Karori Network Improvement Review

Project Name: **Karori Wastewater Network Improvement Programme**

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Our water, our future.

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Executive Summary

Wellington Water Limited (WWL) engaged Stantec New Zealand (Stantec) to undertake a Network Improvement Review (NIR) for the Karori Wastewater Catchment addressing wet weather flows. This report summarises the recent investigation and physical works undertaken by WWL over the period of 2018-2022 within the Karori Wastewater Catchment and is intended to support upcoming consenting activities. This review was completed in parallel with the Jacob's Karori Wastewater Growth Business Case for the Karori catchment and provides a more detailed focus on the specific work to date while the Business Case examines the requirements for long term funding.

The wastewater network serves a population of about 13,000 from the suburb of Karori. The catchment drains to the Western wastewater treatment plant (WWTP) and treated wastewater is conveyed to the South Coast via a main outfall pipeline, built around 1934. The network has several issues that need to be addressed including frequent wet weather overflows to the Karori Stream caused by inflow and infiltration, poor dry weather quality of Karori Stream, and upcoming capacity issues as the population of Karori is expected to increase in the future.

The level of service required for future works will be determined as a part of the proposed conditions for the Wellington City Wastewater Network Overflows Combined Consent. This has been identified as a risk to options improving network performance considered by recent reports, as they may not meet future requirements.

Following the recent renewal works within the Karori 18 South subcatchment, Stantec undertook an analysis of the inflow and infiltration within the catchment using the permanent flow monitors stationed within the network to assess the effectiveness of the works. Although the analysis of the lining for Karori 18 South was largely inconclusive, there was a decrease in groundwater infiltration after lining works were completed and gully trap repairs may have decreased the rate of rainfall dependant inflow and infiltration.

Network improvements that could reduce wet weather overflows in the network and at the WWTP which had been considered by previous reports were summarised and evaluated for any gaps. The options for network improvements included; network rehabilitation, treatment of overflows, storage in the catchment and at the WWTP, and a pipe upgrade between two current overflow locations.

Treatment of overflows and network rehabilitation were unlikely to provide a sole solution, however they may be considered in conjunction with other solutions. Treatment should reduce the environmental impact of remaining wet weather overflows and network rehabilitation would provide other benefits such as improved network performance and reduce seepage into the environment.

Storage is expected to be required at the WWTP, but the volume required could be reduced by WWTP upgrades, storage being built within the catchment, and reducing inflow and infiltration.

There is a potential option to replace storage within the catchment with a pipe upgrade at the existing constructed overflow location. This has the potential to meet requirements at a lower cost but has not been evaluated. It is recommended that this solution has a feasibility assessment and level one cost estimate completed.

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1 Introduction

1.1 Purpose

Wellington Water Limited (WWL) engaged Stantec New Zealand (Stantec) to undertake a Network Improvement Review (NIR) for the Karori Wastewater Catchment. This report summarises the recent investigation and physical works undertaken by WWL within the Karori Wastewater Catchment and is intended to support upcoming consenting activities.

The purpose of the report is to:

1. Review strategies to prevent wet weather overflows to Karori Stream from the network and wastewater treatment plant (WWTP).
2. Discuss the impact to Inflow and Infiltration (I&I) of recent works in 18th South Karori Wastewater Catchment.
3. Meet requirements from the Action Plan of the Western WWTP Monitoring and Technology Review Report (MTRR) completed by Stantec in 2019 (see Section 1.5)

   "Perform a Monitoring and Review of the programme in 2022…

   This review should include:

   - Summary of works completed upstream and downstream completed following this [MTRR] as part of the Karori Wastewater Network Improvement Programme
   - Identify benefits and recommend further work where greatest improvements have been identified".

1.2 Report Scope

The scope of this report includes the following:

- Review of previous reports, background information and the existing wastewater network configuration, see Section 1.6.
- Create a timeline of recent reports, investigations, and physical works relevant to the Karori Wastewater Network Improvement Programme and parallel works, see Section 1.5.
- Discuss previous commentary on level of service (LOS) and summarise potential upcoming changes, see Section 2.
- Assess improvements of recent works undertaken in the 18th South Karori Wastewater Catchment based on flow monitoring data analysis, spend and identified improvements, see Section 3.
- Compile and summarise network improvements identified by previous works. Provide a high-level comment on costs and opportunities of options, see Section 5.
- Recommend any continued investigation into and gaps in improvement options and highlight any risks identified, see Sections 5, 6, and 7.1.

1.3 Assumptions and Exclusions

This report provides a high-level overview of recent proposed improvements to the Karori network, the following assumptions and exclusions are noted:

- The Karori Network is assumed to include the wastewater network upstream of the Western WWTP only. Improvements for the Western WWTP are not included in this NIR.
- Confirmation of LOS and the development of a Network Overflow Reduction Plan will occur as part of consent application and conditions and is excluded from this report.
- The development of cost estimates has not been allowed for.
- No assessment of environmental or stakeholder impacts has been allowed for.
- The improvement options focus primarily on wet weather overflows, but it is noted that dry weather overflows and cross connections still pose a significant risk to the network and should be considered independently.
- Figures and assumptions provided from reports referenced in this document have not been reviewed for accuracy and appropriateness.

Assumptions and limitations directly related to the flow monitoring data analysis are described in Section 3.1.

1.4 Consenting History

The Western WWTP began operating in 1997 and was fully commissioned in September 1998. The wastewater network serves a population of about 13,000 from the suburb of Karori at the head of the catchment. The catchment drains to the WWTP and treated wastewater is conveyed to the South Coast via a main outfall pipeline (MOP), built around 1934. This discharge is authorised by consent WGN060283 [35255].

Wellington City Council (WCC) holds three additional discharge consents, for intermittent wastewater discharges to the Karori Stream, and the South Coast which result from heavy rainfall in the catchment. At times when the capacity of the MOP and the storage located within the WWTP is exceeded, discharge permit [35674] allows the intermittent discharge of disinfected secondary treated wastewater to Karori Stream. At the same time, screened and settled (i.e. partially treated) wastewater is diverted to the MOP to be discharged at the coast under discharge permit [25227]. In extreme cases, discharge permit [35675] allows a portion of the screened (i.e. partially treated) wastewater to be discharged into the Karori Stream via a manhole at the WWTP.

The two consents for intermittent discharges to Karori Stream from the WWTP ([35674,35675]) are due to expire on 31 December 2023. WWL is currently working through the process to renew these existing consents. The wastewater network overflows in the catchment above the WWTP are not currently consented and WWL intend to consent these overflows at the same time. The MOP consents ([35255,25227]) are not due to be renewed until 2035.

The resource consents covering the discharges from the MOP into the coastal marine area initially included conditions requiring replacement of the outfall pipeline by 2023. These conditions were removed in 2018 (following detailed investigations of the pipeline condition) but in their place, consent conditions were added requiring improvements to the wastewater network to be investigated, as they relate to the effects of discharges from the WWTP (not effects from upstream network discharges).

1.4.1 Karori Wastewater Network Improvement Programme

To address the conditions regarding improvements to the wastewater network and to prepare for reconsenting in 2023, funding was allocated to support a project to drive investigations and improvements in the Karori wastewater catchment. From this, the Karori Wastewater Network Improvement Programme (KWWNIP) project was developed in 2019 with the purpose of addressing inflow and infiltration, reducing overflows, and reducing the negative impact on the water quality in the Karori Stream.

One of the first work streams undertaken by the KWWNIP was to ensure compliance with current (and new) resource consent conditions. One of these conditions, Condition 27 of discharge permit 35255, required a Monitoring and Technology Review Report (MTRR) for the Western WWTP be completed in the 9th year of the consented period (2019). The MTRR was included as a mechanism for ensuring that future operations of the WWTP were managed in the most appropriate manner given contemporary environmental conditions, regulatory requirements, and available technologies. Stantec completed the MTRR report and action plan in December 2019.

1.5 Recent Investigations and Works Timeline

From 2018 onwards several reports have been commissioned by KWWNIP and the WWL operation team covering aspects of the Karori wastewater network's performance and improvement options. The reports reviewed as part of this Network Improvement Review are listed below:

- Karori Inflow and Infiltration Assessment, Mott Macdonald, January 2019
- Western Wastewater Treatment Plant Monitoring and Technology Review Report, Stantec, December 2019, (WWWTP MTRR)[1]
- Karori Wastewater Network Options Assessment, Hydraulic Analysis Limited (HAL), May 2021, (HAL Report)
- Karori Wastewater Network Storage Feasibility Assessment, Stantec, May 2022, (Storage Report)
- Karori Post-Rehabilitation Monitoring, Mott MacDonald, May 2022, (Lining Report)
- Karori Wastewater Growth Business Case Programme Business Case, Jacobs, August 2022, (Karori PBC).

Recent works that could have affected the operation of the wastewater network have also been reviewed, a timeline is provided bellow:

- **April 2019 – August 2020:** 36 house to house private gully trap repairs in 18 South Subcatchment and 400 South Subcatchment, Cardno
- **February 2021 – April 2021:** Lining approximately 1km of public mains in 18 South Subcatchment, Connect Water/Hydrotech
- **September 2021 – January 2022:** Lining public mains and laterals[2] in Lewer Subcatchment, GHD/GP Friel
- **April 2022 – May 2022:** Lining public mains and laterals in Samuel Subcatchment, Connect Water/Hydrotech

1 This report was required by Condition 27 of discharge permit 35255
2 Laterals were lined from the public wastewater main to the private property boundary

- **May 2022 – June 2022:** lining 48 private laterals in the 18 South Subcatchment, Connect Water/Hydrotech
- **April 2023 (expected) – August 2023 (expected):** Storage tunnel outlet valve upgrade, GHD/Brian Perry Civil.

A Timeline of the works and reports is shown in Appendix A.

1.6 Network Performance

An overview of the Karori Wastewater Catchment is shown in Figure 1 and a more detailed figure with the location of the Karori Wastewater Subcatchments, flow monitors, and engineered overflow points (EOPs) is shown in Appendix B. The total catchment, outlined in blue, is approximately 400 hectares of predominantly low-density housing. The WWTP is located approximately 2.2km southwest of Karori, with treated effluent ultimately discharging to Wellington's southern coast via the MOP that follows the route of Karori Stream.

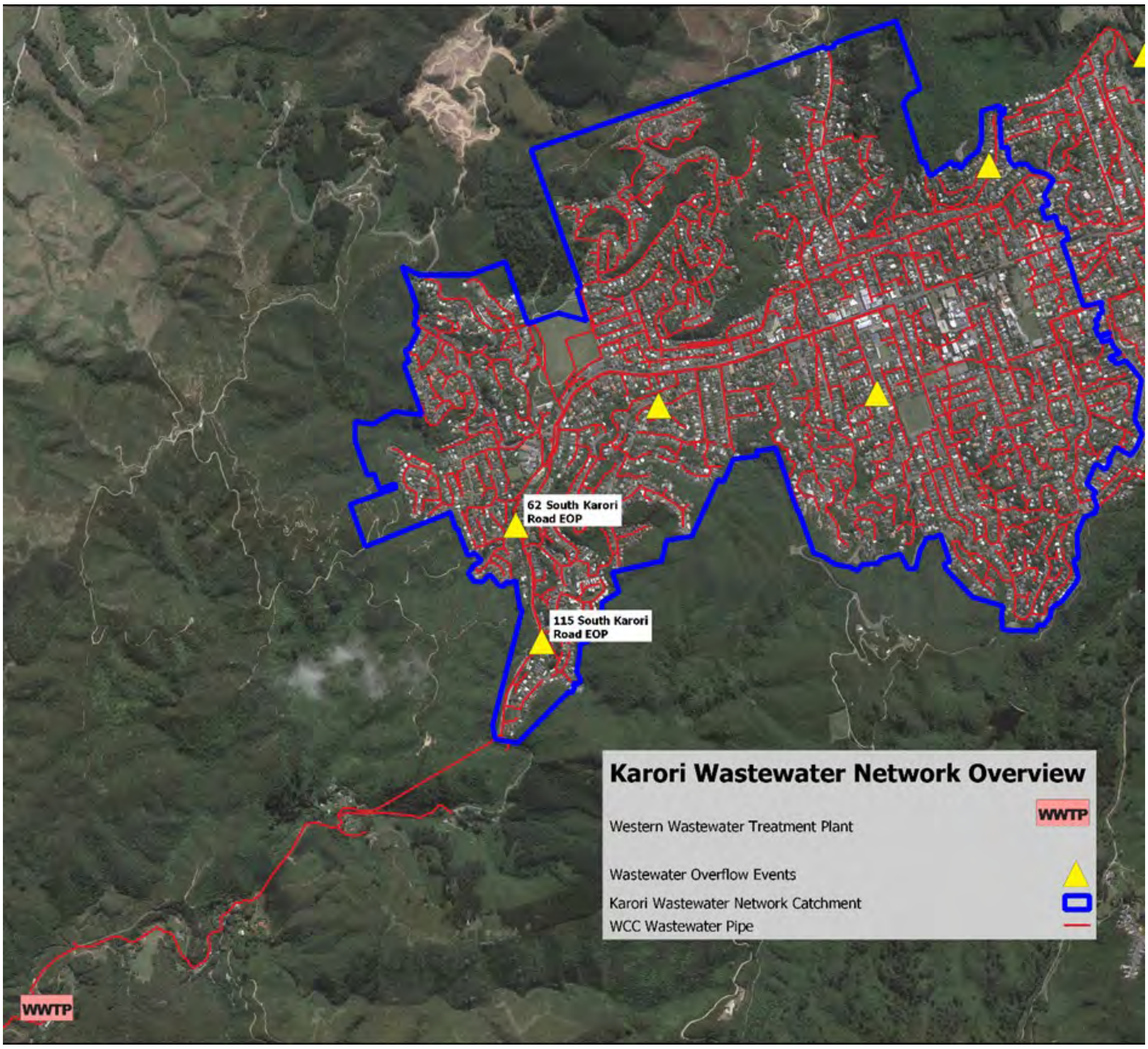


Figure 1: Karori Wastewater Network Overview

1.6.1 Inflow and Infiltration

There are several locations where wastewater overflows within the Karori Catchment during wet weather. Of these locations, the most significant and frequent overflows are currently experienced at two EOPs at 62 South Karori Road and 115 South Karori Road, shown in Figure 1. Currently each overflow has about 5 spills/yr according to flow monitors, but 62 South Karori spills much greater volumes, about 3,400 m3/yr compared with 40 m3/yr at 115 South Karori EOP. In addition to the EOP's several areas within the catchment have been identified as having poor condition and problems with I&I. The HAL Modelling Report from 2021 estimated that an average 42% of annual inflow is attributed to rainfall, although this value has not been scrutinised. Similar I&I issues were identified in the earlier Mott MacDonald report from 2019, which identified groundwater infiltration as the main contributor to I&I.

1.6.2 Water Quality

The Karori Stream is known to have poor water quality with elevated E. coli levels being recorded during both dry and wet weather conditions. The Jacobs Karori PBC Report states that faecal source tracking indicates that the source of E. coli is predominantly human and that this indicates that wastewater contamination of the Karori Stream occurs via a combination of wet weather overflows and pipeline seepage (due to blockages or leaks in the system).

1.6.3 Network Capacity

The HAL report identified the following restrictions with the overall wastewater system:

- The wastewater main discharging to the WWTP has approximately 470l/s capacity
- The WWTP can provide full treatment up to about 200l/s
- The MOP has a capacity of about 160 – 180 l/s.

Currently the WWTP has an estimated 6-7 spills/yr to Karori Stream. Although the planned automation of the existing storage tunnel upstream of the WWTP could reduce this to 2-3 spills/yr, according to the HAL Modelling Report.

The population of Karori was about 13,000 in 2021 according to census data and growth is expected to increase with upcoming planning changes and intensification. The Karori PBC provides low, medium, and high 30-year growth scenarios with a 2053 population predicted to range from about 13,500 to 21,000 people. The WWTP is not expected to be able to service a population over 15,000 and the increasing population is expected to exacerbate existing issues with overflows and I&I. According to the Jacobs Karori PBC Report, WWTP performance may become inconsistent and increase the risk of dry weather overflows if the capacity is not increased to meet population changes in future.

2 Level Of Service

The previous reports considering improvements to the Karori Wastewater network assumed different Levels of Service (LOS) and the actual LOS is expected to be determined following upcoming community engagement.

The HAL Report included the following LOS:

- Uncontrolled overflows to not exceed an average of one spill per year wet weather overflow frequency.
- Overflows at constructed locations to not exceed an average of two spills per year wet weather overflow frequency.

The Karori PBC assumed that for options including I&I management, the I&I programme would target a LOS of 1.5 spills per year in wet weather.

Neither of the LOS options above meet the Whaitua Recommendation target of zero overflows by 2060 except for 25-year Average Recurrence Interval (ARI) events or infrequent situations such as pump failures. The Karori PBC discusses the Whaitua Recommendation in more detail but acknowledges that this target is unlikely to be achievable with the considered options. It has not yet been adopted by Greater Wellington Regional Council (GWRC) in their Proposed Natural Resources Plan (PNRP) or Regional Policy Statement (RPS). The required LOS to meet consenting requirements is expected to be determined via a collaborative committee that will be established once the consents are granted.

3 Analysis of Recent Works

3.1 Stantec Inflow and Infiltration Analysis

Following the recent works within the Karori 18 South Subcatchment, Stantec was engaged by WWL to undertake an analysis of the I&I within the catchment using the permanent flow monitors stationed within the network. The Data Analysis Memo detailing this investigation is provided in Appendix C.

This analysis considered three improvements completed in the subcatchment between 2017 and 2022, summarised in Table 1.

Table 1: Karori Improvement Summary

Works Undertaken	Quantity Completed	Duration	Total Project	Approximate Network Covered	Network Covered Percentage
Gully trap repairs/house investigations	36 repairs	Feb 2019 – Oct 2019	$128,000*	777/5000 properties in Karori Catchment	15%
Main Rehabilitation	920m	Feb 2021 – April 2021	$1,200,000	920/73,000 m of wastewater main in Karori Catchment	1%
Lateral Rehabilitation	408m	May 2022 – June 2022	$600,000	408/159,000 m of wastewater lateral in Karori Catchment	<1%

*The $128,000 spent on gully trap repairs is for both 400 South and Karori 18 South Catchments, this included the inspection of 777 properties.

Additional lining of mains and lateral rehabilitation was completed in other subcatchments in Karori during this time period under the separate Wastewater Renewal programme undertaken following the Stimulus Funding programme across all of Wellington Water, this is briefly described in Table 2.

Table 2: Lewer And Samuel Subcatchment Improvements

Works Undertaken	Approximate Quantity Completed	Duration
Samuel Rehabilitation	620m	April 2022 – May 2022
Lewer Rehabilitation	1850m	September 2021 – January 2022

There was four months of short-term flow survey data available between June 2017 and September 2017 and long-term flow monitor data available from July 2019 to January 2023 for comparison. Flow monitors were located within the 18 South Subcatchment, and results were compared with data from the neighbouring School Subcatchment to try and account for variability in the data. The analysis focussed on assessing the impacts of lining wastewater laterals and mains as these improvements had long term flow monitor data before and after their implementation. Several limitations were identified which restricted the use of the data including:

- The 2017 short term-flow monitors where in a different location to later monitors, so flows were approximated subtracting flow monitors from each other, which would have exacerbated uncertainties.
- Data during COVID-19 lockdown periods was excluded from analysis.
- Changes in flow monitor calibration were not considered.
- Dry weather flow depths are typically less than 100mm and have high uncertainties due to sensor limitations.
- The reported values are intended to only be used for comparison purposes and trend analysis, not for quantifying the extent of inflow and infiltration.
- The rainfall periods after the mains lining and after the lateral linings were significantly wetter than the historical average.
- Only the 2017 flow survey data was available from before the gully trap repairs. This data had higher uncertainties so gully traps have been excluded from the main analysis.
- When RDII is <10%, improvements on metrics are hard to quantify.
- Improvements made to high intensity events with less than 20mm rainfall were not captured in the analysis.
- No adjustments have been made to the rainfall to account for spatial variation or elevation variation.

3.2 Inflow and Infiltration Findings

Although the analysis has limitations, some conclusions can still be made. Groundwater infiltration (GWI) dropped after lining the wastewater mains and laterals in the catchment. This is expected to be because the lining addressed leaks in the network, although, there was no significant change observed in Rainfall Derived Inflow & Infiltration (RDII). RDII had a high variability, with relatively large differences in the School Subcatchment where no works were undertaken. This means that any impact the improvement may have had on RDII is masked by the variability of events between periods. It is possible that the stormwater entering the wastewater network through the pipes is only a small component of RDII and stormwater is still entering the system at other points.

Stormwater inflow (SWI) increased slightly after lining the wastewater mains and laterals. This increase is expected to be because the periods after each improvement were wetter than average, with increased PWWF, but could also be because the lining caused a slight decrease in Average Dry Weather Flow (ADWF) by reducing GWI.

The 2017 flow survey data was excluded from the main analysis due to high uncertainties in the data, however, with an understanding of these uncertainties a limited comparison can be made to identify if the gully traps had an impact. The RDII dropped from 12% in the 2017 flow survey analysis to <5% in the current analysis after the gully trap repairs were completed. Even considering that the 2017 value has lower confidence, there appears to be some reduction. The stormwater entering the network through gully traps contribute to the fast rainfall response so this reduction suggests that the fast response was a large component of the RDII in 18 South Subcatchment.

These results show the difficulty in accurately assessing I&I and measuring improvements accurately over a period of works. It is recommended that future assessments comparing improvement works undertake a gap analysis prior to works, to determine the usefulness of the available data and its limitations.

3.3 Mott MacDonald Inflow and Infiltration Analysis

The 2019 Mott MacDonald Inflow and Infiltration Assessment completed an analysis of flow monitoring data from 2017 where a series of flow gauges were installed to assess I&I in Karori subcatchments. The findings of this report considered GWI to be the biggest contributor to I&I and that the Karori 18 South subcatchment had some of the highest I&I compared with other Karori subcatchments.

It is noted that most of the gauged catchments used the "subtraction" method for determining flow by deducting one flow monitor's results from another. Three of the catchments were "leaf" catchments where flow was directly monitored by a flow gauge. The results for the "subtraction" catchments will have a greater uncertainty in their results due to this indirect method of monitoring.

The 2022 Karori Post-Rehabilitation Monitoring Report completed by Mott MacDonald did find a small reduction in GWI and a small increase in RDII and SWI in the Lewer Subcatchment following lining works in that subcatchment. However, the Lewer results from 2017 used a different subcatchment definition than the 2021-22 results they were compared with, and the 2021-22 results used a much longer monitoring period, which would add to the uncertainty of the comparison.

4 Proposed Network Improvement Options

4.1 Network Rehabilitation

Although the analysis of the lining works has not been able to be accurately quantified, it is noted that ongoing network rehabilitation is expected to aid with reducing seepage into the environment and over large enough area is still expected to reduce I&I even though this has been difficult to conclusively prove.

The HAL Report estimated that if I&I were reduced by 25%, this could reduce the frequency of spills/yr in the wastewater network. HAL also considered raising the EOP levels 0.5m, which would increase spills downstream but could be used in conjunction with WWTP storage for a more effective solution.

Jacobs recommends I&I on the assumption that overflows will be reduced as well as dry weather overflows, by reducing blockages in the network, and seepage, which were also considered as significant drivers to stream improvement in the Karori PBC.

Based on the analysis it appears unlikely that network rehabilitation will reduce overflows to a suitable level by itself, but it is expected that it would still help with the networks performance overall and could extend the life of a selected option by reducing I&I to an extent if rehabilitation is kept ongoing as assets age. Network rehabilitation is needed for wider benefits than wet weather overflows, the network currently has problems with seepage into the surrounding environment and pipes will continue to deteriorate as they age. This agrees with the understanding that I&I reduction can be difficult to quantify.

4.2 Catchment Storage

Installing wastewater storage within the catchment is a generally accepted option to reduce overflows suggested by both the Karori PBC and the HAL Modelling Report. The Karori PBC preferred option was an adaptive pathway solution consisting of network storage, I&I improvements, WWTP Upgrade, and eventual replacement of the WWTP outfall.

The recent Stantec Storage Report assessed the feasibility of catchment storage options suggested by the HAL report and provided a list four options for a technical shortlist of sites, shown in Figure 2.

Figure 2: Technical Shortlist of Catchment Storage Sites

It is noted that the size of storage increases upstream of the EOP (located at 62 South Karori Road) to compensate for capturing less of the network's total flow, but all are expected to achieve similar frequency reductions.

The Storage Report completed Level 1 cost estimates on the technical shortlisted sites giving expected estimates of between $25-40 Million. Technical constraints around constructing the storage were considered. Except for Site S06 all sites are expected to be underground. The cost estimates do not include expected maintenance and operations costs which will be comparatively higher than other options such as a pipe upgrade at the EOPs. Storage will also not provide secondary benefits to the wastewater system like other options such as network rehabilitation, which can reduce leakage and blockages.

According to the HAL Modelling Report, storage within the catchment is only expected to significantly reduce overflows at the EOPs with a relatively minor effect on overflows at the WWTP. A separate storage solution would still be required at the WWTP to meet the expected LOS goals.

4.3 WWTP Storage

Storage at the WWTP is expected to be required separately from a solution to catchment overflows. If storage or I&I reduction is utilised upstream, the size requirements of the WWTP storage may be reduced to a degree. The HAL Report identified the need for WWTP storage and approximated the volume requirement to be up to 6 ML, however specific options were not directly modelled, and the volume requirements are only indicative.

The recent Storage Report assessed the feasibility of WWTP storage options suggested by the HAL report and provided a list two options for a technical shortlist, shown in Figure 3.

Figure 3:Technical Shortlist of WWTP Storage Sites

The Storage Report completed Level 1 cost estimates for the selected sites, both of which had an expected estimate of $33 Million. These sites are generally less constrained than the ones within the catchment and the sites were assumed to be for above ground tanks with 6,000m^3 storage volume. The cost estimates do not include expected maintenance and operations costs. Both sites are located on WCC owned land but not within the fenced boundary of the current WWTP site.

The Jacobs preferred option included an upgrade to the WWTP capacity. This report has not included capacity improvements to the WWTP which could reduce overflows as they are outside the scope of this report, but it is suggested that if storage is progressed it could be aligned with any planned future development with the WWTP to provide a more optimised solution. This includes a potential upgrade to the outfall which is expected to be required within 30 years and could provide an alternative to storage.

4.4 Upgrade Pipe Downstream of Overflow

The HAL Report identified another option to reduce overflows at 62 South Karori EOP, by raising the EOP weir and increasing capacity of the pipe downstream. The HAL Modelling Report estimated an additional 108l/s conveyance may reduce overflows to 1.5/yr, and an additional 150l/s conveyance may reduce overflows down to 0.1/yr.

HAL's assumed pipe upgrade would include constructing either a new 400mm pipe or replacing the existing 525mm pipe with a 600mm pipe from the 62 South Karori EOP to the existing bifurcation and replacing an existing 450mm pipe with a 600mm pipe from the bifurcation to the 600mm trunk sewer. This would require approximately 100m of new pipe for the pipe upstream of the bifurcation and 400m of new 600mm pipe downstream to be constructed. At least one manhole may need to be sealed for this option to function. Alternative pipe sizes and arrangements could also be considered to provide the additional conveyance. The arrangement of existing pipes and alignment of the upgrade is shown in Figure 4.

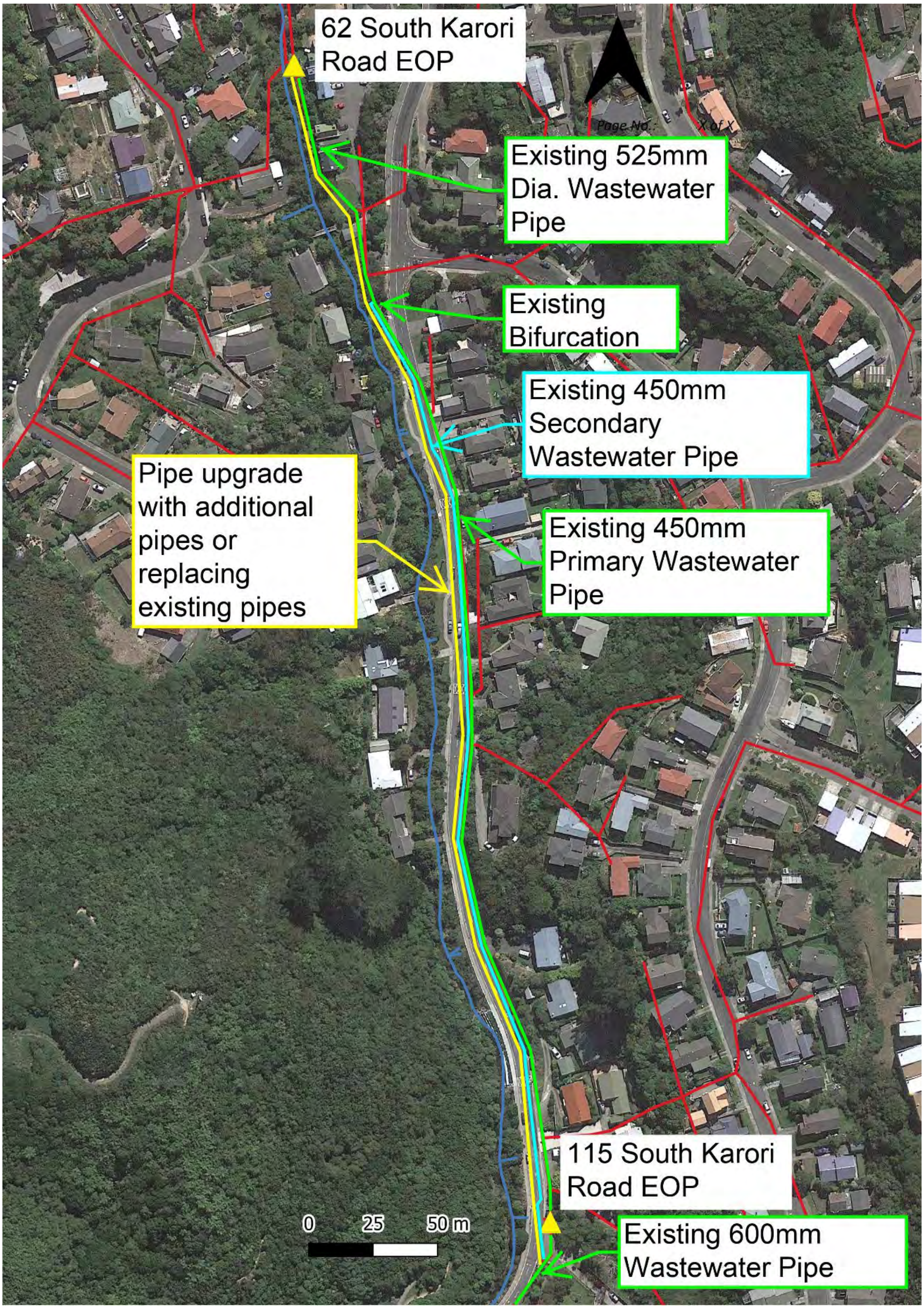


Figure 4: EOP Pipe Upgrade Option

This option decreases overflows at 62 South Karori EOP but will increase the frequency and volume of overflows at the 115 South Karori EOP downstream. This can be mitigated by raising the second EOP level and extending the pipe upgrade up to the tunnel storage downstream if needed, which would be an additional 400m of pipe. The pipe upgrade would also result in an increase to flows at the WWTP, however, as storage is already expected to be required at the WWTP, it may still be more cost effective to increase the size of storage at the WWTP rather than construct separate storage within the catchment.

This pipe upgrade option has the potential to be as effective as a catchment storage option but is likely to cost less both for immediate and whole of life costs. However, the impact on the downstream network would need to be examined more closely and alternative pipe sizes and arrangements could be considered to optimise design.

4.5 Treatment at Constructed Overflows

If the overflow frequency cannot be reduced to none, which is likely, there may still be an option to treat overflows. This could include screening and UV disinfection to reduce the impact of wet weather overflows on Karori Stream. This has not been considered in recent studies concerning the Karori Wastewater Network overflows but has been considered in a recent Porirua Network Improvement Plan.

Treating overflows is not considered to be viable as a sole solution but may be considered in conjunction with other options. It is expected that future consenting policies may have increased emphasis on the receiving environment’s water quality and as such treatment in conjunction with reduced overflows may provide a viable partial solution.

5 Analysis of Options

The information for options considered in Section 4 was evaluated and used to create a comparison table for options, provided in Table 3.

Table 3: Analysis of Options

Improvement Option	Cost Comparison	Benefits	Drawbacks	Recommendations and Gaps
Network Rehabilitation – Gully Trap Repairs	The gully trap repairs are expected to be one of the more cost-effective solutions that had potential improvement on the network.	Network rehabilitation is expected to provide benefits such as improved network performance and reduction of dry weather overflow risk. Rehabilitation is expected to provide some degree of reduction to I&I although this has not been able to be quantified.	A significant level of investment would be needed over an extended period of time in order to achieve an unknown amount of I&I reduction. Consequently, network rehabilitation is not expected to provide a sole solution, although it may still be used as part of ongoing network improvements and has potential to extend to useable life of a selected option by providing some degree of I&I reduction.	Gully trap repairs were potentially one of the more effective and affordable network improvements. It is recommended these repairs are considered for other catchments.
Network Rehabilitation – Public network Main and Lateral improvements	Recent 18 South works rehabilitated about 1.1% of the network, excluding private laterals, for around $2,000,000. This is a high-level approximation of costs, but it can be assumed that rehabilitating the rest of the network is expected to require significant investment over several years. The exact quantity and cost needed to rehabilitate the network has not been able to be quantified.	Network rehabilitation is expected to provide benefits such as improved network performance and reduction of dry weather overflow risk. Rehabilitation is expected to provide some degree of reduction to I&I although this has not been able to be quantified.	A significant level of investment would be needed over an extended period of time in order to achieve an unknown amount of I&I reduction. Consequently, network rehabilitation is not expected to provide a sole solution, although it may still be used as part of ongoing network improvements and has potential to extend to useable life of a selected option by providing some degree of I&I reduction.	It is recommended that if future assessments comparing improvement works are required, they undertake a gap analysis early to determine the usefulness of the available data and its limitations for comparison after works take place.
Catchment Storage	Only storage has had a Level 1 cost estimates completed, which were intended to be used for comparison purposes only. The catchment storage sites cost estimates ranged from $25-40 million for a range of sites. The cost estimates do not include expected maintenance and operations costs.	The catchment storage options have been assessed to a relatively higher degree than the other options due to the recent Storage Study, they are expected to provide a valid option to address catchment overflows. They are expected to reduce the volume of storage required at the WWTP, although the exact volume is still to be quantified.	Catchment storage is relatively expensive due to the constraints of constructing large storage in an urbanised area. If the LOS becomes more conservative cost could increase and create further constraints to storage sites. It will also require more ongoing maintenance than a pipe upgrade likely would.	Further detail of this option is not expected to be required until other options have been progressed for comparison.
WWTP Storage	Only storage has had Level 1 cost estimates completed, which are intended to be used for comparison purposes only. The WWTP storage had an expected estimate of $33 million, with an approximate volume of 6,000m^3. The cost estimates do not include expected maintenance and operations costs	There is potential to align the work with future plans to increase capacity at the WWTP, as this could either reduce the storage volume needed to reduce overflows or larger storage could delay the need to increase the WWTP capacity.	Currently it is expected that some level of storage at the WWTP will be required. The volume of storage needed at the WWTP has not been confirmed to the same degree as catchment storage by the HAL Modelling Report. The volume will need further consideration as it is dependent on several factors such as the LOS, the option selected in the catchment and WWTP upgrades.	It is recommended that a future options study is undertaken which includes consideration of the volume required in conjunction with different options such as WWTP capacity upgrades.
Pipe Upgrade	Currently there is no cost estimate of the potential pipe upgrade which can be used to compare options.	The option has the potential to provide an alternative to catchment storage and cost less both for immediate and whole of life costs.	This option would have more downstream impacts than catchment storage, including increasing the size of the WWTP storage and increasing the risk of surcharge at downstream manholes requiring them to be sealed.	It is recommended that this solution has a feasibility assessment and level one cost estimate completed similar to the storage options so that they can be more easily compared as options.
Treatment of Overflows	Currently there is no cost estimate of the overflow treatment which can be used to compare options.	This option would mitigate water quality impact of remaining overflows.	Treatment of overflows is not expected to provide a sole solution, although it may still be used to mitigate the impact of remaining overflows on water quality in Karori Stream.	The extent of treatment considered, and cost should be included in a future options study in conjunction with other options.

*Exact volumes and details for all options will not be able to be developed until a LOS is confirmed and a target level for reduction of overflows is determined.

*All options will need to be assessed for social impact and environmental considerations before one can be selected.

6 Risk Assessment

Several high-level risks have been identified through this review and should be monitored as future Karori Wastewater work progresses. These risks are summarised in Table 4.

Table 4: Project Risks

Risk Identified	Raw Rating	Mitigation Measure	Residual risk rating/ contingency
The modelling completed as part of the HAL Report may not be accurate and more storage may be required than expected.	High	The report has undergone check and review, later design stages should revaluate if more modelling is required.	Moderate
An LOS may be selected which cannot be easily met by currently considered options.	High	Follow methodologies approved by the regional council to determine the level of service for containment standards.	Moderate
Dry events still pose a risk to the network possibly more significant than wet weather overflows, a solution that helps both may be overlooked	High	Consider dry weather overflows and cross connections at option selection stage.	Moderate
Upcoming Three Waters Reform and other changes to consenting requirements may affect LOS in ways that have not been accounted for.	High	Monitor any planned updates to policy and consenting requirements so they can be incorporated as soon as possible.	Moderate
There is a risk that growth is much greater or less than expected within the Karori Catchment and the considered options will not be the most appropriate or meet requirements.	High	Growth estimates should be reassessed at option selection stage.	Moderate
A valid option to address network problems may have been overlooked by existing studies.	Moderate	This risk has been partially mitigated with this NIR Report, it is also recommended to check for any alternative options at option selection stage.	Moderate
Covid-19 may affect performance of the wastewater network and impact implementation of a solution.	Moderate	Continue to monitor flow monitors for changes in patterns and plan for supply requirements for proposed solutions in advance.	Moderate

7 Conclusion

The Karori Wastewater Network has had several targeted works and investigations completed on it in recent years. This has primarily involved pipe lining and gully trap repairs for works to the network, and reports assessing the impacts of I&I and the potential options to improve network performance. This review of those works and investigations has identified gaps and areas where further consideration of options could be needed to meet future LOS and consenting requirements to reduce overflows.

The analysis of flow data before and after works was found to be variable which made drawing definitive conclusions difficult. Following the wastewater mains lining rehabilitation in the 18 South Subcatchment, GWI dropped slightly, SWI increased slightly, and there was no significant change in RDII, within the subcatchment. The wastewater main lining works within the 18 South Subcatchment accounted for about 1.3% of wastewater mains by length in the Karori Wastewater Catchment.

RDII reduced following gully trap repairs, although there is less confidence in these results due to the flow monitor locations moving within the subcatchment before and after the works. Approximately 11.8% of properties within the Karori Wastewater Catchment were assessed for faults during these works. These repairs were also relatively affordable to undertake, so may provide a good option to undertake in other subcatchments.

The analysis indicates it is unlikely network rehabilitation could reduce overflows to a suitable level by itself, it is noted that rehabilitation works have wider benefits to network performance. This includes reducing leakage to the environment and a decreased risk of blockages. When used in conjunction with another overflow option, such as storage, it could extend that option’s useful life.

Network storage options have been investigated and are a potential solution to reduce overflows but would not provide any further benefits to the network. WWTP storage options have been investigated and are a potential solution to reduce overflows at the WWTP, however the need for storage could be mitigated by future WWTP upgrades such as the upgrade of the outfall pipe.

7.1 Value for Money Opportunities

Value for Money Opportunities were identified in the process of this review. The conveyance option at 62 should be assessed in detail and compared with storage as it has potential to provide an equally or more effective long-term solution at a lower initial and whole of life cost, when compared with storage within the catchment. Storage within the catchment ranged from $25-40 million, and upgrading 500m of 400-600mm pipe is unlikely to cost as much even accounting for downstream impacts.

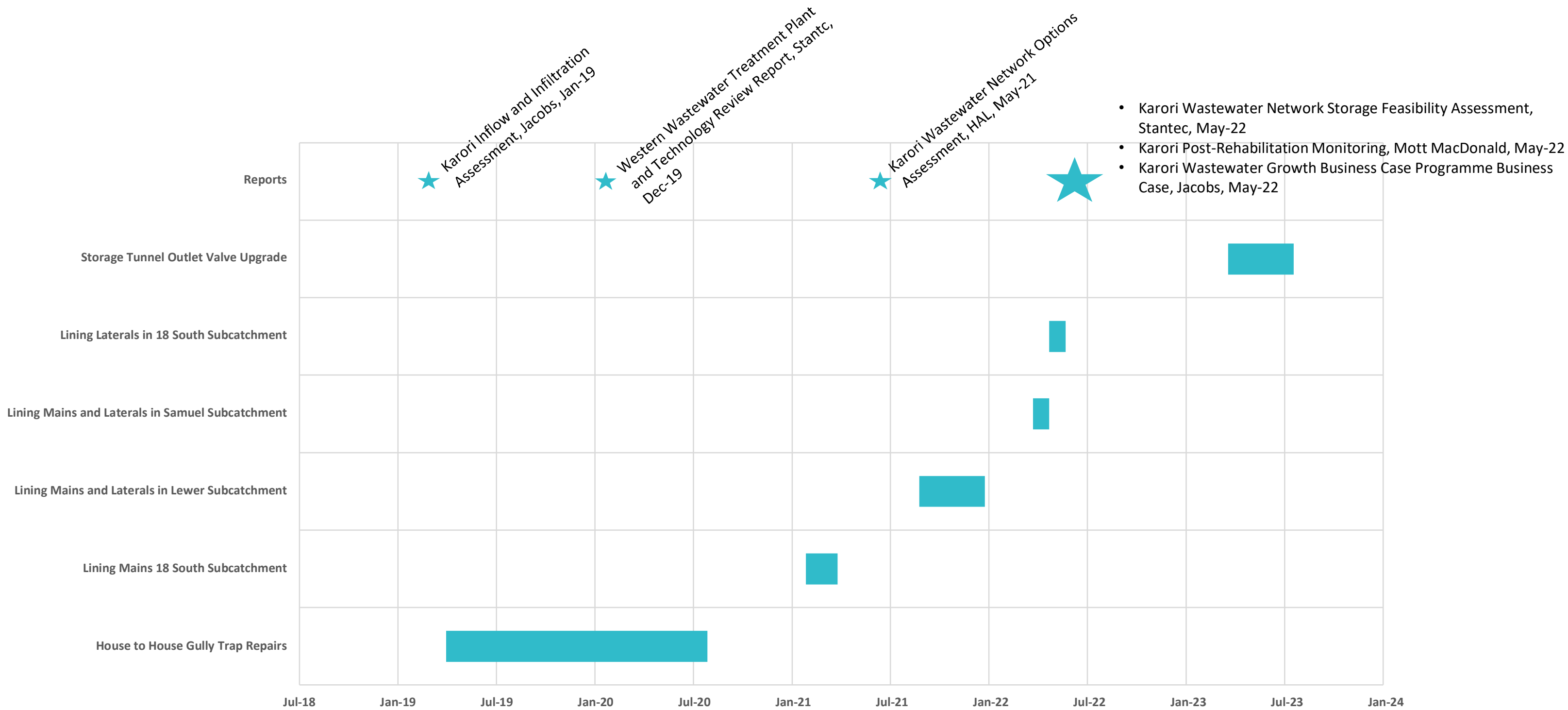
There are also opportunities to align future storage at the WWTP with potential upgrade works to increase the WWTP capacity. If this occurs the storage volume may be less and could save money, or potentially capacity increases could be deferred if the storage is larger.

7.2 Recommendations

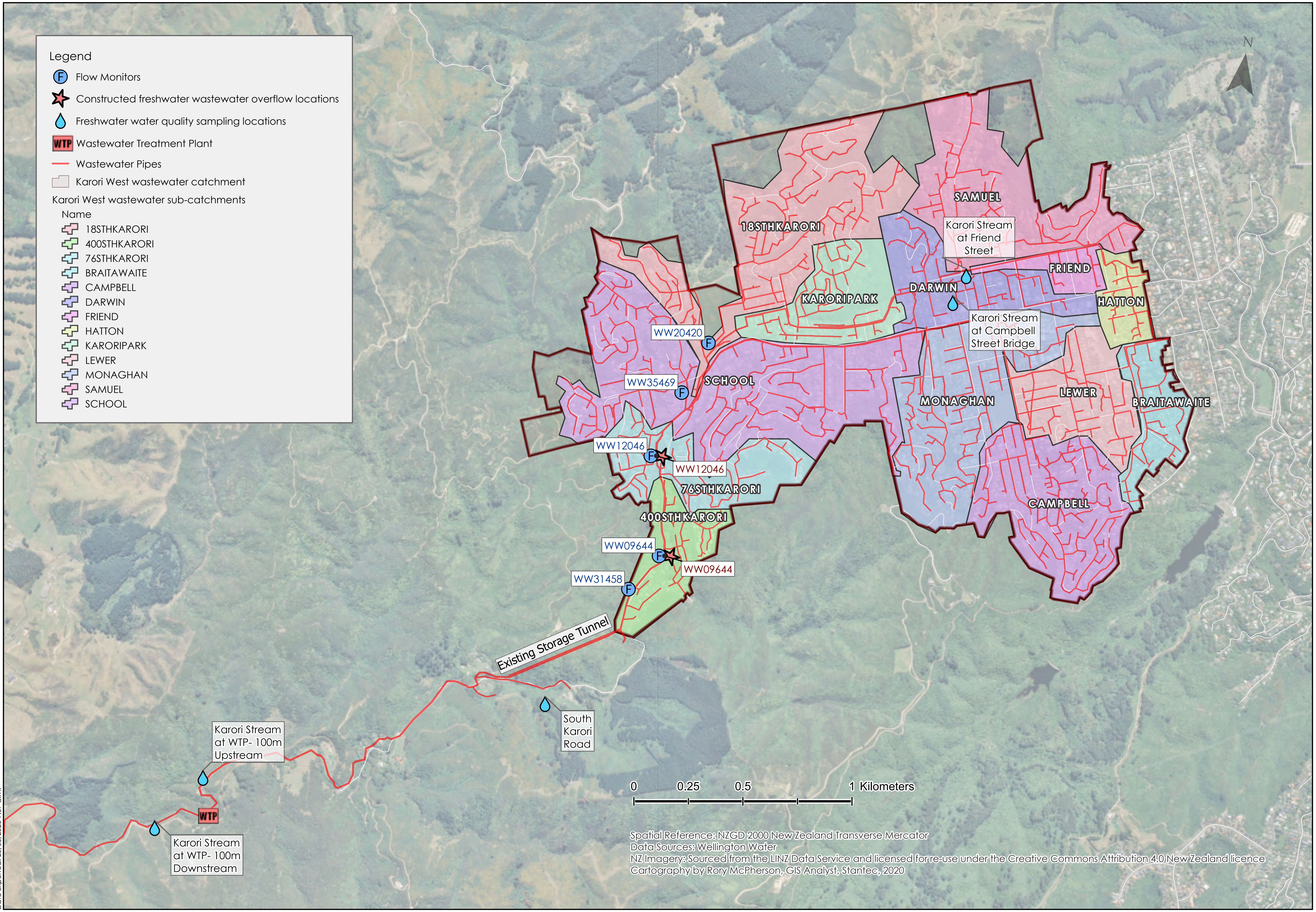
The following recommendations are made to progress existing options and fill gaps in knowledge for potential future options:

- A feasibility Study is recommended to be completed for the pipe upgrade downstream of the 62 Karori South EOP. This should include a level 1 and whole of life cost estimate, an assessment of downstream impacts, a re-assessment of required storage at the WWTP, and a high-level technical check on pipe size and arrangement.
- It is recommended that if future assessments comparing improvement works are required, they undertake a gap analysis early to determine the usefulness of the available data and its limitations for comparison after works take place.
- Gully trap repairs were potentially one of the more effective and affordable network improvements. Gully trap repairs should be considered as a potential option if the fast response rainfall volume is identified as an issue.
- Lining wastewater mains or laterals should both be considered as effective options if groundwater infiltration is identified as an issue.
- All flow monitor data related to a catchment should be stored in Wellington Water's SCADA data system so that data can be sourced from a single location and gaps can be identified early.
- It is recommended that a future options study includes consideration of the volume required for WWTP storage in conjunction with different options such as WWTP capacity upgrades and upstream improvement options.
- The extent of treatment considered, and cost should be included in a future options study in conjunction with other options.
- The planned Network Overflow Reduction Plan should consider confirmation of the LOS, a more detailed assessment of options including environmental and stakeholder impacts, and inclusion of whole of life costs.

Appendix A Timeline of Works


Karori Inflow and Infiltration Assessment, Jacobs, Jan-19
Western Wastewater Treatment Plant and Technology Review Report, Stantc, Dec-19
Karori Wastewater Network Options Assessment, HAL, May-21
• Karori Wastewater Network Storage Feasibility Assessment, Stantec, May-22
• Karori Post-Rehabilitation Monitoring, Mott MacDonald, May-22
• Karori Wastewater Growth Business Case Programme Business Case, Jacobs, May-22
Reports
Storage Tunnel Outlet Valve Upgrade
Lining Laterals in 18 South Subcatchment
Lining Mains and Laterals in Samuel Subcatchment
Lining Mains and Laterals in Lewer Subcatchment
Lining Mains 18 South Subcatchment
House to House Gully Trap Repairs
Jul-18
Jan-19
Jul-19
Jan-20
Jul-20
Jan-21
Jul-21
Jan-22
Jul-22
Jan-23
Jul-23
Jan-24

Appendix B Karori Wastewater Network and Subcatchments



Legend
Flow Monitors
Constructed freshwater wastewater overflow locations
Freshwater water quality sampling locations
WTP Wastewater Treatment Plant
Wastewater Pipes
Karori West wastewater catchment
Karori West wastewater sub-catchments
Name
18STHKARORI
400STHKARORI
76STHKARORI
BRAITAWAITE
CAMPBELL
DARWIN
FRIEND
HATTON
KARORIPARK
LEWER
MONAGHAN
SAMUEL
SCHOOL
N
SAMUEL
18STHKARORI
Karori Stream at Friend Street
FRIEND
DARWIN
KARORIPARK
HATTON
WW20420
Karori Stream at Campbell Street Bridge
SCHOOL
WW35469
MONAGHAN
LEWER
BRAITAWAITE
WW12046
WW12046
76STHKARORI
CAMPBELL
400STHKARORI
WW09644
WW09644
WW31458
Existing Storage Tunnel
South Karori Road
Karori Stream at WTP- 100m Upstream
WTP
Karori Stream at WTP- 100m Downstream
0 0.25 0.5 1 Kilometers
Spatial Reference: NZGD 2000 New Zealand Transverse Mercator
Data Sources: Wellington Water
NZ Imagery: Sourced from the LINZ Data Service and licensed for re-use under the Creative Commons Attribution 4.0 New Zealand licence
Cartography by Rory McPherson, GIS Analyst, Stantec, 2020
Date Exported: 20/05/2020 9:07 a.m.

Appendix C Data Analysis Memo

Data Analysis Memo

Project Name: **Karori Network Improvement Programme**

Project No.: **310101361**

Date: **27/03/2023**

Our water, our future.

Document Control

Panel Member	Stantec
Panel Project Manager	Erin McNary
Client Council	WCC

REVISION SCHEDULE						
Current Status			Draft			
No	Date	Description	Prepared by	Checked by	Reviewed by	Approved by
1	11/07/22	Draft	BC	DP	CH	
2	15/02/23	Updated with FM data up to Jan 2023	BC	MW / DP	CH	EM

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Table 1: Abbreviations and Terminology

Abbreviation	Meaning
FM	Flow Monitor
KPI	Key Performance Indicator
DWF	Dry Weather Flow
ADWF	Average Dry Weather Flow
PWWF	Peak Wet Weather Flow
RDII	Rainfall Dependant Inflow and Infiltration
GWI	Groundwater Infiltration
SWI	Stormwater Inflow
18STHKARORI	Flow monitor catchment upstream of KaroriNet flow monitor
SCHOOL	Flow monitor catchment upstream of KaroriClass flow monitor

1 Introduction

1.1 Background

Work has been done to reduce inflow and infiltration and monitor wastewater flows in Karori. The 18STHKARORI catchment has recorded high levels of inflow and infiltration so was selected as a study area to undertake works. The area has permanent flow monitors which can be used to monitor the effectiveness of these improvements. The location of the area and the available monitors are shown in Figure 1.

1.2 Purpose and Scope of Work

This analysis aims to inform recommendations for the Karori network improvement plan by comparing the effectiveness of each improvement undertaken in 18STHKARORI between 2017 and 2023.

As part of this Stantec has agreed to:

- Identify suitable wet weather events for analysis
- Create a timeline of improvement works in 18STHKARORI
- Assess effectiveness of improvement works at reducing inflow and infiltration

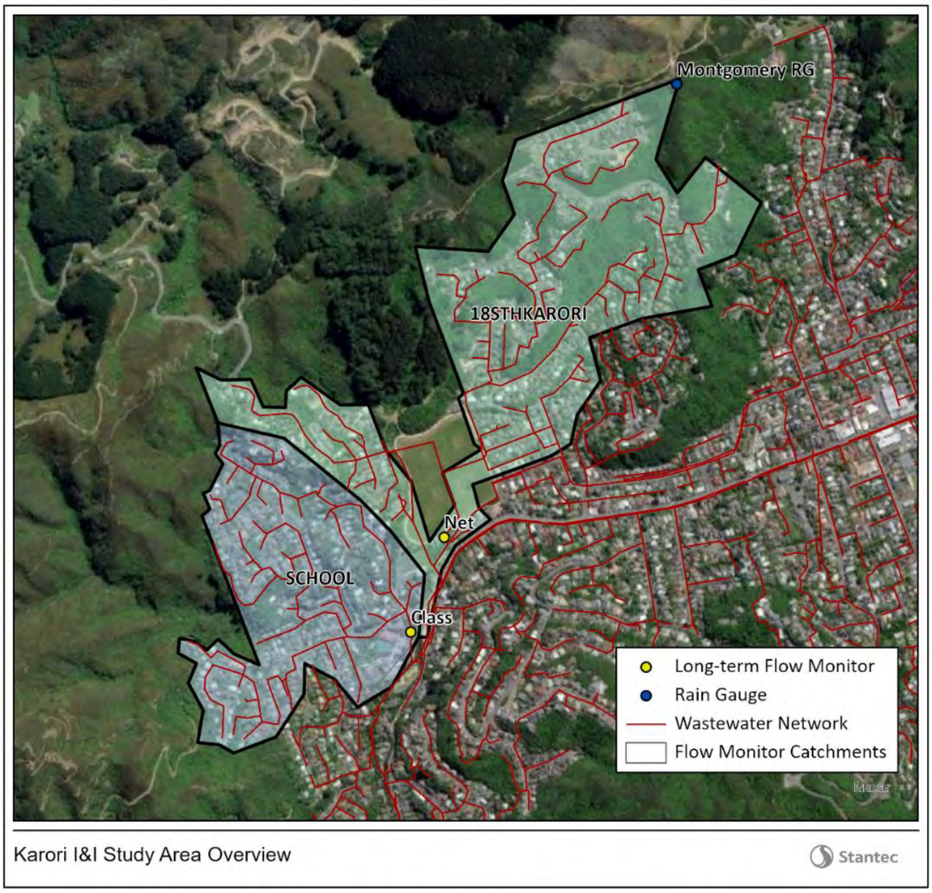

Figure 1: Study area for the analysis showing the flow monitors, rain gauge and catchment boundaries

2 Data

Described in Table 2 and Table 3 is the available data used in this analysis. The flow monitor and rainfall data are used to measure the inflow and infiltration and the improvement information is used to determine appropriate comparison periods.

Table 2: Available Data on Network, Hydrology and Flow Monitors

Data	Description	Date Range	Source
Rainfall	CSV of 5min rain gauge data from the Montgomery RG.	01/07/19 to 12/01/23	Mott MacDonald
KaroriNet	CSV flow monitor data. This long-term flow monitor is within the 18STHKARORI catchment and has had improvement works done upstream.	01/07/19 to 12/01/23	Mott MacDonald
KaroriClass	CSV flow monitor data. This long-term flow monitor is within the SCHOOL catchment and has **not** had improvement works done upstream. This can be used in the analysis as a control monitor.	01/07/19 to 12/01/23	Mott MacDonald
Karori ICM Model	Karori ICM model used for the flow survey calibration. Includes network information.	Not applicable	HAL
Short-term Flow Survey	CSV flow monitor data. Survey data includes data from 17 temporary flow monitors across Karori for a 4-month period.	01/06/17 to 30/09/17	Wellington Water

Table 3: Available Data on Improvements

Data	Description	Date Range	Source
House Inspections	GIS shapefile with records of house inspections done by Cardno in 18STHKARORI. Includes inspection dates, faults identified and reinspection information with pass/fail information. 36/45 of the repairs that passed inspection were done between 01/02/19 and 15/10/19.	31/01/19 to 13/08/20	Cardno

Lining of wastewater mains	Start and end dates for the lining of 1km of wastewater mains in 18STHKARORI.	01/02/21 to 28/04/21	Hydrotech
Private lateral linings	Start and end dates for the lining of 40 private laterals in 18STHKARORI.	16/05/22 to 30/06/22	Hydrotech

2.1 Rainfall

2.1.1 Rain Gauge

The rainfall data from the MONTGOMERYRG was used for this analysis. It is a 0.2mm tipping bucket rain gauge with 5-minute data available for the same period as the long-term flow monitors. This was used as previous investigations have found this to be the most appropriate rainfall for 18STHKARORI (Mott MacDonald, 2021).

2.1.2 Elevation Variation

The MONTGOMERYRG is at the highest elevation point within 18STHKARORI, at 310m. Both the KaroriNet and KaroriClass flow monitors are at 140m elevation, however both catchments have a significant proportion of the area in the higher elevations between 200m – 250m.

It is likely that the rain gauge is overestimating rainfall for the catchments due to this elevation variation. This does introduce uncertainty in any calculated metrics however for comparisons between the catchments or between periods the impact should be consistent, so this rainfall is considered suitable.

2.1.3 Spatial Variation

No adjustments have been made to the rainfall to account for spatial variation. The gauge location is at the northern side of 18STHKARORI, shown in Figure 1, so there is unlikely to be a significant difference for 18STHKARORI. However, the SCHOOL catchment lies further south of the gauge so there may be some variation that is not accounted for.

2.2 Flow Monitor Data

KaroriNet is a 270mm HVQ site that covers the 18STHKARORI catchment. KaroriClass is a 290mm HVQ site that covers the SCHOOL catchment where no improvement works have been done.

Data has been processed by Mott MacDonald and provided for this analysis. Flow monitor data used for the period July 2019 to February 2021 was provided in June 2022 and data updated for the rest of the period, March 2021 to January 2023, was provided in January 2023.

The guide to short term flow surveys of sewer systems has a recommended range where the recordings are reliable (Water Research Centre, 1987). All data from both flow monitors are shown with this range overlayed in Appendix C.

The DWF recordings at both sites are typically <100mm which is outside this range. Therefore, it is expected that the flow values for the shallow flows will have a greater uncertainty. WWF recordings for high volume events are within the range so the largest impact on any calculations will be on the DWF component. For comparisons between the catchments or between periods this impact should be consistent, so the flow monitor data is considered suitable.

2.3 Timeline

There are three improvements done in 18STHKARORI between 2017 and 2022.

- Private repairs of gully traps, February 2019 to October 2019
- Lining of 1km of wastewater mains, February 2021 to April 2021
- Lining of 40 private laterals May 2022 to June 2022

There are four months of short-term flow survey data available between June 2017 and September 2017 and then long-term flow monitor data available from July 2019 to January 2023, all shown on Figure 2.

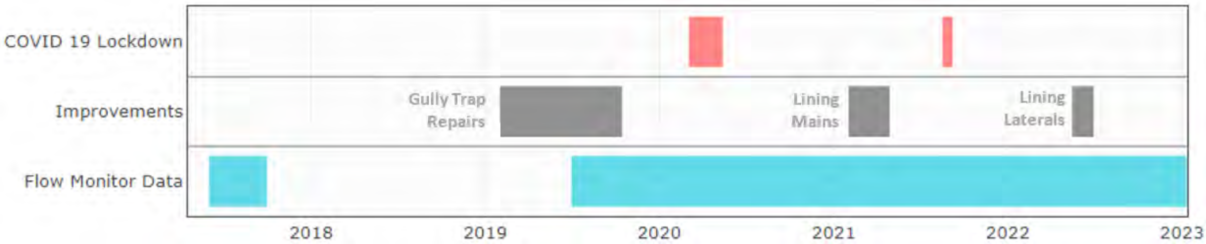

Figure 2: Timeline of available flow monitor data and the improvement implementation dates

2.4 Analysis Periods

As seen in Figure 2, only the lining of 1km of wastewater mains and the lining of private laterals have long-term flow monitor data from before and after the implementation date. So, the periods looked at for this analysis are:

- Before Linings – 15/10/2019 to 01/02/2021
- After Mains Lining – 28/04/2021 to 16/05/2022
- After Lateral Linings – 30/06/2022 to 12/01/2023

The first two periods are longer than a year so impacts on the calculations from seasonal affects should be small for these two. The final period is only six months so may be affected; further investigation into the average rainfall for each period is looked at in the following section, 2.4.1.

2.4.1 Comparison against historical rainfall data

Daily rainfall data was looked at to assess how wet these periods are compared to historical data. Historical data was sourced from the Greater Wellington Regional Council website, looking at the rain gauges at Duthie Street (2000 to 2018) and Samuel Marsden School (2018 to 2022). Averages of the daily rainfall depths are shown in Table 4.

The period from before any linings were done seems to be typical with a daily average that matches the historical average. The periods after the mains linings and after the lateral linings were significantly wetter than usual, with ~15% and ~50% more rainfall respectively.

This should be considered when interpreting the results as it is likely that RDII and SWI will be worse for larger events and wetter periods. However, comparing the observed changes in 18STHKARORI to the control catchment, SCHOOL, will be useful in identifying if a change is due to this increased rainfall or due to the improvement.

Table 4: Average daily rainfall for historical data and analysis periods

Period	Date Range	Average Daily Rainfall (mm)
Historical	01/01/2000 to 01/01/2020	3.72
Available FM Data	01/07/2019 to 12/01/2023	4.17
Before Linings	15/10/2019 to 01/02/2021	3.72
After Mains Lining	28/04/2021 to 16/05/2022	4.36
After Lateral Linings	30/06/2022 to 12/01/2023	5.75

2.4.2 2017 Short-term Flow Survey

There is short-term flow survey data available from before the gully trap repairs, however the flow monitors are in different locations so the flows from 18STHKARORI are approximated by subtracting one flow monitor from another. 18STHKARORI contributes a relatively small amount of flow compared to the two flow monitors used in this approximation, so any uncertainties in the flow monitor’s data are exaggerated by the process.

3 Approach

The analysis is focussed on assessing the impacts of both the lining of 1km of wastewater mains and the private lateral linings as these improvements had long term flow monitor data from before and after their implementation.

For the periods before and after the two improvements, averages of the RDII, GWI and SWI are compared. These are the three KPI’s outlined in the Water New Zealand Inflow and Infiltration Control Manual (Water NZ, 2015). The methodology used to calculate these is described in detail in Appendix B.

Over the analysis period, 01/07/19 to 12/01/23, parts of the data are excluded. This includes data captured during improvement implementation where it cannot be clearly assigned to before or after, and data captured during COVID 19 alert levels 3 and 4 in Wellington where the change in DWF pattern is not well understood.

Flow monitor locations are shown in Figure 1. KaroriNet represents the 18STHKARORI catchment where improvements have been done and KaroriClass represents the west side of the SCHOOL catchment where there have been no improvements. The changes observed at KaroriClass are used as a control dataset to indicate the variability of the data. This is to better understand whether a change observed at KaroriNet is because of the lining done or because of measurement uncertainties.

4 Limitations

Metrics calculated for rainfall events are by nature based on several uncertain factors. The analysis aims to control for these uncertainties to make relevant conclusions, however, the following limitations should still be considered when interpreting the results.

- Data during COVID-19 lockdown periods has been excluded from analysis.
- Changes in flow monitor calibration has not been considered.
- DWF depths are typically <100mm so have high uncertainties due to sensor limitations.
- KPI values shown in the report are intended to only be used for comparison purposes and trend analysis, not for quantifying the extent of inflow and infiltration.
- The rainfall periods after the mains lining and after the lateral linings were significantly wetter than the historical average.
- RDII values calculated from the 2017 flow survey have higher uncertainties.
- Only the 2017 flow survey data was available from before the gully trap repairs. This data had higher uncertainties so gully traps have been excluded from the main analysis (see section 2.4.2).
- When RDII is <10%, improvements on metrics are hard to quantify (Water NZ, 2015).
- Improvements made to high intensity events with less than 20mm rainfall are not captured in the analysis.
- No adjustments have been made to the rainfall to account for spatial variation or elevation variation.

5 Analysis

5.1 Components of Flow

For interpreting this analysis, it is important to understand the major components of wastewater flows and how they have been used in calculating RDII, GWI and SWI. All definitions are as defined in the Water New Zealand Inflow and Infiltration Control Manual (Water NZ, 2015).

Figure 3 illustrates the three major components:

- GWI, the constant flow infiltrating into the network that is not rainfall dependant.
- DWF, the generally diurnal flow generated by the population.
- RDII, the additional flow entering the network in response to a rainfall event.

When comparing metrics between periods:

- GWI is represented as a percentage of the ADWF for that day,
- RDII is represented as a percentage of the total rainfall volume of the event within the catchment,

- SWI is a proportion of the PWWF compared with the ADWF.

Appendix B includes a description of how these metrics were calculated.

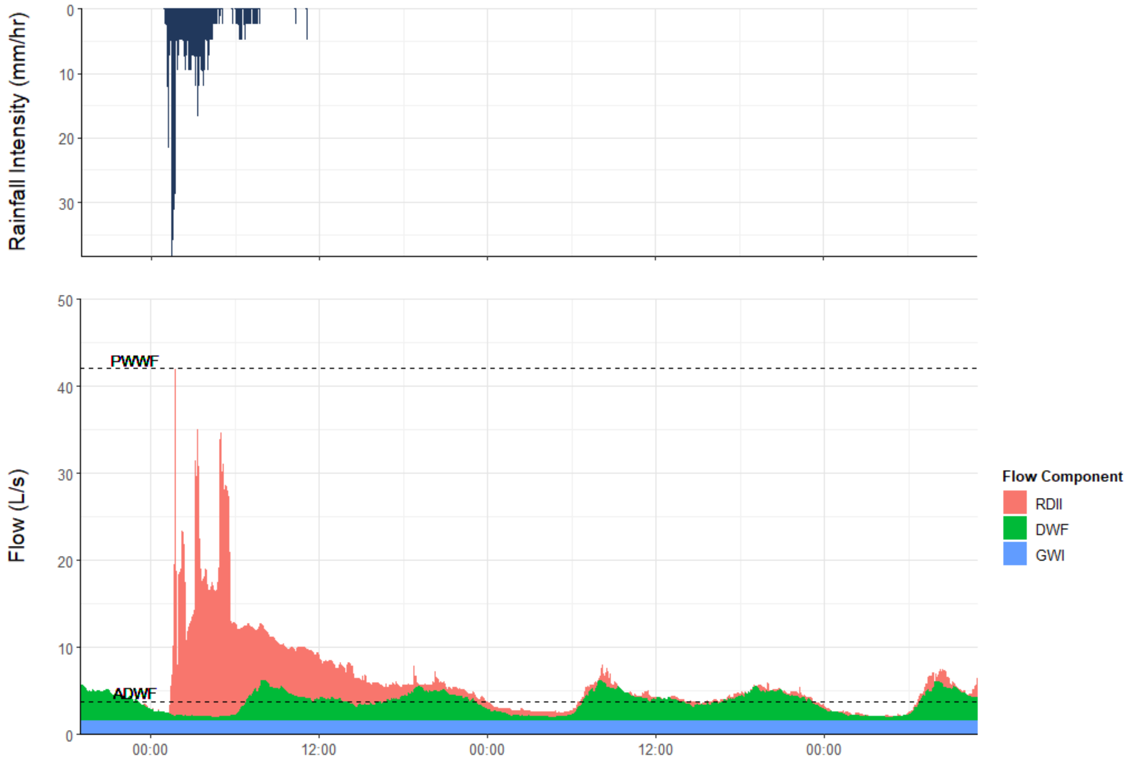

Figure 3: An example event broken down into the major components of wastewater flows

5.2 Rainfall Induced Inflow & Infiltration

RDII is a measure of how much of the rainfall hitting the ground in the catchment reaches the sewer network.

Figure 4 shows a slight increase in RDII at KaroriNet after the mains lining was done and a decrease at KaroriClass. This is interesting as it is not the expected outcome. The significant drop at KaroriClass suggests there is a high amount of variability in this metric as there can be large changes even with no improvements to the network.

After the lateral linings were done there was an increase in RDII in both catchments. This period had ~50% more rainfall than the historical average so an increase is expected. However, there was only a 50% increase in the catchment where the improvements were done compared to a 75% increase in the control catchment. This could be in part due to the improvements mitigating the rainfall response.

When considering these results, it is notable that there is significant variation in the control catchment where no works have been done. This is likely due to RDII being dependant on the size and type of events, so varies as the rainfall varies. Both periods after the mains lining and after the lateral linings have increased rainfall. The reason an increased RDII was not observed in KaroriClass after the mains lining despite the greater rainfall may be due to spatial variation as the Montgomery

RG is at the north end of the 18STHKARORI catchment (Figure 1). To better understand this, a rain gauge at a more appropriate location and elevation for the SCHOOL catchment would be needed.

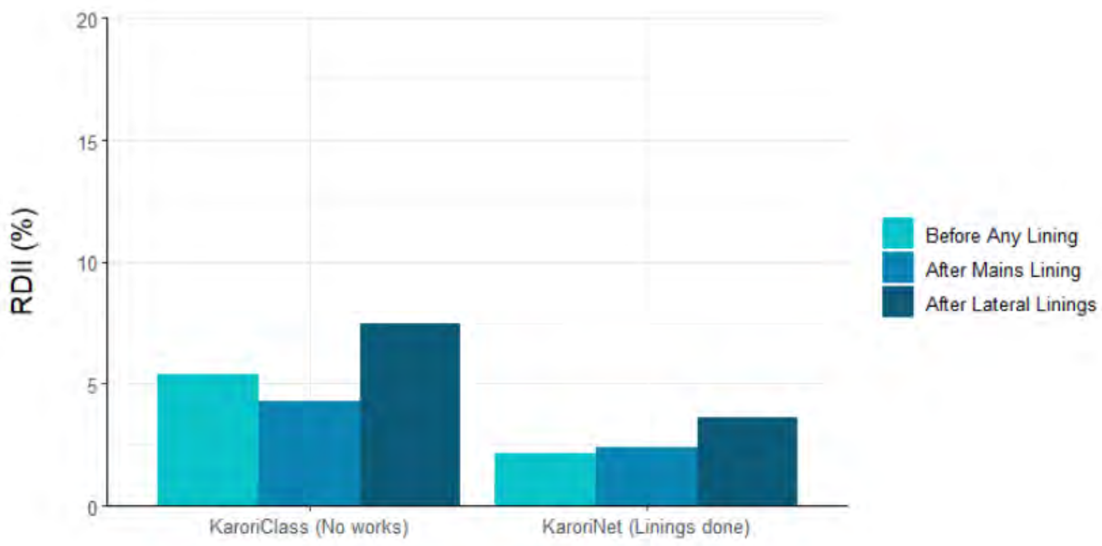

Figure 4: RDII comparison as calculated from KaroriClass FM and KaroriNet FM for the periods analysed in 18STHKARORI

5.3 Groundwater Infiltration

GWI is a measure of the constant baseflow infiltrating into the network, on Figure 5 this is shown as a percentage of ADWF.

GWI can be calculated for any dry day, not just rainfall events, so of the three metrics it has the most data to draw from. There are only small changes at KaroriClass, seen in Figure 5, which suggests that the random variation in GWI is small and that its unlikely that any changes are due to catchment-wide effects like a rising water table.

The GWI measured at KaroriNet drops from 53% down to 43% after the mains lining and down again to 40% after the lateral linings. This is in contrast to KaroriClass where there is no difference after the mains lining and a 5% increase after the lateral linings. This shows that there is evidence that lining the wastewater mains and lining the laterals both caused a drop in GWI at KaroriNet .

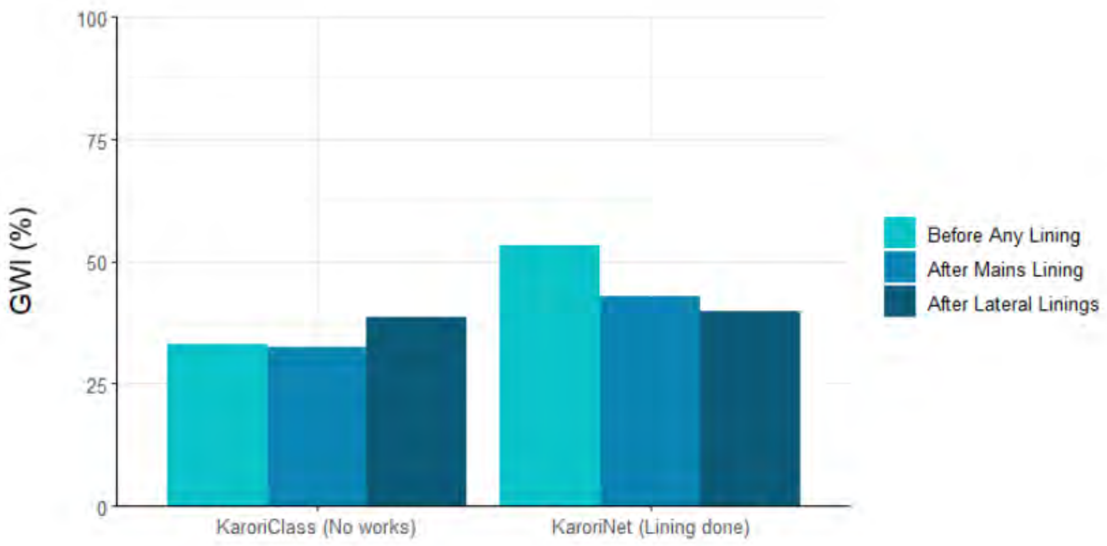

Figure 5: GWI comparison as calculated from KaroriClass FM and KaroriNet FM for the periods analysed in 18STHKARORI

5.4 Stormwater Inflow

SWI is a measure of how high the peak flows of wet weather events are relative to the ADWF.

After the mains lining, there was a small difference in SWI at KaroriClass but a large increase in SWI at KaroriNet, seen in Figure 6. After the lateral linings there is an increase in SWI for both KaroriClass and KaroriNet.

These increases are likely related to the periods being wetter than average. As SWI is a proportion of the PWWF to the ADWF, the changes can be further investigated looking at these metrics individually.

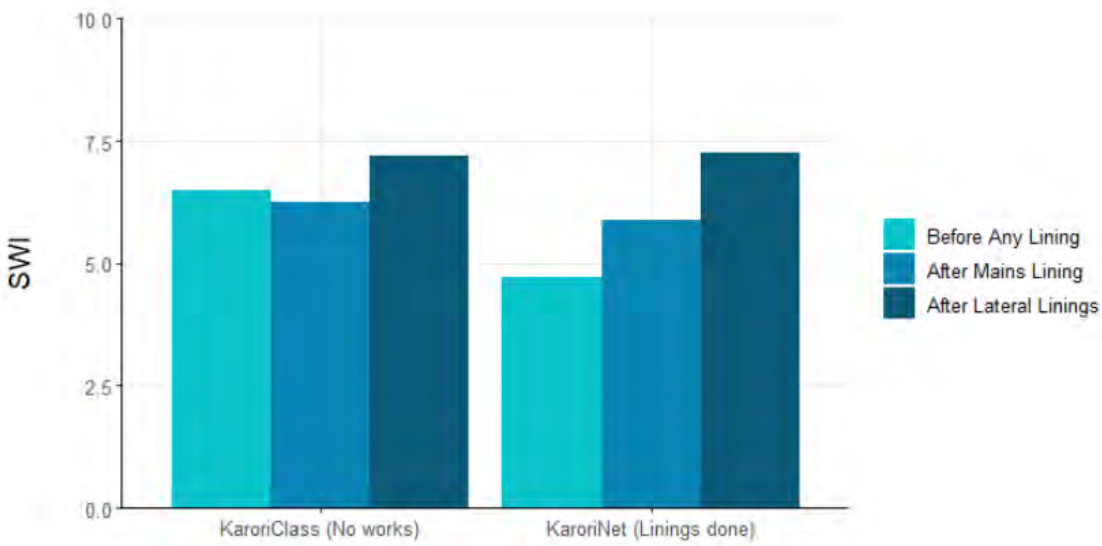

Figure 6: SWI comparison as calculated from KaroriClass FM and KaroriNet FM for the periods analysed in 18STHKARORI

Shown in Figure 7, there is both a consistent decrease in ADWF and increase in PWWF measured at KaroriNet after each improvement. The changes are similar for both mains lining and lateral linings. There is very little variation in ADWF at KaroriClass and its PWWF appears to follow a similar pattern to the RDII in Figure 4. This further supports that the variations in PWWF and RDII observed at KaroriClass are due to the difference in type and size of rainfall events between the periods.

Because the ADWF decreases in 18STHKARORI while there is no change in the control catchment, there is evidence that both linings caused a decrease in ADWF. The decrease in ADWF makes sense as the lining reduces groundwater infiltration. The increase in PWWF is most likely due to the increase in size of rainfall events for the later two periods, however, a possible consideration is that the lining reduces the pipe roughness so flows will move faster. This could be contributing to the increase in PWWF due to the time of concentration being decreased.

It should also be considered that in shallow flow the DWF values have higher uncertainty (section 2.2) so the changes observed here in ADWF could partially be attributed to random variation due to sensor uncertainties.

Figure 7: ADWF and PWWF comparison as calculated from KaroriClass FM and KaroriNet FM for the periods analysed in 18STHKARORI

6 Conclusions

The analysis has limitations. The periods looked at vary in the size and number of rainfall events available, the flows are relatively low and not all improvements had reliable flow monitor data before and after their implementation. These uncertainties should be considered when interpreting results, however, useful conclusions can still be made.

Groundwater infiltration and ADWF dropped after lining the wastewater mains and after lining the laterals. The decreases for both were comparable in size. The decrease is likely because the lining has addressed leaks in the network. There was no significant drop observed in RDII for either improvement. This means that any impact the improvement may have had on RDII is masked by the variability of events between periods. Therefore, it is likely that the rainfall volume no longer entering the network through pipes that were lined was only a small component of the RDII in 18STHKARORI.

Stormwater inflow increased after lining the wastewater mains and after lining the laterals. This is likely due to the periods after each improvement being wetter than average but could also be in part because of the linings causing a slight increase in PWWF.

The 2017 flow survey data was excluded from the main analysis due to high uncertainties in the data, however, with an understanding of these uncertainties a limited comparison can be made to identify if the gully traps had an impact. The RDII dropped from 12% in the 2017 flow survey analysis (Hydraulic Analysis Limited, 2021) to <5% in the above analysis after the gully trap repairs were done. Even considering that the 2017 value has lower confidence, there does appear to be some reduction. The stormwater entering the network through gully traps contribute to the fast rainfall response so this reduction suggests that the fast response was a large component of the RDII in 18STHKARORI. So, there is evidence that gully trap repairs are effective at reducing the fast response rainfall volume entering the sewer.

Finally, for future analysis focussed on comparing improvement works, a gap analysis should be done upfront to determine the usefulness of moving forward with the available data and its limitations.

7 Recommendations

Based on the conclusions of this analysis the following recommendations are made for the Network Improvement Program and future analysis work:

- Lining wastewater mains or laterals should both be considered as effective options if groundwater infiltration is identified as an issue.
- The effects of lining pipes potentially increasing peak wet weather flows should be considered when looking at linings as an option.
- Gully trap repairs should be considered as a potential option if the fast response rainfall volume is identified as an issue.
- All flow monitor data related to a catchment should be stored in Wellington Water's SCADA data system so that data can be sourced from a single location and gaps can be identified early.

8 References

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Mott MacDonald. (2021). *Karori I/I Investigation Annual Report and I/I Study.*
Water NZ. (2015). *Infiltration & Inflow Control Manual.*
Water Research Centre. (1987). *Guide to short term flow surveys of sewer systems.*

Appendix A: KPI Trend Plots

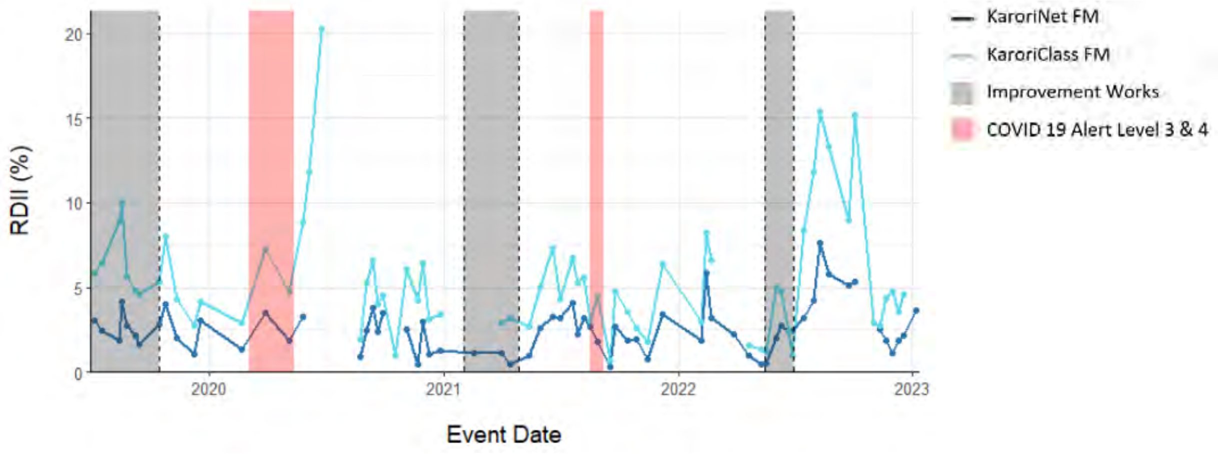

Figure 8: Calculated RDII for rainfall events with >20mm depth

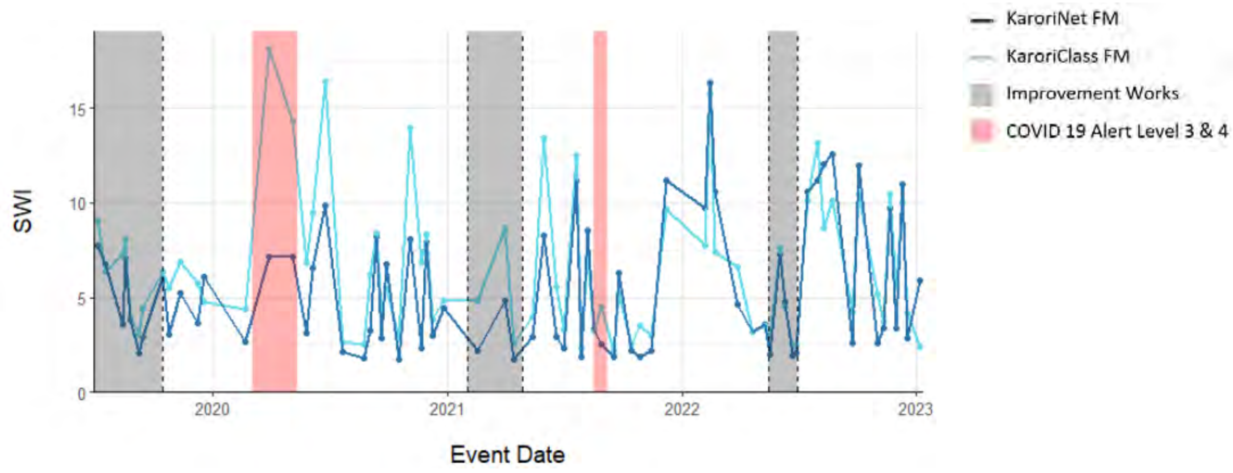

Figure 9: Calculated SWI for rainfall events with >20mm depth

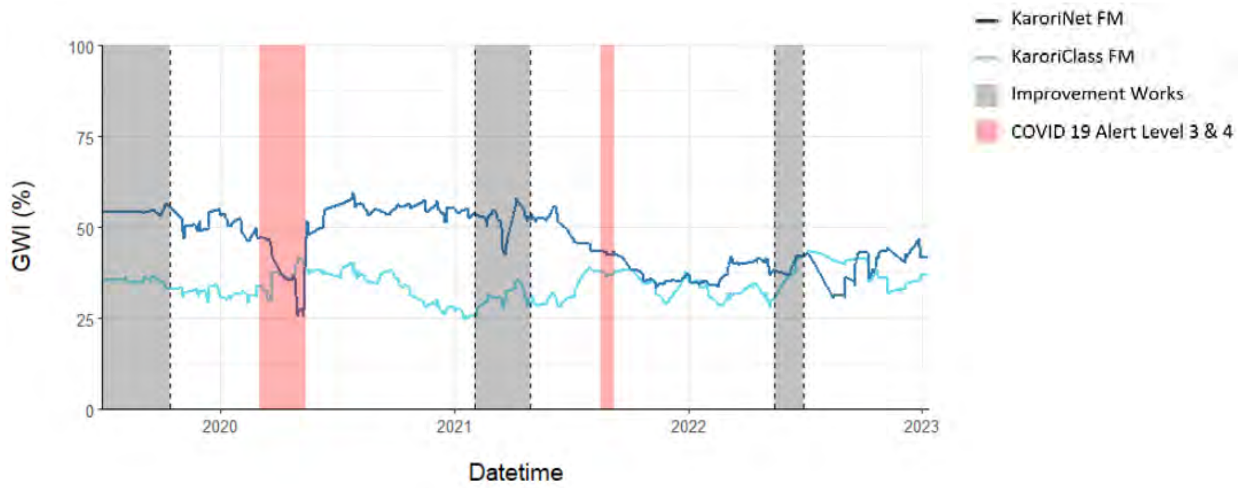

Figure 10: Daily GWI trend calculated from estimate DWF

Appendix B: Analysis Methodology

Formulas

The definitions of key performance indicators have been taken from the Water New Zealand Inflow and Infiltration Control Manual (Water NZ, 2015).

$$RDII = \frac{Wet\ Weather\ Volume - Average\ Dry\ Weather\ Volume}{Rainfall\ Depth \times Catchment\ Area}$$

$$GWI = \frac{0.8 \times Minimum\ Nighttime\ Flow}{ADWF}$$

$$SWI = \frac{PWWF}{ADWF}$$

To calculate these:

- Wet weather events need to be identified from the rainfall data.
- The dry weather flow component of the observed flows needs to be estimated.

Identifying wet weather events

Groups of consecutive timesteps where each timestep has rainfall was identified. If a group of rainfall timesteps happens within 48 hours of the previous group, then they are considered to be part of the same wet weather event.

The 48 hours after the end of the last timestep with rainfall is also considered part of the event. This is done to include the slow response infiltration so that any improvements made to this part of the response is reflected in the RDII.

There will be some uncertainty in estimating how much of the observed flow is from the rainfall, and this uncertainty is exaggerated in low volume wet weather events where the rainfall response is smaller. So, to reduce this, wet weather events with a total rainfall depth of less than 20mm have been ignored for the analysis.

Identifying dry timesteps

To calculate the average dry weather flow profile for a given event, there needs to be a set of timesteps that are considered dry.

For this analysis, a timestep is dry if it has no rainfall and has had no rainfall for the 72 hours before it, this is to reduce the impact that slow response RDII has on the estimates.

Calculating DWF

For a given wet weather timestep the DWF component is calculated by looking at nearby dry timesteps. It finds the average of the closest 7 dry timesteps that are at the same time of day.

Calculating DWF this way was chosen instead of using a fixed profile because this way it uses recent data for any given event. It also provides a method of analysing the trend in GWI over time which only uses DWF for its calculation.

Calculating Key Performance Indicators

GWI is calculated for each day in the period by taking 80% of the minimum observed flow and dividing by the ADWF value for the day.

SWI is calculated for each rainfall event chosen for the analysis by taking the maximum observed flow during the event and dividing by the ADWF for the event.

RDII is calculated for each rainfall event chosen for the analysis by:

1. Calculating the rainfall volume in the sewer by subtracting the estimated dry weather volume from the observed volume during the event.

2. Calculating the total volume of the rainfall event by multiplying the rainfall depth by the catchment area.

3. Dividing the two to get the RDII of the event.

The catchment areas used are 27.6 Ha for KaroriClass and 44.9 Ha for KaroriNet to stay consistent with previous investigations (Mott MacDonald, 2021).

Sensitivity Tests

To check this methodology against previous work, this method was applied to the 2017 flow survey data giving an RDII in 18STHKARORI of 11.9%. This matched the value found in the original analysis done by Mott MacDonald which was 11.8%.

The events identified in 2020 were also compared against the metrics calculated in Mott MacDonald's annual monitoring report (Mott MacDonald, 2021). For these events, this method tends to estimate RDII to be 0 – 1% lower, GWI to be 0 – 5% higher and SWI to be approximately equal. These differences are small and are considered acceptable for this analysis which is focused on the change in values over time and not on quantifying the exact extent of infiltration.

Example Wet Weather Event

Between 28/11/21 and 19/12/21 there was a series of consecutive rainfall events, shown in Figure 11. The gaps between each rainfall event were all less than 48 hours so the whole period is considered to be under the effects of rainfall induced infiltration and will be treated as a single event.

Dry days are shown in green on Figure 11. The average DWF profile is calculated from these surrounding dry days and is shown on the middle flow plot in purple.

This DWF profile is then subtracted from the observed flow to get an estimate for rainfall volume in the sewer. Outside of the wet weather event the rainfall volume in the sewer hovers around zero, with approximately 5 L/s uncertainty.

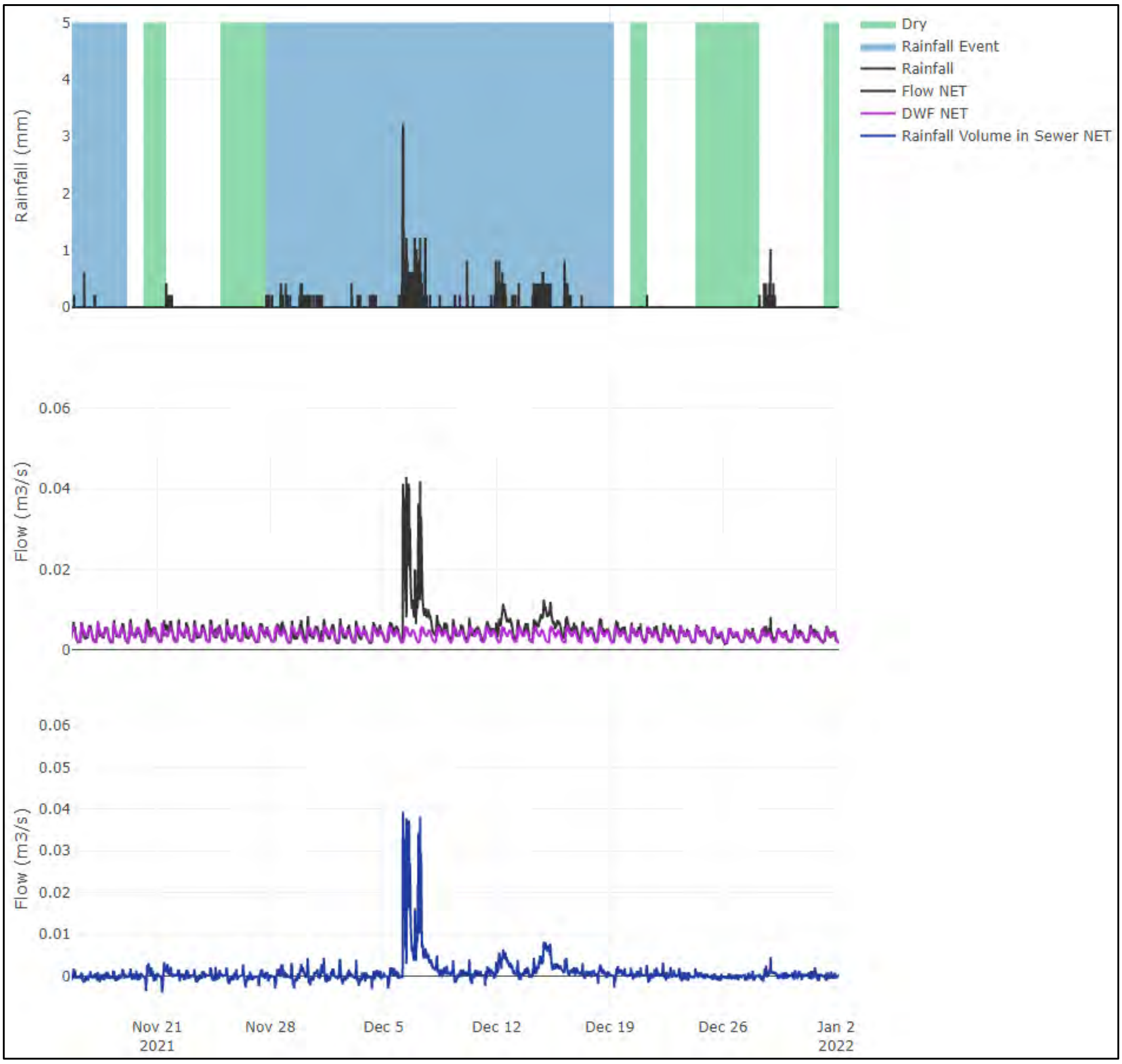

Figure 11: Plots for rainfall, observed flow, calculated DWF and estimated rainfall volume in the sewer from an example period

Appendix C: Monitor Performance Envelopes

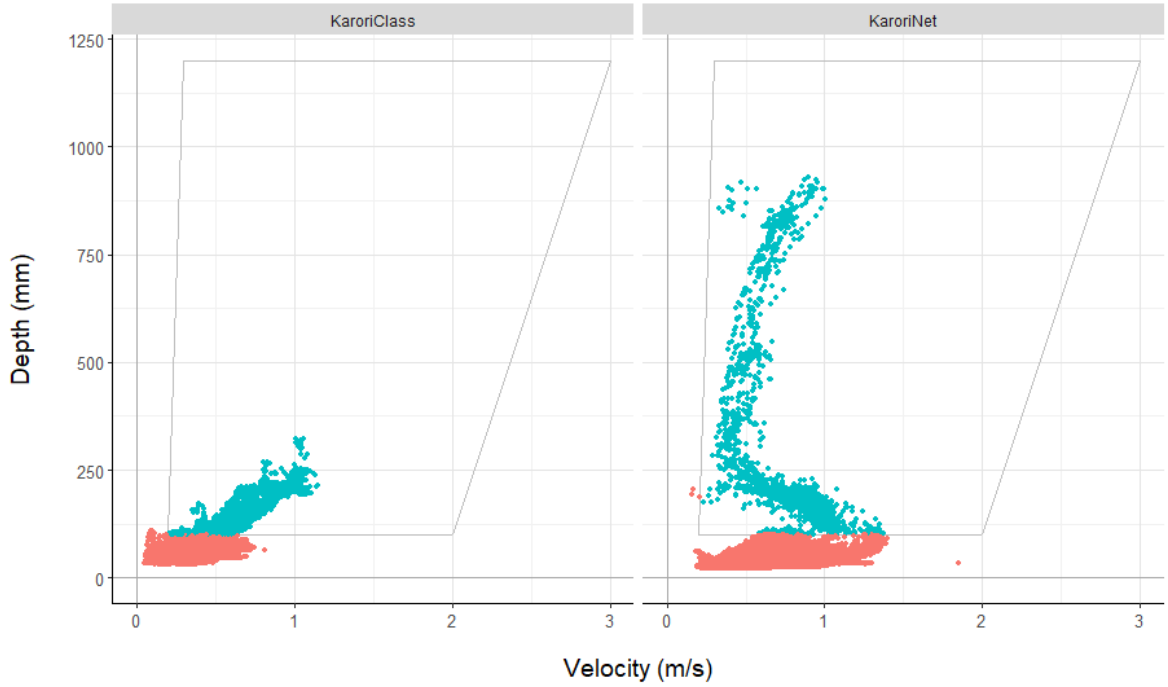

Figure 12: Flow monitor data overlayed onto the performance envelope from the guide to short term flow surveys of sewer systems (Water Research Centre, 1987)