NUTRIENTS AND BACTERIAL LOADS IN URBAN STORMWATER

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ABSTRACT

The paper discusses the availability in New Zealand of generally available information in contaminant annual load data to predict loads of nutrients (Nitrogen N and Phosphorus P) and bacteria (E.coli and Faecal coliforms FC) for stormwater catchments.

The sources reviewed are; Contaminant Load Model (CLM) (Auckland Council), TP10 Stormwater management devices design guideline (Auckland Council), Waterways Wetlands and Drainage Guide (Christchurch City Council), Stormwater Treatment Standard for State Highway Infrastructure (NZTA) and On-site Stormwater Management Guideline (NZWERF).

Based on the available information, nutrients and bacterial loads are estimated for a specific stormwater catchment and compared with the wastewater discharge quality from the same catchment's wastewater treatment plant.

The intention of this comparison is to provide an order of magnitude assessment on relative contributions of stormwater and wastewater source discharges. This determines the importance of nutrients and bacterial loads to be further investigated with respect to the impact on downstream stormwater quality.

KEYWORDS

Stormwater quality, Contaminants and contaminants loading, Environmental impacts assessment

PRESENTER PROFILE

Patricia has worked in engineering for 7 years, and for MWH for the last 2.5 years on a range of stormwater, water and wastewater projects.

She studied Civil Engineering in Spain and completed her studies with a Master of Environmental Engineering Management from the University of Technology of Sydney in 2012. She moved to Christchurch to work in the Stronger Christchurch Infrastructure Rebuild Team (SCIRT) projects in 2013.

She has developed a wide understanding of the New Zealand stormwater management framework and implemented it in a wide range of roading, planning and resource and discharge consent projects.

1 INTRODUCTION

This paper discusses the general availability in New Zealand sources of contaminant annual load data to predict loads of nutrients (Nitrogen N and Phosphorus P) and bacteria (E.coli and Faecal coliforms FC) for stormwater catchments.

Based on the general available information, the total load of nutrients and bacteria are estimated for an urban and rural catchment in Invercargill.

In order to provide an order of magnitude assessment on the relative contributions, the estimated results are compared to each other and to treated wastewater loads from the same catchment in Invercargill.

This paper is based on an Invercargill City Council project. Invercargill City Council aimed to confirm the main stormwater contaminant loads to be included in the stormwater assessment and provided a proposed methodology to mitigate those contaminants. Invercargill City Council has provided information to support the stormwater contaminant load estimates and comparison to the treated wastewater loads.

2 INFORMATION REVIEW

2.1 SOURCES

The sources reviewed were:

- Contaminant Load Model (CLM), Auckland Council, September 2010 and supporting documentation TR 2010/003 Contaminant Load Model User Manual and TR 2010/004 Development of the Contaminant Load Model
- TP10 - Stormwater management devices design guideline, Auckland Council, 2003
- Waterways, Wetlands and Drainage Guide, Christchurch City Council, February 2003
- Stormwater Treatment Standard for State Highway Infrastructure, NZTA, May 2010
- On-site Stormwater Management Guideline, NZWERF, October 2004.

2.2 CONTAMINANT ANNUAL LOAD DATA

The available information and limitations on contaminant annual load data regarding bacterial (E.coli) and nutrients (N and P) are summarised below based on the specific source documents.

2.2.1 CONTAMINANT LOAD MODEL (CLM), AUCKLAND COUNCIL

The Contaminant Load Model (CLM) is a spreadsheet-based model. The model is simple in principle - the area of a particular land use (source) within the area being studied (the catchment) is multiplied by the quantity of contaminants discharged from that land use (source yield) to provide an annual load from that source.

Given that the calculation of load does not use the local rainfall conditions, the model can be applied across New Zealand. It has not been calibrated for the specific Auckland weather patterns. This translation across NZ assumes that the generation of contaminant load from activities in the catchment is similar across the country, which is considered a reasonable assumption, where stormwater becomes the vehicle for mobilization and transportation of the contaminants.

The main limitations from the CLM for the estimation of nutrients and bacteria loads are:

- N, P and E.coli are not included in the model

- There is no explicit explanation for N, P and E.coli (or the lack of) in the Contaminant Load Model User Manual or in the Development of the Contaminant Load Model.
- A value from a load range is selected by the CLM spreadsheet for the quantity of contaminants discharged from that land use (source yield) to provide an annual load from that source. This potentially masks the inherent variability in contaminants loads from stormwater sources, unless this variability is applied independently. Maximum and minimum estimates are also provided.

2.2.2 TP10 STORMWATER MANAGEMENT DEVICES DESIGN GUIDELINES, AUCKLAND COUNCIL

The objective of this guideline is to provide a commonly accepted design approach for stormwater management practices for both water quantity and water quality benefits. As such, TP 10 presents typical loadings for a number of contaminants and land uses. However, it focuses on suspended solids as the key contaminant of concern.

The main limitation for the estimation of nutrients and bacteria loads is:

- E.coli are not included in the contaminant loading ranges for various land uses as per the figure below. However, there are some contaminant loading ranges for FC (Faecal Coliforms), which can be used as an indicator for E.coli load.

TP10 contaminant loading ranges is provided in Figure 1.

Table 4-4
Contaminant loading ranges for various land uses
Figures are in kg/ha/yr except for FC (no./ha/yr)

Land use	TSS	TP	TN	Pb (median)	Zn	Cu	FC	COD
Road	281-723	.59-1.5	1.3-3.5	.49-1.1	.18-.45	.03-.09	1.8E+08	112-289
Commercial	242-1369	.69-.91	1.6-8.8	1.6-4.7	1.7-4.9	1.1-3.2	5.6E+09	306-1728
Residential (low)	60-340	.46-.64	3.3-4.7	.03-.09	.07-.20	.09-.27	9.3E+09	NA
Residential (high)	97-547	.54-.76	4.0-5.6	.05-.15	.11-.33	.15-.45	1.5E+10	NA
Terraced	133-755	.59-.81	4.7-6.6	.35-1.05	.17-.51	.17-.34	2.1E+10	100-566
Bush	26-146	.10-.13	1.1-2.8	.01-.03	.01-.03	.02-.03	4.0E+09	NA
Grass	80-588	.01-.25	1.2-7.1	.03-.10	.02-.17	.02-.04	1.6E+10	NA
Pasture	103-583	.01-.25	1.2-7.1	.004-.015	.02-.17	.02-.04	1.6E+10	NA

Figure 1. Table 4-4 TP10 Stormwater management devices design guideline

2.2.3 WATERWAYS, WETLANDS AND DRAINAGE GUIDE, CHRISTCHURCH CITY COUNCIL (CCC)

This document references a Simple Method for Estimating Annual Urban contaminant loads from developing areas (Schueler, 1991).

This simple method uses a flow weighted mean concentration factor for the contaminants. Values for N and P are included and are reported as being appropriate for Christchurch.

The main limitations for the estimation of nutrients and bacteria loads are:

- The methodology does not include a flow weighted mean concentration factor for *E.coli* or other bacterial indicators.
- The flow weighted mean concentration factors for the contaminants are based on data for other cities and is reported as appropriate for Christchurch conditions. It is unclear if they would be appropriate for other regional towns in the Southland Region.
- The CCC guide uses a concentration based method calibrated for Christchurch rainfall, rather than a land use based method. This means that direct application of the method to Invercargill is not appropriate because doubling the annual rainfall depth will double the contaminant load, with no change in the type of land use.

  For example, based on available data mean monthly rainfall from NIWA 1981 - 2010, the Invercargill Mean average rainfall depth (1150 mm) is approximately double the Christchurch Mean average rainfall depth (650 mm). Following the Simple Method formula, presented in Figure 2, and assuming that the other parameters are the same for Invercargill and Christchurch (catchment runoff coefficient, flow weighted mean concentration of pollutants, area and corrector factor), the estimation for TN and TP will be approximately double for Invercargill in comparison to Christchurch:

  - TN Invercargill 37,074 kg/year in comparison to TN Christchurch 20,955 kg/year
  - TP Invercargill 3,707 kg/year in comparison to TP Christchurch 2,095 kg/year

Without calibration for Invercargill, this method is not recommended for a contaminant load estimation.

$$L = \varphi P C K_p A/100{,}000 \quad \text{(kg/yr)} \qquad \text{Eqn (6-1)}$$

where P = Rainfall depth (mm/year). Adopt mean annual rainfall depth given in Figure 21-4 (typically 650 mm).

φ = A correction factor for P for storms that produce no runoff. Adopt 0.85 for Christchurch.

C = Catchment runoff coefficient for the site. Refer to *Chapter 21.3.4: Runoff Coefficient.*

K_p = Flow-weighted mean concentration of pollutant in urban runoff (mg/m³). Use values in Table 6-3.

A = Total area of site (ha).

Table 6-3: Recommended provisional mean concentrations of pollutants in urban runoff (K_p values) for Christchurch (Schueler, 1991). Data are from other cities, but seem appropriate for Christchurch conditions.

Urban Pollutant	Flow Weighted Mean Concentration (K_p) Factor	
	g/m³	mg/m³
Suspended solids		
less than 10 ha	33	33,000
greater than 10 ha	33-200	33,000-200,000
construction	4000	4×10^6
Total Phosphorus		260
Total Nitrogen		2500
Chemical Oxygen Demand (COD)		35,600
Biochemical Oxygen Demand (BOD)		7000
Zinc		400
Copper		50
Lead		75
Hydrocarbons		500

Figure 2. Table 6-3 and Simple Method for Estimating Annual Urban contaminants Waterways, Wetlands and Drainage Guide

2.2.4 STORMWATER TREATMENT STANDARD FOR STATE HIGHWAY INFRASTRUCTURE, NZTA

This guidance manual assist roading practitioners with the selection and design of roading stormwater management practices.

For roads, the contaminant model considers various vehicles per day and applies contaminant loads for that situation. Contaminants of concern considered in the document for highways are; cooper, lead, zinc, sediment, and total petroleum hydrocarbons (TPH)

The main limitation for the estimation of nutrients and bacteria loads is:

- No numerical concentrations are provided for the contaminants of interest

2.2.5 ON-SITE STORMWATER MANAGEMENT GUIDELINE, NZWERF

This guideline, as shown in Figure 3 and Figure 4, provides a general guide to contaminants in stormwater from various site land uses, and a guide to contaminants in stormwater from specific industry types. However, it does not provide a detailed description of the contaminants. This guideline uses TP10 as the main resource for the general guide of contaminants.

Table 3.1 General guide to contaminants in stormwater

Source: ARC TP10

Land use	Contaminant (refer key below for abbreviations)								
	pH	SS	HC	ME	OD	NU	PA	TO	LI
Residential roofs	✓	?		✓?	✓?	✓?	?		
Residential: paved, parking driveways		✓	✓	✓	✓?	✓	✓		✓
Residential grassed areas		✓?			✓	✓	✓		✓
Roads and road berms		✓	✓	✓	✓	✓	✓		✓
Commercial: roofs	✓	?		✓?	?	?	?		
Commercial: paved, parking, driveways, yards		✓	✓	✓	✓?	?	✓	?	✓
Commercial landscaped, grassed areas		✓?			✓?	✓	✓		✓
Industrial: roofs	✓			✓?	?	?	?		
Industrial: paved, parking driveways, yards	?	✓	✓	✓	✓?	?	?	?	✓
Water blasting		✓		✓?	✓?				
House painting		✓			✓?				

Figure 3. Table 3-1 General guide to contaminants in stormwater from On-site Stormwater Management Guideline, NZWERF

Table 3.2 Industry activity and associated contaminants

Sources: ARC TP10; Environment Waikato Proposed Regional Plan, Appeals version 2002

Industry / activity	Contaminant (refer key below for abbreviations)								
	pH	SS	HC	ME	OD	NU	PA	TO	LI
Mechanical workshops, service stations, refuelling areas		✓	✓	✓				?	
Spray painting facilities spray drift								✓	
Wood preserving outside storage of timber		✓	✓	✓	✓			?	
Agricultural chemicals, fertilisers-outside storage		✓		✓	✓	✓		?	
Asphalt, paving and roofing materials		✓	✓	✓	✓			?	
Concrete products yard activities	✓	✓		✓	✓				
Iron steel lead foundries yard areas	✓	✓		✓	✓				
Waste management sites transfer stations, landfills, composting		✓	✓	✓	✓	✓	✓		✓
Automobile dismantler yards-yard		✓	✓	✓				?	✓
Scrap recycling yards		✓		✓	✓			?	✓
Bakeries with outside washing of trays etc.				✓	✓	✓	✓		
Furniture / wood manufacturing and refinishing – outside activities sawdust	✓	✓			✓				
Car wash and valet		✓	✓	✓	✓				
Steam cleaning		✓	✓		✓				
Stock sale yards		✓			✓	✓	✓	✓	

Figure 4. Table 3-2 Industry activity and associated contaminants from On-site Stormwater Management Guideline, NZWERF

The main limitation is:

- No numerical concentrations are provided for the contaminants of interest.

2.3 CONCLUSION

Based on the limitations discussed above, it was recommended to use data from the TP10 stormwater management devices design guidelines from Auckland Council to develop the estimate of the nutrients and bacteria loads for the urban and the rural stormwater in Invercargill.

3 URBAN STORMATER LOADS IN COMPARISON WITH TREATED WASTEWATER AND RURAL STORMWATER LOADS

3.1 ESTIMATION OF NUTRIENT AND BACTERIA LOADS IN URBAN STORMWATER

The Stormwater Discharges – Application Document prepared by MWH now part of Stantec for the Invercargill City Council on September 2016, presented the Invercargill stormwater catchments discharging to the different water bodies, as per Figure 5. Clifton, Waihopai, Kingswell and Otepuni catchments were included in this load estimate. Table 1 summarises the catchment areas for each of the Invercargill stormwater catchments.

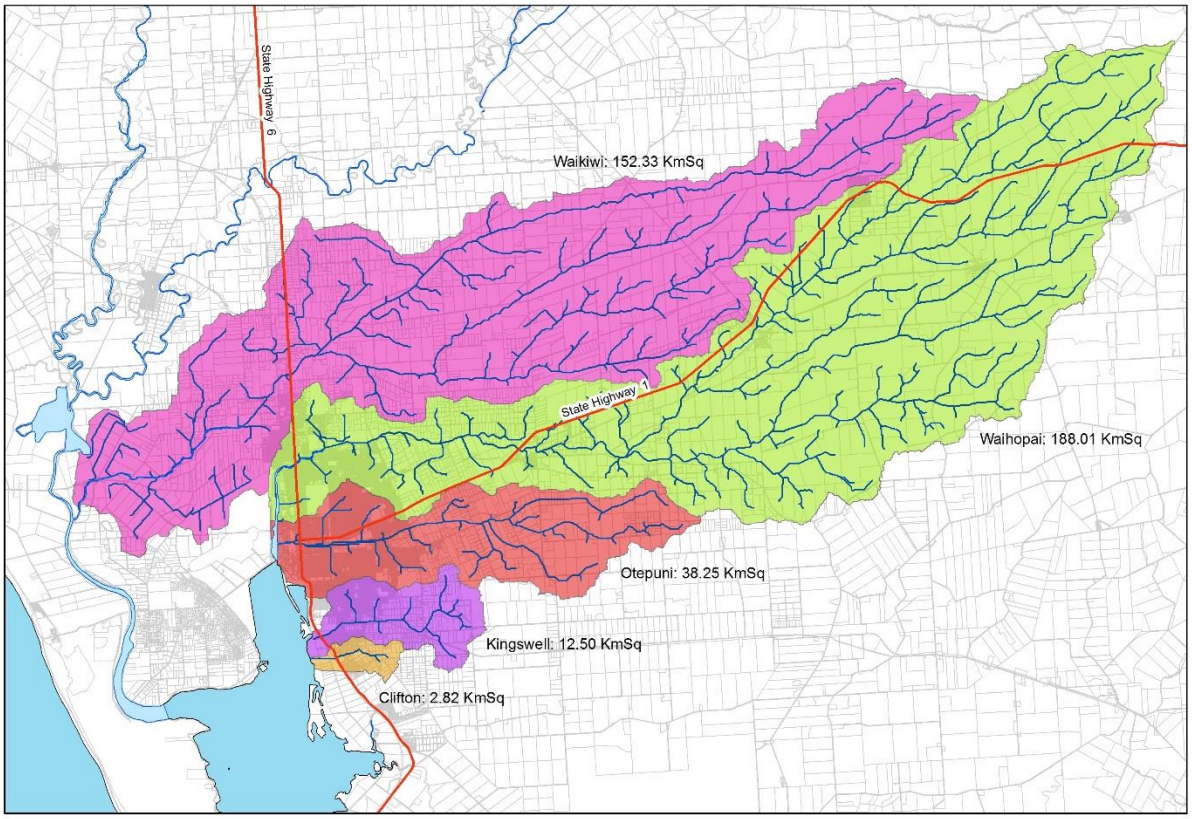

Figure 5: Extent of the catchments and the receiving streams

The Waikiwi catchment was not included in this exercise because the size of the urban stormwater catchment within Waikiwi is very small in relation to the overall Waikiwi River catchment.

Catchment	Receiving Stream Catchment Area (sq-km)	Urban Invercargill Stormwater catchment area (sq-km)	Rural stormwater catchment Area (sq km)
Clifton	2.82	1.31	1.51
Waihopai	188.01	7.03	180.98
Kingswell	12.54	3.82	8.72
Otepuni	38.25	10.49	27.76
Total	**241.62**	**22.65**	**218.97**

Table 1 Catchment areas for each of the Invercargill stormwater catchments

As discussed above, TP10 includes a wide range of contaminant loads for contaminants for each of the land uses. As a sensitivity check for each of the land uses considered, the lowest and the highest contaminant loads were calculated and included in Table 2.

In the absence of E.coli contaminant annual load data, the FC values provided by TP10 were adopted for this exercise.

It was assumed that the Invercargill urban stormwater catchment is a mixture of road, residential (low) and commercial. An approximate assumption of the proportion of land area in each land use type was made for this stage of the project as shown in Table 2.

Table 2 summaries loads of TN, TP and FC expected per year in the urban stormwater discharge.

Land use	% of catchment	TN (kg/year)		TP (kg/year)		FC (No/year)
		Low	High	Low	High	
Road	10%	294	793	134	340	4.08E+10
Commercial	20%	725	3986	313	412	2.54E+12
Residential (low)	70%	5,232	7,452	729	1,015	1.47E+13
Total	100%	6,251	12,231	1,175	1,767	1.73E+13

Table 2. Estimation of nutrient and bacteria loads based on TP10 contaminant loading ranges for urban Invercargill stormwater catchment area

3.2 ESTIMATION OF NUTRIENT AND BACTERIA LOADS IN RURAL STORMWATER

In order to compare the contaminants produced by urban stormwater and rural stormwater, the total local load of N, P and E.coli is estimated for the rural catchment based on TP10 contaminant annual load data. Table 3 summarises the results.

Land use	TN (kg/year)		TP (kg/year)		FC (No/year)
	Low	High	Low	High	
Pasture	26,276	155,469	219	5,474	3.50E+14

Table 3. Estimation of TN, TP and FC based on TP10 contaminant loading ranges for rural stream catchment area

While this is a total load, it is worth noting that the rural catchment is 3 times the urban catchment area.

3.3 NUTRIENTS AND BACTERIA LOADS COMPARISON FOR STORMWATER AND WASTEWATER

Based on the expected wastewater discharge quality for the Invercargill Wastewater Treatment Plant provided by Invercargill City Council, and the total annual inflow, the total nutrient (N and P) and bacteria (faecal coliforms) loads for the Invercargill urban stormwater and wastewater can be compared as presented in Table 4.

The base information provided for the Invercargill Wastewater treatment Plant were:

- Total annual inflow: 9,052,300 m3/year
- Population connected: 50,000 people
- Expected Maximum Wastewater Discharge quality:
  E.coli: 1,516 MPN/100 mL (FC values 20% higher than E.coli values)
  TN: 33.0 mg/L
  TP: 4.7 mg/L

Contaminant	Wastewater estimates	Urban stormwater catchment estimates	Percentage of the stormwater over the wastewater
TN	298,726 kg/year	6,251 – 12,231 kg/year	2 – 4 %
TP	42,546 kg/year	1,175 – 1,767 kg/year	3 - 4 %
FC	1.65E+14 No/year	1.73E+13 No/year	10.5 %

Table 4. Nutrient and bacteria load comparison for Invercargill urban stormwater and Invercargill wastewater loads

3.4 NUTRIENTS AND BACTERIA LOADS COMPARISON FOR URBAN AND RURAL STORMWATER

Based on the expected rural and urban contaminant discharge calculated above, the total E.coli, N and P loads for the rural and urban stormwater catchments can be compared as presented in Table 5.

Contaminant load for Urban and Rural stormwater is presented in a range, for comparison purpose the mid-range value will be selected.

Contaminant	Rural stormwater catchment estimates	Urban stormwater catchment estimates	Percentage of the urban contaminant over the whole stormwater catchment
TN	90,873 kg/year	9,241 kg/year	9.20%
TP	2,847 kg/year	1,471.5 kg/year	34.10 %
FC	3.50E+14	1.73E+13 No/year	4.71%

Table 5. Nutrient and bacteria load comparison for Invercargill for Invercargill rural and urban stormwater catchments

3.5 NUTRIENTS AND BACTERIA LOADS COMPARISON FOR URBAN, RURAL STORMWATER AND WASTEWATER

Figure 6 shows the comparison in percentage for a discharge based on the expected rural and urban contaminant discharge estimated above and the expected wastewater discharge quality for the Invercargill Wastewater Treatment Plant based on the total annual inflow.

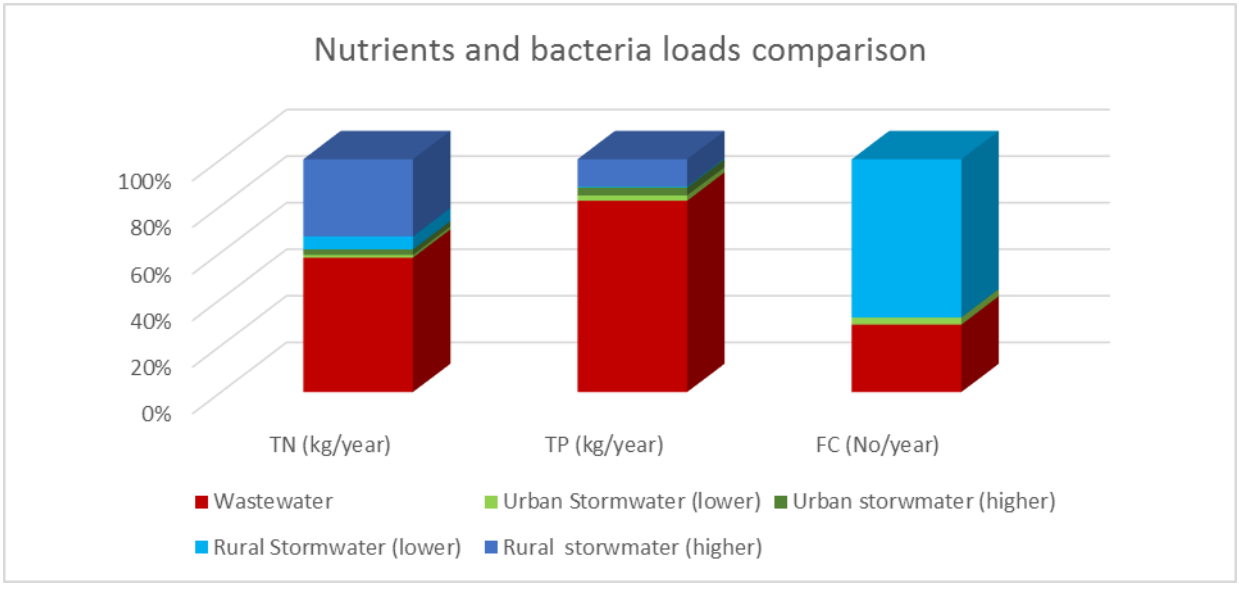

Figure 6: Nutrients and bacteria loads comparison in percentages

4 CONCLUSIONS

As it can be observed from the results of contaminant load estimates, the nutrient load from urban stormwater is minimal in comparison with the wastewater source, being less than 5%. The estimate of bacteria load is an order of magnitude lower than the wastewater.

The results of the comparison of the urban and rural stormwater are not conclusive as sources of contaminant are difficult to be generalized on an extended rural catchment area and further research and investigation is required to determine a magnitude of assessment on contaminant contributions.

However, as a full comparison of the nutrients and bacteria loads in percentages, it can be observed that the percentage contribution of nutrients and bacteria loads from urban stormwater is minimal over the whole catchment (stormwater and wastewater).

The main limitation of the estimates presented above are:

- No field verification has been carried out. This project has been a desktop analysis of the available information.

- Limited model input data based on generally available contaminant loading ranges and information provided by Invercargill City Council.

This result has led to a concentration in Invercargill on the removal of wastewater discharges and overflows in the first instance and a focus on stormwater assessment on the other parameters included in the Auckland Contaminant Load Model, ie solids, copper, zinc, and total petroleum hydrocarbons (not including N, P and FC parameters).

ACKNOWLEDGEMENTS

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"On-site Stormwater Management Guideline", NZWERF, October 2004

"The Stormwater Discharges – Application Document prepared" by MWH for the Invercargill City Council on September 2016

Mean monthly rainfall from NIWA 1981 -2010 by NIWA