USING I/I REDUCTION AND MODELLING TO SHAPE A WASTEWATER RENEWAL PROGRAMME - PALMY'S EXPERIENCE.

Tim Preston and Chris Pepper
GHD Ltd, New Zealand

ABSTRACT

Palmerston North City Council is well aware of significant inflow and infiltration issues throughout the city of Palmerston North, and its impact on the spare capacity of the trunk wastewater network, the capacity at the Totara Road Wastewater Treatment Plant, and associated operational costs.

A major capacity upgrade to the Totara Road Wastewater Treatment Plant is scheduled for 2029, which will meet the discharge consent that will be renewed by 2030. As part of managing the future capacity upgrade of the wastewater treatment plant, the Council is committed to reducing Inflow and Infiltration by 30% through rehabilitation of the wastewater network.

This paper investigates how fourteen years of data from seven different flow monitoring programmes was analysed to determine three key Inflow and Infiltration parameters for each wastewater catchment. These parameters were then used to rank and prioritise a city-wide rehabilitation programme to reduce Inflow and Infiltration. This has reshaped Council's wastewater renewals works programme.

The programme began by carrying out pilot rehabilitation studies in the two worst catchments to better gauge the likely success of the works in reducing Inflow and Infiltration city-wide.

To achieve their 2030 target, it is estimated that the Council is likely to be required to double their renewals budget to target the Inflow and Infiltration alone. The impact of Inflow and Infiltration on treatment and power costs was quantified and used in a cost/benefit analysis of the works programme to determine how much of the works could be offset through savings in power and chemical costs.

KEYWORDS

Inflow and Infiltration, flow monitoring, renewals programme, wastewater

1 INTRODUCTION

Palmerston North is an inland city of some 80,000 people located in the lower half of the North Island of New Zealand situated on the banks of the Manawatu River. Palmerston North is at the centre of a thriving agricultural region and houses a signification education sector spearheaded by two Massey University campuses, and a large military base at Linton.

Treated sewage effluent from Palmerston North has been discharged into the Manawatu River for over 100 years. Significant upgrades to the treatment systems to improve the quality of the effluent discharge have been undertaken in 1968, 1984, and 2007. The current discharge consent, which expires in 2028, requires the removal of Dissolved Reactive Phosphorus (DRP) from the effluent discharge into the Manawatu River in time of low flows in the River.

Increasing concern about the ecological health of the Manawatu River has been reflected in the review of the Regional Plans and Policies by the local Regional Council, Horizons. This has led to the publications of guidelines for the desired effluent standards that will be required in the future. Simply put this will mean that a future discharge to the Manawatu River will need to be treated to a much higher standard and for much longer period of time per year that at present. In particular, the amount of nitrogenous compounds in the discharge will have to be reduced.

This presents a problem for the Palmerston North City Council (PNCC) as at present the high sewage flows resulting from rainfall events generally do not coincide with low river flows, and the discharge consent conditions are written to take into account the occasions where these events do coincide. In the future, therefore, it appears that these high flows will need to be treated, and furthermore to a higher standard than at present, to reduce the amount of nitrogenous compounds in the discharge.

An option for the PNCC may be to switch to a land-based discharge for all or part of its treated effluent. These systems will also need to be sized to take account of the high sewage inflows, with major impacts on capital and operating costs.

As part of the preparatory work for the latest plant upgrades, the PNCC has undertaken long-term flow monitoring, commencing in 1997. This was complemented with a series of CCTV inspection contracts, which also encompassed smoke testing and on-site inspections of properties for low gully traps and stormwater discharge connections. The result of this work was expected to reduce the number of sewer overflows experienced over time. However, the peak discharges into Palmerston North’s wastewater treatment plant do not appear to have reduced significantly.

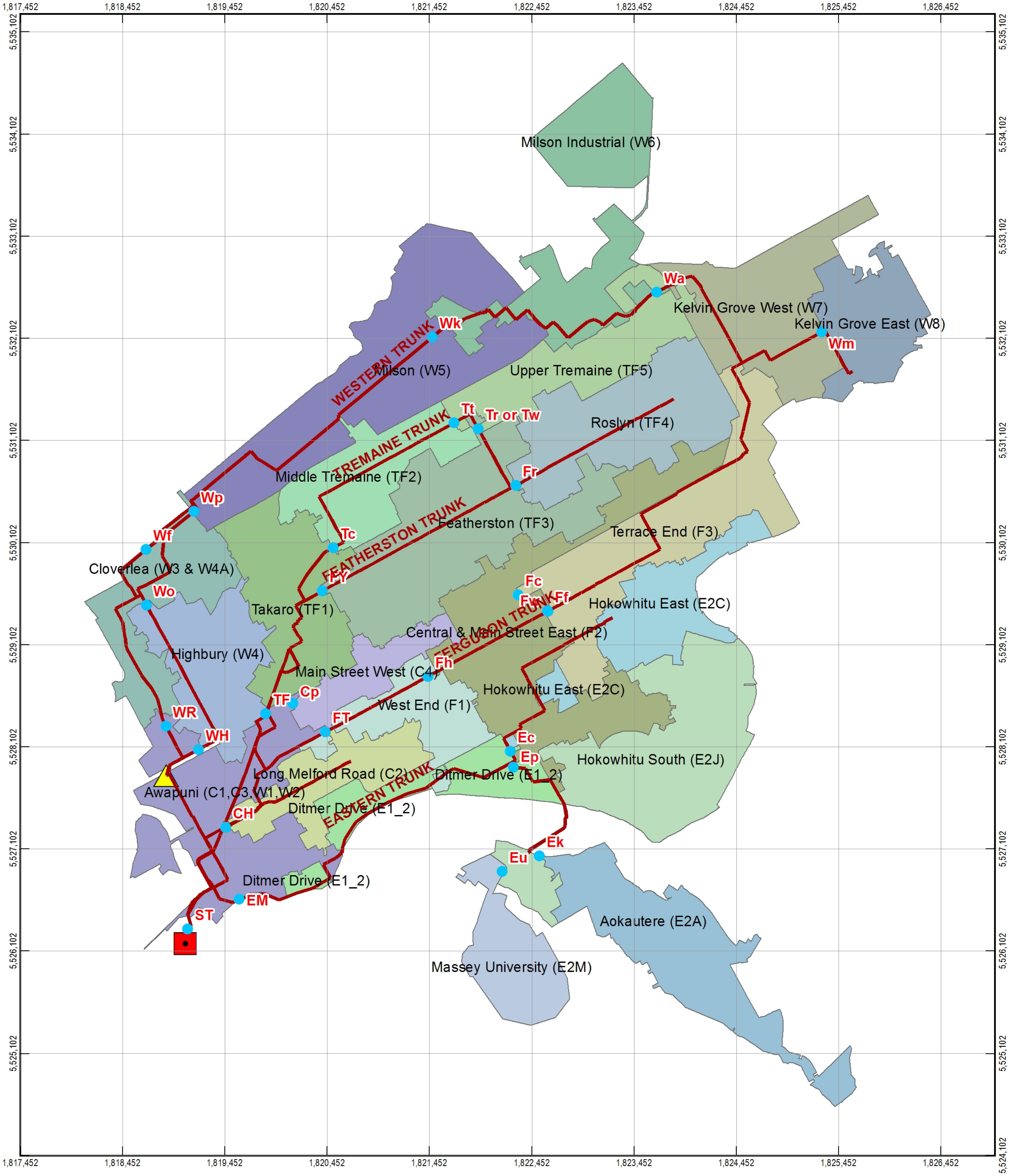
Given the likely future constraints on Palmerston North’s treated sewage effluent discharge, and the volume of flow monitoring data that was available, further analysis of this data was appropriate. The ultimate outcome of this was to develop a long term plan to progressively reduce inflows into the WWTP to a manageable level. This would minimise likely future capital and operational costs likely to be incurred. Therefore the following outcomes were required;

- Was the high flow from a catchment Inflow or Infiltration?
- Ranking of sub-catchments in terms of I/I produced
- What is the cost of the I/I
- How could I/I be reduced
- Are there any constraints in the trunk main system

2 DATA ANALYSIS

During the 14 years of flow monitoring seven separate periods of flow gauging were carried out with the locations of the loggers in various combinations. These locations are shown in Figure 1 below along with their respective catchments and trunk sewers.

In order to develop a better understanding of the cause of GHD engaged ADS as a sub-consultant to determine key I/I severity indicators using its software, SLIICER™. Detailed below is the methodology undertaken to determine the I/I indicators.



LEGEND

- Flow Gauge
- Trunk Sewer Mains
- WWTP
- Maxwells Line Sewer Pump Station

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Kilometers

Map Projection: Transverse Mercator

Grid: NZGD 2000 New Zealand Transverse Mercator

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Wet Weather Flow Impacts

Study Area
Gauged Catchments

Job Number	51-28511
Revision	A
Date	17 MAR 2011

Figure 1

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Key I/I Parameters Definitions

GHD specified the following three key I/I parameters for ADS to be calculated using SLIICER™:

$$\text{Groundwater Infiltration Indicator [l]/[m]/[d]} = \frac{\text{[Litres of Baseflow]}^{1}}{\text{[Total Length of Pipe in Catchment] x [Day]}}$$

$$\text{I/I Volume Indicator [R\%]} = \frac{\text{[Volume of I/I] x 100\%}}{\text{[Catchment Area] x [Total Rain Event Depth]}}$$

$$\text{Direct Inflow Indicator (Peaking Factor) [unitless]} = \frac{\text{[Peak Wet Weather Flow]}}{\text{[Average Dry Weather Flow for Season]}^{2}}$$

Gross (all catchments upstream of gauge) and net values (contributions from upstream catchments deducted) were automatically generated by SLIICER™ for the first two parameters but only gross peaking factors for the latter due to there being no efficient way of determining the effects of attenuation on flows. Thus, groundwater infiltration and I/I volume are reported at a catchment level but peaking factors are only reported by gauging location.

These three indicators enable the various catchments with a sewerage network to be assessed with respect to gross flow volumes and the inflow and infiltration aspects of theses flow volumes. These are mapped and tabulated below. (figures 4,5 & 7).

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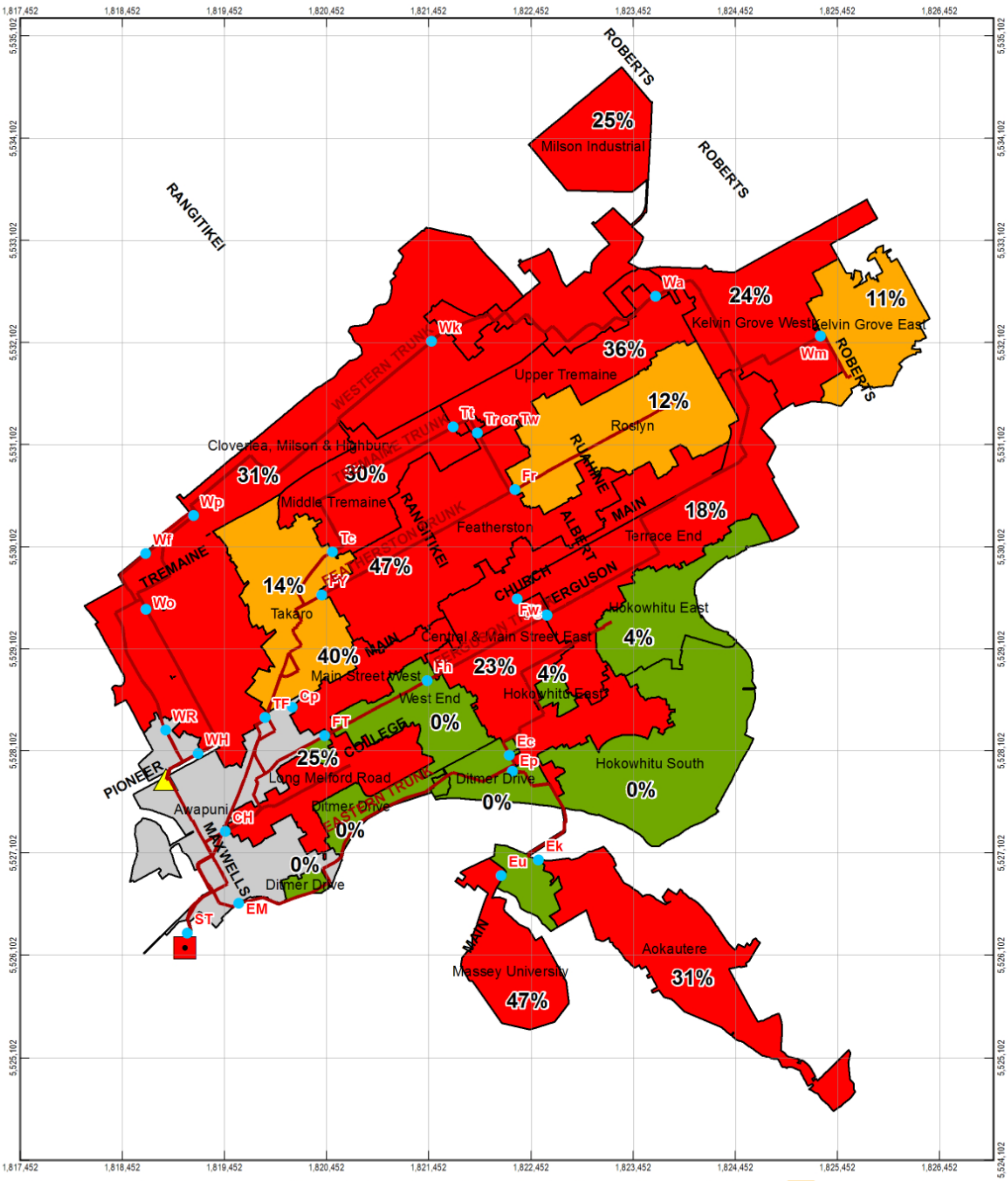
[1] Derived using Stevens/Schutzbach method (an iterative method used to fit the Manning Equation to flow monitoring data).

[2] Summer and Winter dry weather flow patterns were developed for each year analysed and adjusted automatically by SLIICER® to represent ground antecedent conditions immediately prior to each rain event analysed.



LEGEND

- Flow Gauge
- Maxwells Line Sewer Pump Station
- WWTP
- Trunk Sewer Mains

Baseflow / ADWF

- 10% to 15%
- Less than 5%
- Greater than 15%
- 5% to 10%
- Unknown

Note that baseflow values are from winter periods

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0 0.25 0.5 1 1.5

Kilometers

Map Projection: Transverse Mercator

Grid: NZGD 2000 New Zealand Transverse Mercator

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Groundwater Infiltration Indicator (Baseflow)

Figure 4

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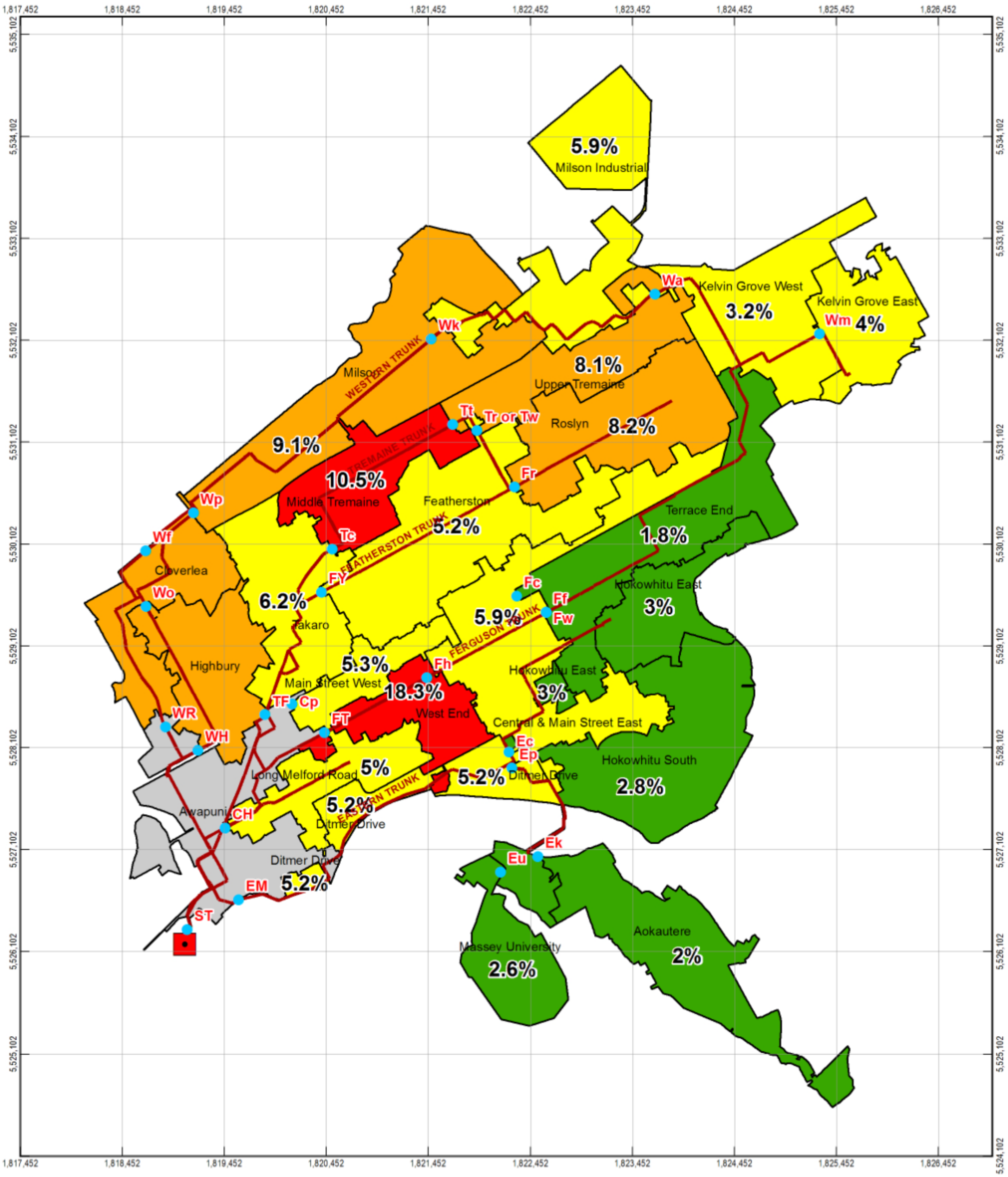

LEGEND

- Flow Gauge
- WWTP
- Trunk Sewer Mains

I/I Volume as R%

- Less than 3%
- 3% to 8%
- 8 to 10%
- Greater than 10%
- Unknown

Note that R% values are 90th percentile

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Kilometers

Map Projection: Transverse Mercator

Grid: NZGD 2000 New Zealand Transverse Mercator

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I/I Volume Indicator
I/I Volume as R%

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Figure 5

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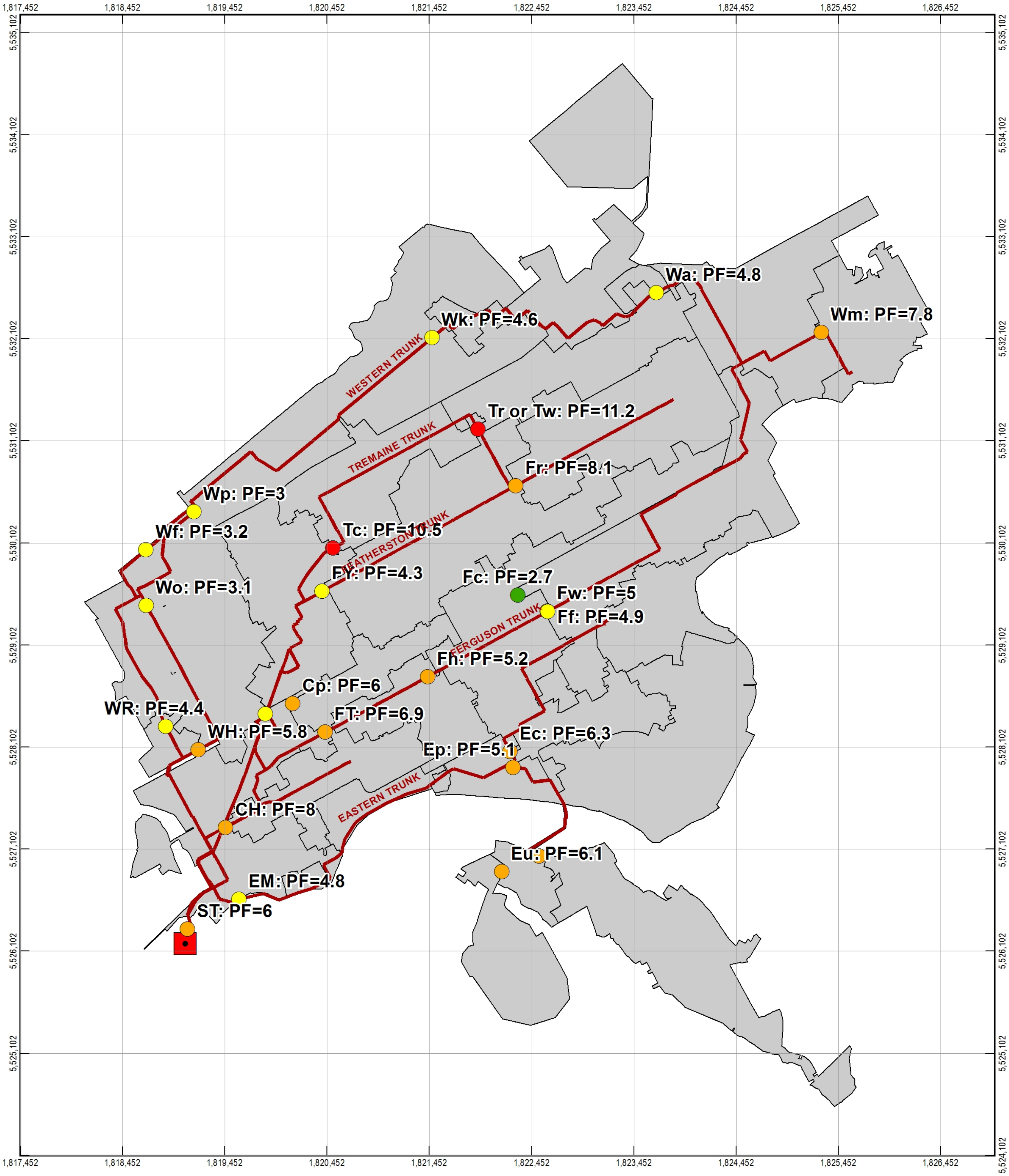

LEGEND

- WWTP
- Trunk Sewer Mains
- Study Area

Peaking Factor At Flow Gauge

- 0 - 3
- 4 - 5
- 6 - 10
- 11 - 15

Note that Peaking Factor values are 90th percentile

1:50,000 (at A4)

0 0.25 0.5 1 1.5

Kilometers

Map Projection: Transverse Mercator

Grid: NZGD 2000 New Zealand Transverse Mercator

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Direct Inflow Indicator
Peaking Factor

Figure 7

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What the analysis revealed

This showed that the worst catchments were generally located along the Western Trunk, with two other worst catchments at Tremaine and West End. The Groundwater Indicator revealed that infiltration was the greatest contributing factor for the Western Trunk and Tremaine catchments. Conversely, for the West End catchment showed a high Inflow Indicator.

The analysis clearly revealed areas where efforts to reduce flows should be concentrated.

The cost of I/I flows was also calculated. These costs (on an annual basis, 2010 dollars) are estimated to be $8560 for network pumping power costs, $87,960 for WWTP power costs and $58,660 for WWTP chemical costs. Total annual cost $155,180. However an enhanced treatment regime in the future would increase the WWTP cost considerably as the nutrient removal process would need to expand to include nitrogenous compounds and run for a considerably longer period of time every year. A back of the envelope calculation indicates this cost could increase by a factor of 3 for an upgraded WWTP, to an annual cost in the order of $450,000 per year.

The capacity of the existing trunk sewers was also reviewed. About 7.5 km of main was identified where flows exceeded design capacity, of which 6.3 km was in the Western Trunk sewer. This is tabulated below.

Table x Length of Trunk Not Meeting Design Capacity

	Length [m] of Trunk Not Meeting Design Capacity by Dia [mm]								
Trunk	**375**	**450**	**525**	**600**	**750**	**900**	**1350**	**Total**	**Length Assessed**
Western		1208	4666	407				**6281**	15,576
Tremaine	107				82	125	48	**363**	7351
Featherston				101				**101**	4212
Ferguson								**NIL**	7028
Eastern				793				**793**	5817
Total Length	**107**	**1208**	**4666**	**1301**	**82**	**125**	**48**	**7538**	**39,983**

3 SOLUTION DEVELOPMENT

As result of feedback received during the analysis, PNCC instigated a series of works and concurrent studies to begin to address some of the issues and provide further information on how to address these issues. These actions were as follows;

- The Kelvin Grove catchment was diverted from the Western Trunk to the Ferguson Trunk sewer. As noted in the table above, no part of the Ferguson Trunk was identified as being deficient in capacity. This diversion was primarily intended to minimise the risk of overflows along the Western trunk sewer.

- An inspection regime of the Western Trunk was commissioned. An infiltration point at a stream crossing was identified and some sections of the trunk have had considerable amounts of debris removed.

- Following the Christchurch earthquake on September 4 2011, GNS Science Ltd. was engaged by PNCC to review the liquefaction risks area within Palmerston North City.

- PNCC also undertook a review of risk and identification of critical assets for the wastewater system (in conjunction with the other water systems).

WHAT CAN I/I REDUCTION ACHIEVE?

In a normal wastewater system upgrade project, improvement works are formulated around the following three principles:

Accept existing flows and increase the system conveyance capacity (eg pipe and pump station upgrades) to cater for them; and/or

Attenuate flows by the use of storage or catchment diversions; and/or

Reduce flows through I/I reduction works.

The optimum improvement works program is often a combination of solutions based on these three concepts. I/I management programmes should be tailored to target the worst catchments first and by matching the nature of I/I with the appropriate source detection and faults rehabilitation. Three levels of I/I management programmes are available:

- Level 1 – rectification of inflow defects and manholes
- Level 2 – Level 1 plus complete sewer sealing/rehabilitation including public part of house laterals
- Level 3 – Level 2 plus complete lateral sealing/rehabilitation including all of the public and private part of the laterals.

Approach to developing a long-term I/I management strategy

The range of intended strategies to reduce the entry of stormwater runoff through either inflow or infiltration to the wastewater system includes:

Programmes to reduce the entry of stormwater to the wastewater system in private properties (infiltration/inflow programmes);

Renewal of pipelines where there is excessive entry of either inflow or infiltration and or groundwater through defects in the pipes; and

Providing additional stormwater capacity.

The approach taken to developing an I/I management strategy for Palmerston North is as follows:

- Rank the worst catchments for I/I based on all three parameters;
- Review the current strategy, including stormwater improvements and CCTV coverage;
- Review PNCC's capital expenditure budget to determine any available means to ramp up I/I rehab work;
- Prioritise the existing budget towards the worst catchment(s) and determine the likely improvements; and
- Identify the additional budget required, if any, to maximise the I/I rehab work at a cost effective level.

Catchments with I/I Volumetric R% values of greater than 8% have been selected for Level 2 rehabilitation works. Previous work in Auckland and elsewhere in New Zealand has generally found that rehabilitation work is of marginal benefit if the catchments have an initial pre-rehabilitation R% value of less than approximately 8%. This is also a key guideline in the determination of the I/I Management Plan for PNCC.

Where inflow has been identified as an issue in a catchment but the R% is less than 8% then Level 1 works is proposed.

Catchments with high baseflow, that is, baseflow is greater than 10% of the average dry weather flow have also been selected for Level 2 rehabilitation works.

Due to the expense and responsibility ownership issues of replacing laterals etc no level three rehab works is recommended.

Improvements that could be expected on system capacity

Modelling was carried out to gain an understanding of the improvements to the spare capacity in the trunk network that could be achieved if the I/I rehab programme in suggested was adopted. The following assumptions were adopted to model the I/I rehab programme:

For Level 1 works a 20% reduction in the fast response parameter and 10% reduction in the slow response parameter; and

For Level 2 works, a 40% reduction in the fast response parameter and 30% reduction in the slow response parameter.

These values are based on results obtained in similar studies completed elsewhere in New Zealand.

A 1 year ARI, 6 hour duration rain event was used as the test rainfall event. The pipe full capacity of the current trunk network was used to assess where the I/I works could result in the pipe full capacity category changing. The average improvements in spare capacity for each trunk are summarised. In Table 1. An assessment of the Trunk capacity was carried out by comparing the capacity with the design criteria of 4xADWF. This identified a number of pipes that currently do not meet the design criteria. An estimate of the spare capacity as a result of I/I rehab works and upgrading of the Trunk to meet the design criteria is contained in Table 1.

Table 1 Summary of Predicted Improvements in Spare Trunk Capacity

Trunk	Average Predicted Spare Capacity: Current	Average Predicted Spare Capacity: Post I/I Works	Average Predicted Spare Capacity: Post I/I Works & Trunk Upgrade to 4xADWF [3]
Western	42%	48%	59%

[3] Note that a complete hydraulic and hydrologic assessment has not been carried out and these values are indicative only.

Trunk	Average Predicted Spare Capacity: Current	Average Predicted Spare Capacity: Post I/I Works	Average Predicted Spare Capacity: Post I/I Works & Trunk Upgrade to 4xADWF [3]
Tremaine	10%	24%	30%
Featherston	13%	22%	24%
Ferguson	62%	63%	63%
Eastern [4]	19%	19%	22%

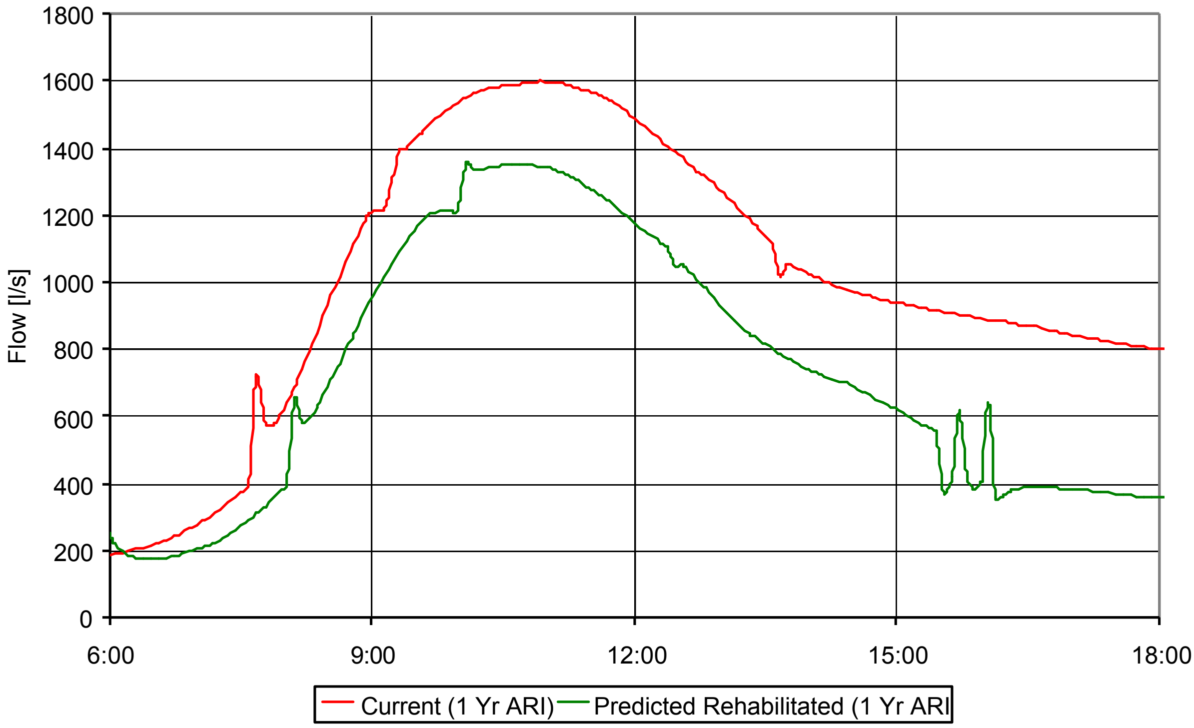
Peak flow reduction

Currently, it is not unusual for the PNCC WWTP inflows to peak at 1500 l/s, and can be as high as 1800 l/s, the maximum capacity of the high lift pumps at the front end of the plant. The average DWF flow is 250 l/s thus, flows occasionally peak at approximately six (6) times ADWF.

Ideally a peak flow in the order of three times ADWF should be achieved to lessen the impact on the WWTP performance, which currently includes issues such as:

- Limited high lift pump capacity ;
- Biomass wash out in the sedimentation tanks;
- Expensive flow rated chemical dosing for phosphate removal, though this is lessened if river flow is high; and
- Low river flow discharge consent is limited to 42,000 m^3/day

The model results used to determine the improvement in spare trunk capacity were also used to determine the impact on peak flows entering the WWTP for the 1 year ARI rain event. The results from this are plotted in **Error! Reference source not found.**.



[4] No rehabilitation works are proposed in this catchment.

4 I/I REHABILITATION WORKS DEVELOPMENT

An NPV cost/benefit comparison was carried out for the following two scenarios:

Scenario 1:

Do not carry out a I/I rehabilitation programme;

Adopt a 1 year ARI containment design standard and upgrade trunk network accordingly over the next 18 years to time completion with WWTP consent renewal; and

Renew the non-trunk/local reticulation over the next 30 years.

Scenario 2:

Carry out I/I rehabilitation works over the next 18 years to time completion with WWTP consent renewal;

Adopt a 1 year ARI containment design standard and upgrade sections of the trunk network that still not meet this as a result of the I/I rehabilitation works over the next 18 years; and

Note that the analysis does not take into account the impact of future growth on the spare capacity of the Trunk network and that the I/I rehabilitation works are assumed to prolong the service of the pipe by 30 years. Thus, other sections of the trunk that do not require upgrading as a result of the I/I rehabilitation works would inevitably be required to be upgraded 30 years later. Likewise, the renewal of the non-trunk/local reticulation can also be assumed to be deferred 30 years.

The total capital and operational expenditure for Scenario 1 is estimated to be $20.3M, and $21.0M for Scenario 2. The cost differential of the two is only $700,000, or 3.6%, which is significantly less than the cost estimate accuracy.

The implication of this is that the implementation of the I/I rehabilitation works is not conclusively advantageous or disadvantageous. In other words, proceeding with the I/I rehabilitation programme would not be a poor use of financial resources.

5. Conclusions

The key findings of this study are:

- Baseflow as a percentage of average dry weather flow is very high (>15%) for most catchments, indicating groundwater infiltration is a major problem with the exception of the Takaro, West End, Hokowhitu, Ditmer Drive, the newer part of Kelvin Grove, Roslyn and Terrace End.
- I/I volume as a percentage of rainfall entering the network is a significant issue for more than half of the city, with the Middle Tremaine and West End catchments having the most severe results. Colverlea, Milson, Highbury, Upper Tremaine and Roslyn areas are all significant in this regard.
- Peaking factors, indicative of direct inflow, are elevated in only a limited number of areas, indicating the relative success of PNCC's previous I/I reduction programme. The peaking factors are the highest in the Tremaine Trunk. Peaking factors are even elevated in the relative new eastern part of Kelvin Grove.
- I/I has a significant impact on operating costs for PNCC.
- I/I has an impact on the trunk capacity and the following are drawn from the model results for a 1 year ARI, 6 hour duration rain event. The system capacity analysis indicates that on average, the trunk system currently has 31% spare capacity, ranging from 54% on average in the Ferguson Trunk to only 10% in the Tremaine trunk.
- Stormwater drainage appears to be less in the Catchments along the Western Trunk, which experiences high levels of ground water infiltration and rain dependent I/I. PNCC is currently targeting new stormwater works in parts of the city that require improved drainage.
- The modelled city wide I/I rehabilitation programme predicted a 15.3% decrease in peak wet weather flows during the 1 year ARI rain from 1600 l/s to 1355 l/s. This equates to 5.4 times average dry weather flow, and indicates that other strategies will need to be employed to deal with washout of biomass.
- Implementation of the I/I works would result in of deferred upgrades of Trunk serwers.
- A cost/benefit analysis was carried out and found that there was no significant relative financial advantage or burden to implementing the I/I rehabilitation works. In other words, proceeding with the I/I rehabilitation programme would be a reasonable use of financial resources.

ACKNOWLEDGEMENTS

REFERENCES