network and assume no cross connections or leakage (across all flows)	• 100% of all urban areas	• 100% of all urban areas
Wastewater Overflow Improvements	Reduce wastewater overflows through entire network (assumed to occur through WS mitigations detailed)	• Reduce wastewater overflows by ~67% (from an average of 12 per year to 4 per year in TAoP Whaitua)	• Reduce wastewater overflows ~83% (from an average of 12 per year to 2 per year in TAoP Whaitua)

5.2 Stormwater Cost implications of Improved and Water Sensitive Scenarios

The cost implications of implementing some of the water sensitive GI mitigations in the improved and water sensitive scenarios was calculated using a Cost Aggregation Model (CAM) adapted from the TAoP Whaitua (Ira 2018). Specifically, this only accounted for:

1. GI identified in Table 9, *excluding* all wastewater improvements (i.e. cross connections, leaks and overflows).
2. Urban GI only, excluding all rural mitigations.
3. Excludes all roof replacements costs for residential, industrial and commercial land.

Important assumptions of the CAM assessment are (Ira 2018):

- It does not make any assumptions about the feasibility, uptake, timing or optimisation of interventions, or about financing, governance or distributions of costs for particular catchments or activities
- takes no account of topography, water balance assessments in and between catchments, nor funding and financial constraints or opportunities
- The total life cycle cost is the lump sum amount that a person would need today to meet all the costs of installing, maintaining and using that device over its lifetime

The updated CAM for Whaitua Te Whanganui-a-Tara was undertaken by Ira (2020). Based on the exclusions above, the costs of the full suite of these two scenarios would be greater than estimated in Table 11. The costs presented include the full life cycle costs (LCC) (assumed to be 50 years), which incorporates annual maintenance. Annual maintenance costs have also been extracted and presented in Table 12 for reference. In addition, the total LCC over 50 years has been broken down to annual cost per dwelling (based on combined existing and new residential builds).

A low and high range has been provided for LCC calculations to account for uncertainty and variance in cost estimates. An example of this would be for a roof replacement, where the low and high costs for a 140 m^2 roof would equate to $24,000 and $56,000 when considered over a 50 year replacement period.

A critical component of Table 11 is that roof replacement costs haven't been included. This is on primary assumption that replacement of old roofs to low yielding zinc roofs would occur through attrition over the 50 year period, undertaken by the private sector. If there was a significant movement towards replacing roofs in a shorter timeframe, potentially through local or regional policies, then the costs of the improved and water sensitive scenarios would be significantly greater.

Table 11. 50 Year Life Cycle Cost estimates for the improved and water sensitive scenarios (excluding wastewater and rural mitigations and any roof replacement costs).

Urban stormwater scenario	Total Life Cycle Cost over 50 years ($)	
	Low	**High**
Improved	$596 million	$816 million
Water Sensitive	$1.83 billion	$2.73 billion
	Proportioned LCC ($/dwelling/year)[6]	
Improved	$83	$114
Water Sensitive	$255	$380

Table 12. Annual maintenance costs ($/year) for the improved and water sensitive scenarios referenced in Table 11.

Urban stormwater scenarios	Low	High
Improved	$6.5 million	$9.1 million
Water sensitive	$17.9 million	$25.5 million

Table 11 shows that urban mitigations in the improved scenario (when excluding roof replacements and any wastewater mitigations) could be ~ $816 million over 50 years, whilst the more comprehensive mitigation suite in the water sensitive scenario could equate to costs of $1.83 - 2.73 billion over 50 years. Consideration of an annual cost per dwelling over a 50 year period provides a greater appreciation of the magnitude of these costs that could be paid for by rate payers and businesses. This ranges from ~$83 to $380 per dwelling/year when calculated off residential dwellings only, and would likely be less if incorporating commercial and industrial business contributions. This is indicative only and would need a full financial assessment

[6] Only residential dwellings (~143,500) has been used to estimate annual LCC costs per dwelling. Commercial and industrial activities (and their business premises) would also contribute to LCC costs, meaning the values presented could be lower. Costs could be significantly different when proportioned to new or existing dwellings, depending on cost sharing arrangements. It is likely more costs would fall on new builds.

incorporating aspects such as debt, interest, commercial and industrial contributions to better inform impacts on rates.

Calculation of the roof replacement costs results in a significant increase in total LCC for these scenarios. The improved scenario could increase to $2.0 – 4.1 billion, while the water sensitive scenario could increase to $4.7 – 9.3 Billion.

Inclusion of rural mitigation costs (including aspects such as retirement of land, fencing and riparian planting) and wastewater repair costs would further increase the costs of these scenarios.

5.3 Wastewater Cost implications of Improved and Water Sensitive Scenarios

Wellington Water undertook a high level cost assessment of wastewater mitigations considered in the scenarios (see Table 13). It is worth noting, these cost assessments are not exact replications of mitigations in Table 10 for each scenario. Subsequently, the assessment by the expert panel (see Greer 2020) aren't directly correlated with the cost estimates in Table 13, although are reasonably close (with the main difference in Wellington Waters waste water mitigations is the inclusion of constructed overflow storages).

Table 13 is also only intended to show the magnitude of costs associated with upgrading the wastewater network and are not being suggested as the best option to be considered (and may subsequently differ from what has been discussed with councils to date).

Important assumptions of this work are detailed in Wellington Water Limited (2020b) and includes:

1. The area considered is the urban extent of the Whaitua and cost estimates allow for 30 years of growth.

2. The base CAPEX cost estimates are consider Level 0 (prefeasibility) with low confidence, and additionally incorporates contingency (~40%) and funding risk (~60%). Level 0 estimates fall outside of standard practice when estimating project construction costs.

Table 13. Level 0 cost estimates for wastewater mitigations in Whaitua te Whanganui-a-Tara (Wellington Water Limited 2020b).

Mitigation Considered	Comment	Cost Estimate (over 30 years)
Wastewater pipe renewal to minimise leakage	Grade 4 and 5 pipes on the public wastewater gravity network	$1.4 – 1.7 billion
Storage of wastewater to reduce constructed overflows	Storage tanks sized to store events up to 6 months (0.5 year) ARI, reducing discharge to environment	$430 – 530 million
Inspection and renewal of private wastewater laterals	To remove any cross connections, groundwater infiltration and leakage to environment. Proportion of laterals was based on	$250 – 350 million

	proportion of poor grade public pipes (~32%).	
Estimated Level 0 Total expenditure		$2.08 to 2.58 billion

5.4 Total cost estimates for scenarios

The combined cost estimate ranges for the improved and water sensitive scenarios is detailed in Table 14. These are indicative only and should be used as a guide about the relative costs above business as usual process.

These costs are a combination of the 50 year LCC for stormwater (Ira 2020) and the 30 year wastewater costs (incorporating growth) from Wellington Water, and are presented as a lump sum only.

Table 14. Total combined cost estimates for stormwater and wastewater mitigations for Improved and Water Sensitive scenarios (adapted from Table 11 and Table 13)

Range	Improved Scenario	Water Sensitive Scenario
Low	$2.68 billion	$3.91 billion
High	$3.40 billion	$5.31 billion

6. Climate Change

Climate change may influence the long-term management of stormwater quantity with increased incidences of extreme weather events and sea level rise. A predicted increase of heavy rainfall events could exacerbate stormwater network capacity issues, stormwater flooding in low lying areas, and continue to flush contaminants into receiving environments. Sea level rise can contribute to raised groundwater levels, in turn reducing ground soakage capacity (and increasing groundwater infiltration), and ultimately intensifying pressure on the stormwater network (GHD 2017). WSD will help to reduce some of the climate change impacts by promoting hydrological neutrality.

Reducing stormwater connections to the wastewater network (from inflow) will help mitigate the risk of greater overflows due to the expected increase in extreme rainfall events, however will not entirely solve the problem of leakage and ongoing overflows where pipe infrastructure is near capacity. Wastewater pipe renewal will be necessary to reduce leakage into the environment and to prevent infiltration from groundwater and salt water, in areas affected by a rising sea level. In some situations existing wastewater pipes in these low lying areas and their appropriate pump stations (where gravity flow isn't possible) may be significantly impacted from sea level rise, and require re-designs and retrofits.

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Appendix A – Wastewater Overflows

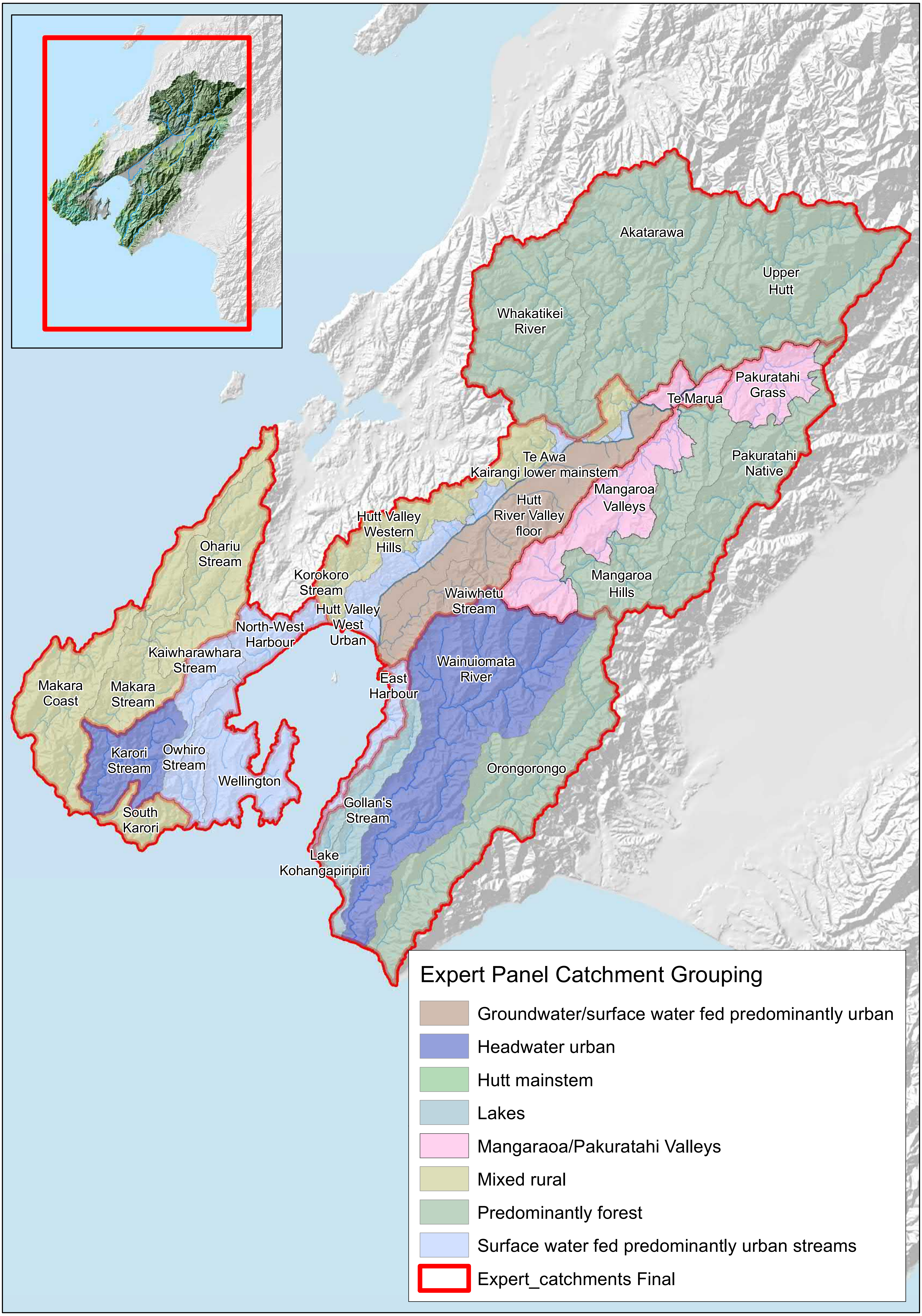
Table A 1. Most problematic monitored wastewater overflow assets based on the frequency of overflows through 2018 and 2019

Rank	Location Name	No. of Overflows 2018 & 2019	Percentage (%) of recorded events within that catchment	Volume Est (m^3)	Subcatchment
1	Wellington Road	26	63%	20,777	Wainuiomata River
2	Kent & Wakefield (WW2693)	19	39%	2,601	Wellington
3	60 Kent Terrace (WW30078)	12	24%	2,034	Wellington
4	Silverstream Storm Tank Discharge Events	12	100%	194,598	Hutt River Valley floor
5	Oriental Pde, (S End Central Fire S), TP96 Moa Point	10	20%	585	Wellington
6	23 Rowe Parade (710002R00936)	15	37%	8,834	Wainuiomata River
7	Pump Station 23	9	18%	-	Wellington
8	Manhole located outside 50 Fraser Street	7	17%	300	Wainuiomata River
9	Taranaki/Ghuznee St (WW35569)	7	14%	37	Wellington
10	Wainuiomata Storm Tank	7	17%	51,282	Wainuiomata River

Table A 2. Most problematic monitored wastewater overflow assets based on the volume of overflows through 2018 & 2019.

Rank	Location Name	No. of Overflows 2018 & 2019	Volume Est (m^3)	Subcatchment	Comment
1	Silverstream Storm Tank Discharge Events	12	194,598	Hutt River Valley floor	243,480 m^3 in 2016/17
2	Wainuiomata Storm Tank	7	51,282	Wainuiomata River	18,059 m^3 in 2016/17
3	Wellington Road	26	20,777	Wainuiomata River	12,977 m^3 in 2016/17
4	23 Rowe Parade (710002R00936)	15	8,834	Wainuiomata River	25,727 m^3 in 2016/17
5	Murphy Street (WW38277)	4	6,259	Wellington	~60,918 m^3 in 2016/17
6	Main Road (710006R00896)	5	3,150	Wainuiomata River	2,694 m^3 in 2016/17
7	WW18884	4	2,919	Wellington	
8	Kent & Wakefield (WW2693)	19	2,601	Wellington	1,712 m^3 in 2016/17
9	Barber Grove Pump Station	4	2,596	Waiwhetu Stream	4,439 m^3 in 2016/17
10	60 Kent Terrace (WW30078)	12	2,034	Wellington	

Appendix B – Subcatchment Map



Akatarawa
Upper Hutt
Whakatikei River
Pakuratahi Grass
Te Marua
Pakuratahi Native
Te Awa Kairangi lower mainstem
Mangaroa Valleys
Hutt River Valley floor
Hutt Valley Western Hills
Ohariu Stream
Korokoro Stream
Mangaroa Hills
Waiwhetu Stream
Hutt Valley West Urban
North-West Harbour
Kaiwharawhara Stream
Wainuiomata River
East Harbour
Makara Coast
Makara Stream
Karori Stream
Owhiro Stream
Wellington
Orongorongo
South Karori
Gollan's Stream
Lake Kohangapiripiri
Expert Panel Catchment Grouping
Groundwater/surface water fed predominantly urban
Headwater urban
Hutt mainstem
Lakes
Mangaraoa/Pakuratahi Valleys
Mixed rural
Predominantly forest
Surface water fed predominantly urban streams
Expert_catchments Final

Appendix C – WSD examples ('More than Water' tool)

WSUD Case Study: Kirimoko Park

Master-planned, pipeless residential subdivision with small sections but spacious feel due to lack of fences, integrated landscaping and protected mountain-view shafts that combined with comprehensive maintenance provides a regenerative, resilient residential subdivision for people and nature.

Selecting a WSUD approach was driven by the developer's vision, but it cost less and delivered increased values by Stages 2 and 3 partly due to:

- Lower earthworking costs and no pipes (permeable sub-soils, suitable slopes and low intensity rainfall)
- Smaller sections increasing section yields
- Narrower streets using swales and bioretention as traffic calming measures
- Cost efficient treatment of a range of stormwater contaminants exceeding 'code'
- Increased native biodiversity and connectivity of natural areas, quality green spaces enhance the aesthetic appearance and provide benefits for carbon sequestration and water quality treatment
- Resilient, long term infrastructure provided by multiple, distributed treatment trains

Features

- Five-star walking and cycling through road and landscape design
- Plants and soil used to reduce stormwater volume and remove contaminants
- Community sign-up to the '***Kirimoko Code***'; individuals choose from list of sustainable / ecological features for building and landscapes
- Maintained locally, funded by annual residents levy at no cost to Council
- Limited on and off-street parking and strict covenants not for everyone!

About Kirimoko Park

The Kirimoko Park subdivision is about 2km north of the Wanaka town centre and 1km east of Lake Wanaka.

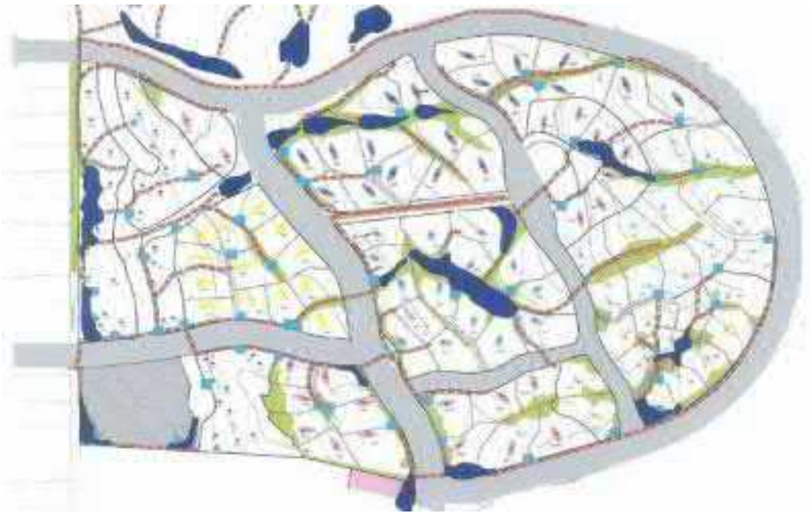
The site was farmland with patches of kanuka remnants, about 30m above the shoreline of Lake Wanaka. The topography has undulating gradients, gently sloping at grades of between 2 and 18%. The localised geology of the site and surrounding environment is loess (wind-blown silt) and glacial till material. Soils throughout the site are dominated by sandy silts and silty sands, and infiltration rates across the site are, on average, about 50 mm per hour, much higher than rainfall. Water exfiltrates into permeable subsoils, reducing surface runoff.

Plant growth is limited by a relatively short growing season due to cold temperatures (many frosts and occasional snowfall) in winter and drought in summer. In many places deep, free-draining soils allow large trees to develop. The area was a farm dominated by non-native grasses, but with scattered kanuka (a small native tree) remnants.

Stage 1 of the development was completed between 2011 and 2013 in the south west corner of the site across approximately 4.15 hectares. Stage 2 was a similar size and completed in 2014 and 2015 (4.17 hectares); Stage 3 was completed in 2015 and 2016 (3.58 hectares).

Staging plan courtesy of AR and Associates

Stormwater management approach



The Kirimoko Park WSD Concept Plan (Pattle Delamore Partners Ltd, 2009) highlights that virtually all primary and secondary stormwater flows are managed on the surface, through swales, raingardens, detention / infiltration basins and fords, with very little or no piping. Stormwater infrastructure in the existing urban areas downstream of the development had limited stormwater capacity. The ultimate receiving environment is Lake Wanaka – a high value mountain lake used for contact recreation and showing recent degradation from sediment, (human) faecal and nitrogen inputs. In view of the rapid growth that Wanaka is currently experiencing there is strong community interest in addressing how development can be managed to retain the high natural values of Lake Wanaka and the surrounding landscape[1].

More information about each of the development stages, including specifics about design, cost, maintenance and post-construction observations are presented in the following sections.

Stage 1

Stage 1 treats and infiltrates stormwater via rain gardens, permeable paving and infiltration basins.

What works well	Missed opportunities
Narrow roads reduce the overall impervious areas.	Raised concrete edges of raingardens on the road edges are prone to damage, especially from trucks, but prevent vehicle entry.
Landscaping was carefully researched to find plants that perform well in Wanaka's environment, both exotic and native plants are used.	Feature trees are generally deciduous non-native trees – where these are next to infiltration areas their leaves require seasonal removal. Some tussock and bidibid (*Acaena*) groundcovers may be relatively short lived, requiring replacement to maintain high aesthetics. Acaena are too short to exclude common weeds.
Raingarden sandy media used FAWB[2] 2009 specification (>3% w/w organic matter, <3% silt and clay), was locally sourced and installed at 600 mm depth. Raingarden design included specific exfiltration rate of 800 mm/hr at construction due to reliance on soakage.	Basalt cobbles were expensive and are inconsistent with local geology. Poured resin pervious paving was difficult to maintain (i.e. remove sediment) and accessible to heavy vehicles that can damage it.
Roads have reduced traffic speeds of 25 km/hr. Low speeds are reinforced by clever placement of trees, raingardens, and varying surfaces used for roads and parking areas; this encourages walking and cycling.	Raingardens with raised concrete edges and vertical sides placed immediately adjacent to the road (so requiring strong edges) are expensive to construct.
General absence of fences and use of hedges and creates sense of cohesion and flow across landscape.	Rain tanks are not included as part of the stormwater design.
Infiltration basin doubles as recreational facility by incorporating seating, local boulders and local gravels (petanque), but lacks plants, in contrast to the stage 3 basin.	The low cost housing area, whilst incorporating WSUD features has a "traditional" feel as the road and turning circle are very wide and landscaping is focussed at the back of properties. There are no places to sit and enjoy landscape and limited privacy as all are on the flat compared with other areas of Kirimoko.

[1] See the Wanaka Water Project at: https://www.uppercluthalakestrust.org/your-water/district/wanaka-water-project/

[2] Facility for Advancing Water Biofiltration, Monash University (Melbourne, Australia)

Photo 1: Stage 1 Rain gardens shortly after construction, before house construction showing raised edges.

Photo 2: Entrance with low-speed signs five years after construction.

Photo 3: Permeable (poured resin) car parking area around street tree with steel separation strip.

Photo 4: Permeable carpark (background) and detention area (foreground) which doubles as a petanque court with benching and boulders providing seating. The deciduous tree creates additional maintenance (leaf removal) in autumn.

Stages 2 and 3

Stages 2 and 3 treat and infiltrate stormwater via swales, rain gardens and infiltration basins. Stage 2 has no pipes. The cost of treatment is lowered by predominantly using swales which discharge to fewer, larger rain gardens with minimal use of concrete.

What works well	Missed opportunities
Stage 2 narrow roads reduce the overall impervious areas.	Standard road widths in Stage 3 were required by Council; these are inconsistent with Stage 2.
Reduced piping lowers construction and maintenance costs, and also creates a more resilient stormwater system as long as swales are not damaged by vehicles or filled in during buildout. Review of plans and supervision throughout build period reduces potential for such mistakes.	Council requirement for Stage 3 to have yellow lines on roads and signs lowers aesthetics and creates a disconnect with Stage 2 where these are absent (and aesthetics are higher).

What works well	Missed opportunities
Steep sided swales were established using browntop “ready-lawn” to avoid erosion during establishment. Browntop performs well in the Wanaka environment and under low-fertility conditions, it looks attractive even when allowed to flower and seed and stays dense – it can also tolerate relatively close-mowing.	The few ‘rain gardens’ have a significant pebble mulch surface with no plants to hide ugly metal domes; including native tussocks or taller, upright shrubs near the domes would mask them and complement landscaping.
Rain gardens and swales are used as traffic calming devices. The use of tussock planting on upper parts of some swales and steeper sides of swales protect them by discouraging driving across, or parking on, swales.	Some deciduous (non-native) trees, including large-leafed trees (English plane) create a seasonal maintenance requirement to keep swale pipes under driveways clear.
Landscaping was carefully planned and budgeted, and focusses on native plants, both groundcover and trees. More food for tui / bellbirds than when in farmland due to planted kowhai, flax and cabbage trees. More food for lizards by planting native berry-producing plants near remnant.	Some swales are particularly steep-sided to retain flood capacity. In places slopes could have been reduced by using more expensive (concrete) drive-way crossings
Native remnant kanuka has been retained and provides an amenity area for residents.	Residents have planted non-native bulbs under the kanuka canopy; such planting and any fertilisation does not assist the kanuka.
Many ‘iconic’ small trees are used in stages 2 and 3, including ribbonwood, lancewood, kowhai and cabbage trees, as well as totara – all are performing well. Most plantings have a variety of species, which increases resilience to drought or adverse events	Some tussocks have a relatively short life of 5 to 10 years without ‘grazing’ especially when stressed by irrigation (or being driven on); the ground-cover Coprosmas, Hebes and Pimelea probably have a longer life
Use of fords for overland flow paths reduces the need for large, expensive pipes. Fords also help traffic calming	
Driveway crossings use local stone to stabilise the pipe culverts and large boulders that act as bollards to protect corners from traffic.	Boulders need to be large enough not to move when hit by trucks (including rubbish trucks). Wooden bollards can be expensive to replace when broken (especially ‘frangible’ bollards);

Photo 5: Raingarden with unplanted stone mulch and exposed overflow dome.

Photo 6: Local stone used for retaining wall with flattened dome (from vehicle damage) despite protection provided by planted tussock and light stand.

Photo 7: Relatively steep swale with base of dense Browntop turf grass edged with local boulders, native tussocks and shrubs that together provide resilient, stable site and separation of sites without fences.

Photo 8: Fords for overland flow paths reduce need for pipes and are traffic calming features.

Photo 9: Local boulders used to protect swales from vehicles.

Photo 10: A native kanuka shrubland remnant has been retained.

The Kirimoko Code

Owners of the lots have to abide by Kirimoko Code (KC) and be part of the residents' association. Within the KC there are requirements around passive solar design, solar heating, composting, worm farms, use of native materials, incentives, and other environmental requirements. Understanding the importance of creating green, sustainable cities and the importance of landscaping, the developer gifted a native planting package for the lot owners to use. Houses are individually designed to maintain view shafts to the lake and ensure compliance with the KC.

Consent notice conditions and covenants underpin the KC and residents are required to pay a fee which is then used for maintenance of the green infrastructure.

The resulting effect of the KC is that there is a price premium on the lots over and above conventional subdivision lots.

Costs and benefits – "*More than Water*"

"*More than Water*" Assessment Tool

Using the newly developed "More than Water" Assessment Tool[3], the costs and benefits of the WSUD Kirimoko subdivision can be assessed and compared with a traditional (business as usual – BAU) approach to development. The tool allows the user to select the level of each benefit or cost criteria (from low to high), level of importance of a particular criteria, and reliability of the information used to make the assessment. Detailed guidelines are available to guide the user as they make their assessment. The range of assessment criteria are shown in the two tables below.

"*More than Water*": benefits assessment criteria

		Benefit	Level	Importance	Reliability
Water	Environmental	Hydrology	High	High	High
		Water quality	High	High	High
		Aquatic habitat quality	N/A	High	High
		Drainage network and aquatic ecosystem connectivity	N/A	High	High
		Natural character (water bodies)	N/A	High	High
	Social	Supplementary water supply	Low	High	High
		Reduced wastewater/CSO loading	Low	High	Low
		Drainage & flood management	High	High	High
		Climate change adaptation	Med	High	High
		Recreation	N/A	High	High
		Provisioning (e.g. fishing)	N/A	High	High
		Connectedness with nature (water bodies)	N/A	High	High
Non-water	Environmental	Preservation of natural soils	Med	High	High
		Microclimate management (UV, temperature, air quality)	Med	High	Low
		Carbon sequestration and mitigation	Med	High	High
		Terrestrial habitat quality	Med	High	High
		Terrestrial ecosystem connectivity	Med	High	High
		Natural character (land)	Med	High	Low
	Social	Reduced building material consumption	Med	High	Low
		Infrastructure resilience	High	High	High
		Food & fibre production	Med	High	Low
		Public safety	High	High	Low
		Connectedness with nature (land)	Med	High	Low
		Community health and wellbeing	Med	High	Low
		Property values	High	High	Low

"*More than Water*": costs assessment criteria

		Cost	Level	Importance	Reliability
PROJECT	Cost effectiveness	Housing affordability	Low	High	High
		Private development yield	High	High	High
		Public infrastructure delivery	High	High	High
		Health and wellness affordability	Low	High	Low
	Avoided costs	Avoided earthworking costs	Low	High	High
		Avoided hard infrastructure/ pipes costs	High	High	High
		Reduced impervious area costs	Low	High	High
		Avoided landscaping costs	Low	High	Low
		Avoided property operation costs	Low	High	Low
ENVIRONMENT	Cost effectiveness	Water quality cost effectiveness	High	High	High
		Hydrology cost effectiveness	High	High	High
		Aquatic habitat quality cost effectivenss	N/A	High	High
		Terrestrial habitat quality cost effectivenss	Med	High	Low
	Avoided costs	Avoided environmental remediation costs	High	High	Low
		Avoided property remediation and storm damage costs (flc	High	High	Low
		Avoided costs of future proofing (climate change; resilienc	High	High	Low

The assessment was undertaken via a workshop approach comprising the research team, project information provided by consultants involved in the development of Kirimoko Park, a site visit and discussions with the relevant development consultants. Detailed cost information was available for certain aspects of the development and this has been used in the assessment.

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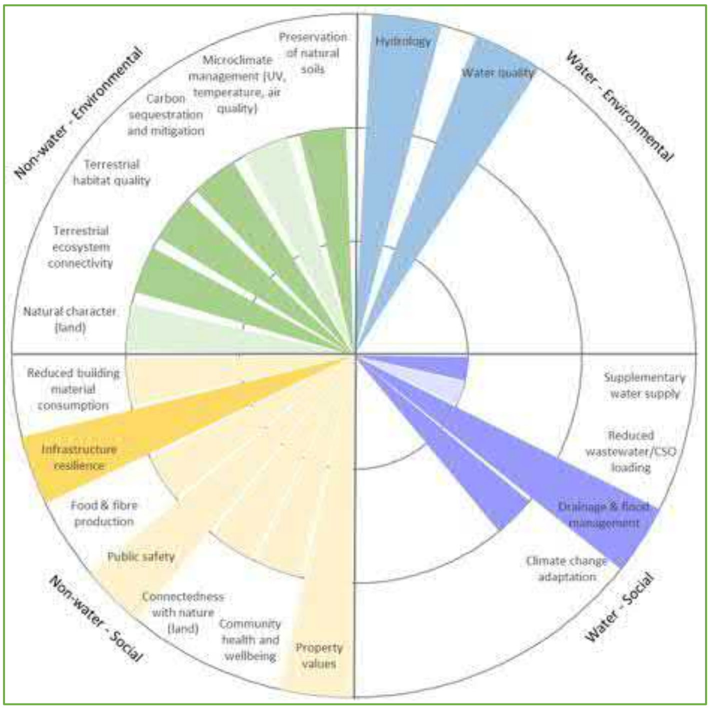
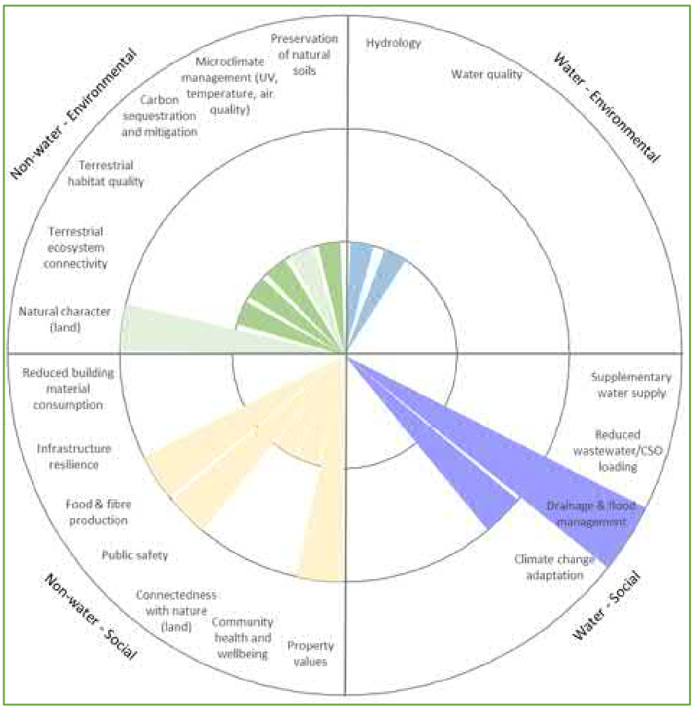
[3] More than Water Assessment Tool: https://www.landcareresearch.co.nz/science/living/cities,-settlements-and-communities/water-sensitive-urban-design

"*More than Water*" Benefits Assessment

Kirimoko Stage 2: As constructed

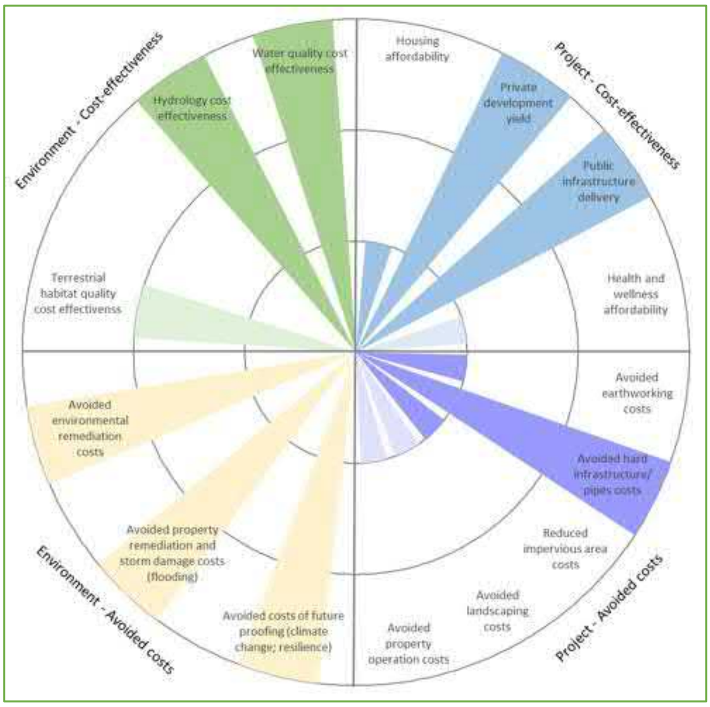


KIrimoko Stage 2: BAU

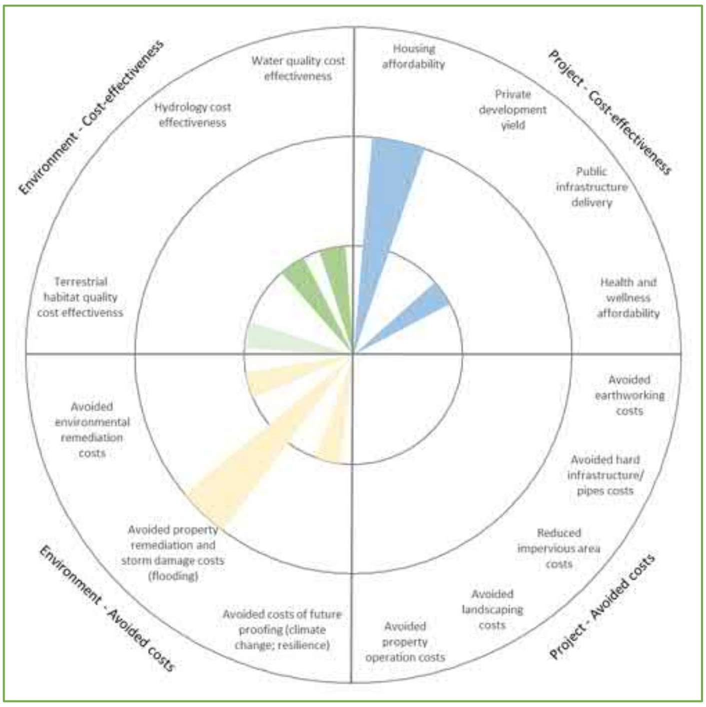


"*More than Water*" Costs Assessment

Kirimoko Stage 2: As constructed



Kirimoko Stage 2: BAU

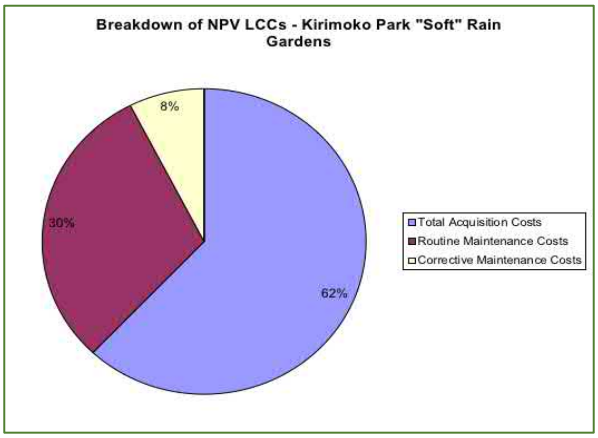


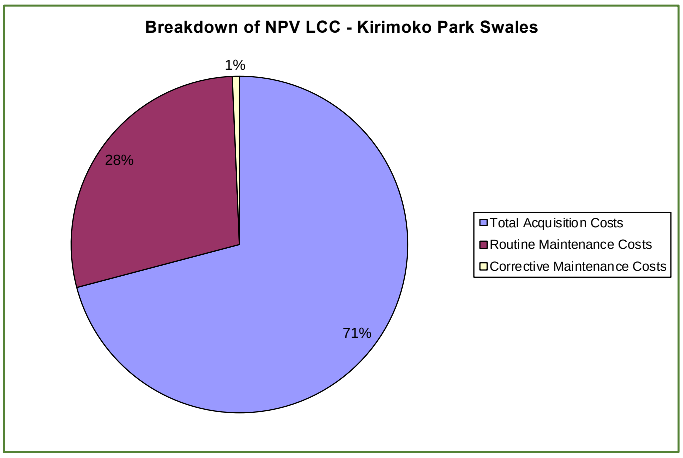
Learnings on costs of WSUD

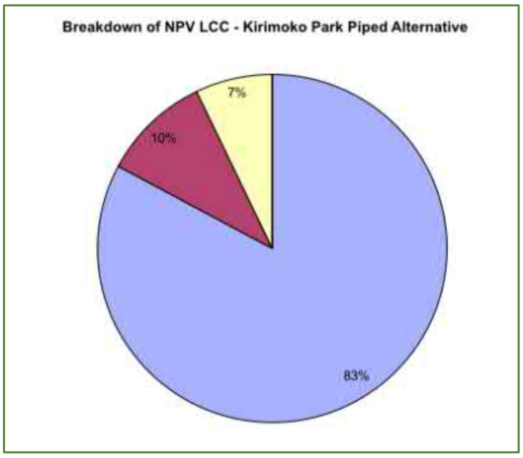
LIFE CYCLE COSTS

Kirimoko Park includes a number of different types of green infrastructure. The indicative estimate life cycle costs are shown below for some of the practices. These estimates are net present value estimates over a life span of 50 years.

Stormwater Practice	LCC $/unit/year
Stage 1 “concrete” edge rain gardens	$44/ m^2
Stage 2 and 3 “soft” infiltration rain gardens	$12/ m^2
Swales	$9/ linear m
Pipes	$11/ linear m

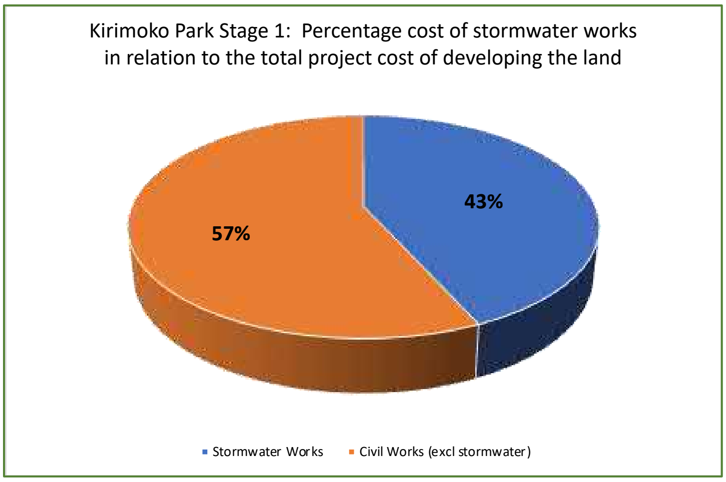


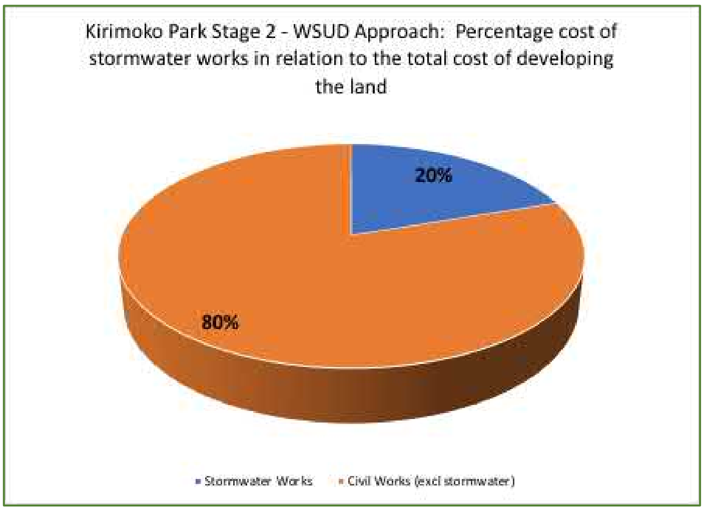




DEVELOPMENT RELATED COSTS

Overall, the water sensitive design approach of using swales over pipes, reducing the amount of earthworking needed and using narrower road widths resulted in an average saving of 22% over a traditional piped, kerb and channel approach to development. Landscaping features are integrated into the green infrastructure practices rather than being additional to it. No savings were realised through Stage 1 due to the use of expensive imported basalt materials, concrete edged rain gardens and pipes.





The two pie charts show that a WSUD approach can also reduce the total proportion that stormwater infrastructure contributes to the overall development cost.

Learnings on landscaping and maintenance

Most maintenance of swales, soakage/detention basins and rain gardens is integrated into general landscaping maintenance. Most devices are on public road reserves, maintained by the community organization through an annual rate. This means one or two people maintain the whole c.15 ha area, delivering cost-efficiencies and capturing of local knowledge. The Kirimoko 'stormwater systems and operation plan' (OMP) (AR Civil Consulting, 2012) clearly explains how the different components operate, who owns and is responsible for the different components, the maintenance practices (and how they relate to stormwater performance) and frequency. It includes a checklist that serves as a record of specific maintenance activities. The plan includes Appendices with the concept design drawings and raingarden media specification. With 'as built' plans appended and a list of landscape plant species this becomes a valuable resource to guide ongoing maintenance. Trees are maintained on a separate contract to an arborist, approximately 2-yearly while the young trees are developing. This includes removing lower branches to maintain 'clear zones' along roads. The OMP does not cover permeable paving (only used in stage 1).

Clever landscaping uses design elements to protect swales and overland flow paths from the most usual threats, being vehicle invasion and lawn-mower scalping or over-spraying. Protection is provided by corner boulders, wood bollards, tree placement (with protective staking/bollards or under-planting) and use of gravel mulching where vehicles can cut corners.

The most frequent maintenance activity is mowing grassed swales and removal of any debris in the swale systems (including slotted weir controls , pipes and cesspit inlets), approximately two-monthly, followed by trimming of hedges (although most hedges in the road reserve are maintained by adjacent owners) ; mowing frequency is likely increased where adjacent owners use irrigation (and fertiliser). At least annually (or after significant rain events) the following occurs:

- swales are checked for channelized erosion , sediment buildup and oil spills,
- raingardens are checked for infiltration (and if ponding remains 24 hours after rain),
- the condition of the top of overland flow bunds is checked,
- detention ponds spillways, freeboard, embankments, overflows are checked.

Raingardens and infiltration basins are maintained every 6- and 2-months respectively:

- Removing debris, floatable material or trash
- Removing weeds, maintaining plant cover

Acknowledgements

Several people assisted the Activating WSUD research partners in compiling this case study. Special thanks to Andrés Roa at AR and Associates for providing our team with information, support, expertise and assistance.

Our warmest thanks also go to Meridian Land Development Consultants, Southern Land Consultants and Southern Ventures for permission to use Kirimoko Park as a case study and for all your assistance.

WSUD Case Study: TALBOT PARK

About Talbot Park

The Talbot Park Community Renewal project aimed to improve living conditions for Housing New Zealand residents by providing medium-density housing, quality urban design and community strengthening that addressed key community concerns: personal and community safety, lack of local employment and poor community health. The project, completed in 2007, used WSUD and CPTED principles to deliver sustainable urban design for about 750 people within 219 homes. Strong community support for sustainable design features was given by iwi, conservation and recreational groups. A land exchange with Auckland City Council transformed the long, narrow, unsafe Talbot Park to two highly-visible individual parks.

Rain gardens along the new, narrow roads are the most highly visible WSUD features, along with retention of several large specimen trees in prominent places and planting of new trees. These are supported by small areas of permeable paving and 31 rainwater storage tanks which were plumbed to enable reuse in toilet flushing and garden watering. Overland flow paths were retained, defined and protected from development by using permeable decks and plantings to passively exclude vehicles.

Stormwater management approach

Talbot Park had some of the first roadside rain gardens in Auckland city, constructed in January 2006 and enabled by an Infrastructure Auckland grant from Auckland Regional Council (c. $450 K) and cost-sharing between Auckland City Council and Housing NZ. Talbot Park has 14 roadside rain gardens on three new roads in the 5 hectare redevelopment.

Despite significant design, construction and maintenance flaws, the rain gardens have largely functioned since installation:

- Road runoff is no longer piped directly to Omeru Creek. The rain gardens have intercepted sediment washed into them during the building phase, and since then intercepted pollutants such as concrete cutting wash, detergents (from car washing), grass clippings and other gross pollutants.

- Even with minimal current maintenance, and low cover of ground-cover plants, the raingardens contribute to street aesthetics and cohesiveness of the social housing cluster; the use of trees in rain gardens are core to this. The use of CPTED principles[1] in landscaping greatly improved the sense of open space, sense of safety through accessibility and greater passive surveillance.

- The rain gardens' location as 'bump-outs' and shapes together with the narrow roads are fundamental to slowing traffic speeds[2], and enhance the walkability of the area – a specific objective of the project. Children can walk and bike safely on or near the roads.

Talbot Park before redevelopment (left photo) and as redesigned and implemented (right photo).

Talbot Park Renewal Project

The Talbot Park rain gardens illustrate the types of issues which surface when new devices are designed and implemented within a city or region:

- Auckland City Council (ACC) roading engineers did not want rain gardens on the streets – they were concerned about water affecting the road subgrade.
- ACC asset managers were not supportive as they considered point source contamination (galvanised zinc from roofs) to be the key stormwater issue, that rain gardens would not fix this, and they did not want to maintain the rain gardens.

[1] Crime Prevention through Environmental Design uses design to create naturally safer environments by reducing fear and incidence of crime and increasing public surveillance and positive public interactions. https://www.mfe.govt.nz/publications/towns-and-cities/national-guidelines-crime-prevention-through-environmental-design-new and see Auckland Design Manual www.aucklanddesignmanual.co.nz

[2] At the time there was no way to designate a 30 km/hr zone

- ACC consenting staff were not supportive of the narrow roads or reduced car park provision despite the close proximity to trains, buses and Glen Innes centre. However, the ACC policy staff were supportive of the approach.
- Housing NZ did not want rain gardens on private lots because they would require maintenance (for which there was no additional budget), and the small yards were already compromised by rain tanks in some units.
- The design company had experience with rain gardens, but the construction contractors had no experience with rain gardens. This resulted in 10 of 14 rain gardens being constructed with flaws:
    - Inlets were specified as 500 mm wide but were constructed 200 to 300 mm wide, so were prone to blockage.
    - Sloping parking plus gutter design exacerbated bypass flow and reduced inflow in some rain gardens, then overloaded other raingardens.
    - Some inlets were very close to overflows, resulting in short-circuiting of flow.
    - The design 150 mm live storage was not achieved due to a combination of low overflow grates (constructors thought they were fixing a design fault) and overfilling with media and/or mulch.
    - Some inlets concentrated flow as their bases were not absolutely flat – this caused scour in 8 of the 14 rain gardens in 2008.
    - Several overflow grates were 50 mm too high, so water ponded on the road.
    - In one case the impermeable plastic liner installed to protect the road subgrade from water was displaced, diverting stormwater into the subgrade.
- To allow issue of 224c title certificates, rain gardens had to be completed before the adjacent buildings were constructed. Subsequent building construction filled some rain gardens with up to 20 cm of sediment, killed a high proportion of ground-cover plants, and broke branches of trees. The rain garden surface was compacted by waste and building materials stored in them, and builders walking through them.
- Some individual plants were too tall and bulky for rain gardens because they grew into sight lines e.g. some flax and toetoe.

Scouring at raingarden inlets displaced mulch and soil (left). Stormwater inflow showing concentration of water to one side of the cut, but no scouring or leaf litter displacement (centre) and stormwater prevented from entering the raingarden due to overfilling with media/mulch (right). All photos in June/July 2008.

A joint, post-construction assessment undertaken in June 2008 identified implementation issues and workshopped solutions. Solutions included:

- To reduce scour, increase kerb cuts by 250 mm minimum, install 'wings' or baffles in the drainage gutters to slow flow, and install concrete rock aprons.
- To restore design ponding depths, raise overflow grates where they are too low and excavate rain gardens where they are overfilled. Because trees had already been established for 2 years, a pragmatic decision was made to only excavate sections of raingarden without tree root mass and avoiding creating trenches that would short-circuit stormwater from inlet to overflow.
- One raingarden was near a large-leafed deciduous tree. Its leaves covered the stormwater grate in autumn; this grate was identified as needing more regular maintenance in autumn to keep clear.
- Local soils were suitable rain garden media unless overly-compacted. The design minimum permeability was 300 mm/day (c. 20 mm/hr) as per TP10 (2003). Infiltration rates in September 2006 were 30 to 74 mm/hr and in March 2007 the median infiltration rate was 480 mm/hr. The organic mulch surface layer effectively protected the soil from sediment in runoff causing surface sealing. By 2018 the mulch had been replaced by dense carpet of fallen magnolia tree leaves in most raingardens.

The combination of inlet placement and gutter design means most runoff bypassed this rain garden, so overloaded the next raingarden; blue marks indicate where new kerb cuts were to be made (left) 2008. Newly renovated raingarden with c. 150 mm of media removed except around retained trees and plantings, e.g. dense flax at the far end. New inlets improve flow from the street gutter (right) 2008.

Solutions identified to scouring issues, June 2008. At this stage most groundcover plants and trees were about 18 months old, but the tree on the right is new (left). Overfilled rain garden with concrete gutter 'wing' to improve runoff entry (2008) (right).

The following strategies are suggested for cities/ districts where rain gardens/bioretention are new to minimise the potential for similar mistakes and retrofitting:

- Use hold points for pre-construction meetings to ensure contractors understand critical design features (especially ponding depth and overflow function) and use a pre-planting inspection/sign-off to check levels, inlets, overflow locations.
- Ensure all key stakeholders, including councils, support the WSUD approach. Councils can incentivise WSUD by not slowing-down consents and considering removing reserve or stormwater connection contributions. Early discussion of WSUD with the community during consultation helped optimise plant selection.
- The objective of local employment was met by Housing NZ in the short term, with a Talbot Park resident maintaining the rain gardens and landscape. This work was reported as 'vital for removing weeds and litter' but unfortunately stopped. There is huge potential to create such local maintenance jobs, but council contracting methods can be hostile to this approach, especially if they require large insurances, and/or if traffic controls are needed.
- Rain gardens should be commissioned (surfaced and planted) after construction of buildings or bonded and physically protected from construction sediment and traffic, and the raingardens regularly monitored throughout the build to ensure compliance. Bonds must be adequate to allow replacement of all plants, mulch and media.
- Retain dominance of rain gardens in public spaces, as raingardens within individual lots are probably vulnerable to removal. For example, substantial areas of landscaping in individual lots that were protected by bollards have been removed and replaced with grass, used for carparking.
- Avoid very small and/or narrow rain gardens. At Talbot Park the presence of two new adjacent parks could have allowed larger rain gardens and wetlands in each park as attractive and multi-functional landscape features (e.g. as in Westgate and Flat Bush) that also contribute to native biodiversity, carbon sequestration, and potentially weaving resources. Lots of small rain gardens are more expensive to maintain and are susceptible to 'edge' effects.

Features which should be replicated include:

- Conserve space for community gardens where high quality natural soils are present. The Tamaki area has deep, free-draining soils and the existing community gardens could be expanded into the parks as orchards.
- Conserve mature trees and create ‘street corners’ where space for additional large trees can be placed (and these are also useful places for raingardens as corners receive greatest inputs of contaminants from tyre and brake wear).
- Employ local people to maintain the rain gardens and landscaping, especially during establishment – this can be a cost effective approach as people on the ground can quickly remove litter and weeds, treat scour/erosion and identify damage.

Further lessons from the Talbot Park experience are detailed in the following:

- Bracey S, Scott K, Simcock R. 2008. *Important lessons applying low impact urban design: Talbot park.* NZ Water and Wastes Association Conference. https://www.landcareresearch.co.nz/publications/researchpubs/Bracey_etal_NZWWA_2008.pdf
- Bracey, S. 2007. *Making Talbot Park a better place to live*. Building Magazine June/ July 2007. https://www.buildmagazine.org.nz/assets/PDF/B100-41-TalbotPark.pdf and http://www.cmnzl.co.nz/assets/sm/2306/61/1600StuartBracey.pdf
- Community renewal – Housing New Zealand Corporation, Talbot Park, Auckland https://www.mfe.govt.nz/publications/towns-and-cities/urban-design-case-studies-local-government/community-renewal-%E2%80%93-housing
- Scott K. 2009. *Talbot Park residents’ perceptions of sustainable urban design*. Landcare Research Report.
- *Talbot Park Low Impact Urban Design and Development Case Study*: https://www.landcareresearch.co.nz/publications/researchpubs/Talbot_July2007.pdf

Tall toetoe were removed to ensure sight lines were maintained (2013)(left); Large trees planted in large spaces on street corners provide sense of place and welcome summer shade (right).

Talbot Park assessment

What works well	Missed opportunities
Reduced road width reduces impervious areas and, with raingarden 'bump outs' that lower traffic speeds, and off-street parking (fewer on-road parks) deliver safer roads.	Many rain gardens are very small, increasing risk of damage and cost of maintenance. Some weeds have established in bare areas of rain gardens: these include privet, moth plant and agapanthus. Inlets and overflows are not adequately maintained, and some have reached a condition where stormwater inflow is restricted; performance is also hampered by initial construction flaws
Landscaping and stormwater devices fulfil some additional values; trees provide shade and shelter; hedge and groundcover species are mainly native and provide resources for insects and birds. Native trees are growing well in some areas of Talbot Park (non-raingardens) and provide a range of ecological and cultural values. **Some large trees were retained and these provide disproportionate amenity, shade and shelter, especially where integrated into small public spaces.**	Rain garden trees are all evergreen magnolias, which have low ecological values and do not reflect site history or local culture, but do create a long-lasting, dense leaf mulch that is supressing weeds in most rain gardens. The two parks are dominated by mown grass and non-native species including weedy palm trees; the free-draining, fertile soils would support a range of locally-depleted native trees (kohekohe, titoki etc.); the parks could also have contributed to stormwater treatment.
Four groundcover species were initially used in each rain garden, increasing resilience to variable conditions.	There are extensive linear and bulk plantings of single plant species such as broadleaf (*Griselina littoralis*), hebes and sedges. Summer droughts have led to substantial deaths of broadleaf; these hedges have been removed and not replaced.
A restricted number of native plant species with few colourful flowers were used in general landscaping areas (hebe being an exception) and these established well. Some tenants have added or replaced this planting – generally with non-native colourful foliage or flowers, or edible plants (vegetables and fruit).	Some sedges have sharp edges – this may have contributed to their removal, including from overland flow paths where the plants were protecting areas.
Most landscaping had relatively low maintenance; annual trimming of hedges and occasional remulching along edges and weeding. Some of this landscaping has been removed and replaced with lawn – and this needs more maintenance	Find out why landscaping has been replaced with grass as grass lawns are available in parks less than 5 minutes-walk from any house.
Community gardens and private gardens	There is lots of space for gardens and orchards (citrus, plums, feijoa) in the two parks as local parks have (unusually) high-quality, free-draining soils.

Benefits and costs of Talbot Park green infrastructure

"*More than Water*" Assessment Tool

Using the newly developed "More than Water" Assessment Tool[3], the costs and benefits of the WSUD Talbot Park redevelopment were assessed and compared with a traditional (business as usual – BAU) approach to development. The tool allows the user to select the level of each benefit or cost criteria (from low to high), level of importance of a particular criteria, and reliability of the information used to make the assessment. Detailed guidelines are available to guide the user as they make their assessment.

The assessment was undertaken via a workshop approach by the research team using project information provided by consultants involved in the redevelopment of Talbot Park, a site visit and discussions with development consultants. The detailed rationale behind the assessments can be found in the "More than Water" Assessment Tool report[3].

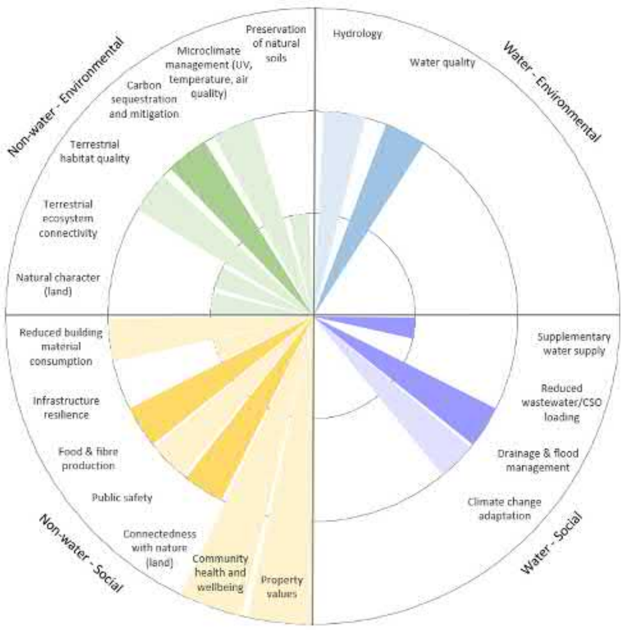
Talbot Park 'as constructed' was assessed as delivering better outcomes than 'business as usual' (BAU). In the case of benefits, 'business as usual' was assessed as delivering all of the non-water criteria at exactly the same level as Talbot Park 'as constructed' (see identical left-hand sides of MTW outputs, in the figures overleaf). This reflects the assumption that, for this assessment, the BAU version of Talbot Park uses trees and landscaping to the same extent as actually exists. The majority of non-water benefits were assessed as being delivered at a medium level under both scenarios, with two delivered at a high level (community health and wellbeing and property values). However, because plantings in the BAU version were assumed to provide no stormwater management function, the water benefits criteria were virtually all assessed to be 'none' (with two exceptions: Hydrology and Drainage and Flood management, assessed as low). In contrast, four of the water benefits criteria were assessed being present at a medium level under Talbot Park 'as constructed'. The reliability of the assessment of benefits criteria was high for six criteria, but otherwise low.

Eight of the cost criteria were assessed as being delivered at a medium level by Talbot Park 'as constructed', only three of these were also assessed as being delivered by the BAU. These were all project scale criteria: development yield, health and wellbeing affordability and avoided property operation costs. The BAU performed much more poorly than Talbot Park 'as constructed' in terms of the assessed level of environment scale criteria (see left-hand sides of MTW cost outputs overleaf). The 'as constructed' version was assessed as delivering one criterion at a high level (avoided costs of future proofing) and four at a medium level. The BAU was assessed as failing to deliver on the majority of environment cost criteria (level of "none"), with three exceptions delivered as a low level. The reliability of the assessment of all cost criteria was considered to be low.

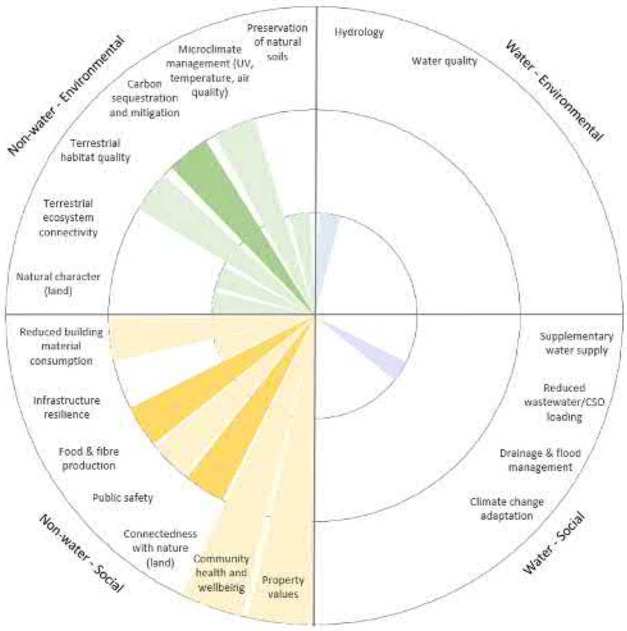
[3] More than Water Assessment Tool: https://www.landcareresearch.co.nz/science/living/cities,-settlements-and-communities/water-sensitive-urban-design

“*More than Water*” Benefits Assessment

Talbot Park: As constructed

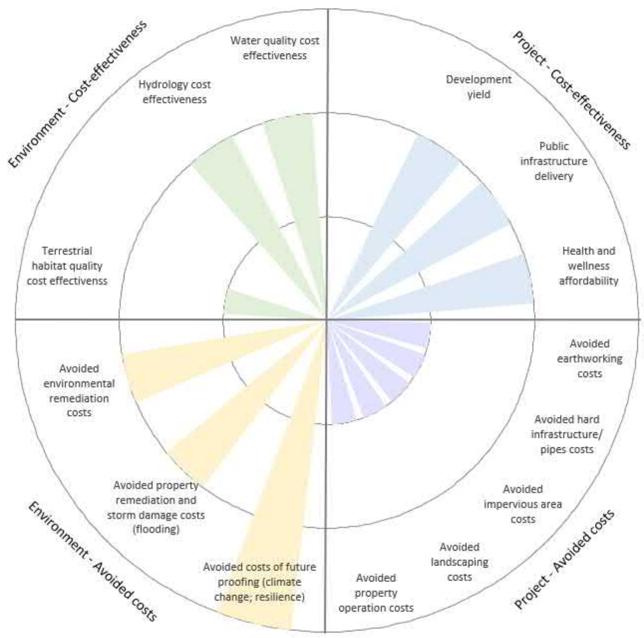


Talbot Park: BAU



“*More than Water*” Costs Assessment

Talbot Park: As constructed



Talbot Park: BAU