DETERMINING STORMWATER TREATMENT REQUIREMENTS FOR A GREENFIELDS DEVELOPMENT IN THE CATCHMENT OF A HYPERTROPHIC LAKE

Jim Cooke[1], Tim Cox[1], Mike Stewart[1], Ngaire Phillips[1], Rob Hart[2]

1. ***Streamlined Environmental Ltd, PO Box 7003, Hamilton East 3247***
2. ***Hartland Environmental Ltd, P O Box 290, Whitianga, 3542***

ABSTRACT

As one of a number of studies supporting an ICMP, we were commissioned by the sponsors of a proposed Greenfields urban development at Rotokauri near Hamilton City to: (i) provide defensible water quality targets for a range of receiving waters potentially impacted by the development, (ii) identify the contaminants that are most limiting (i.e. will require the greatest treatment to ensure that water quality targets are not breached), and (iii) quantify the stormwater treatment required both during the development phase and when the urbanized area is 'mature'. Here we focus on Lake Rotokauri, since this shallow hypertrophic lake is closest to the bulk of the development area.

There were relatively abundant nutrient data available for the lake from previous studies but data on potential urban contaminants, e.g. metals, PAHs, and emerging contaminants, were sparse. We obtained baseline data on these contaminants by deploying passive sampling devices on inflow and outflow streams, and from lake sediment samples. From these data, we could propose water quality targets for lake water and sediments based on USEPA and ANZECC guidelines.

Nutrient limits for the development were based on the policy (Vision & Strategy) that some improvement in lake water quality is required. We constructed a spreadsheet model to estimate the annual nutrient load during both construction and mature phases, which provided input to a calibrated SLAM (Simplified Lake Analysis Model) for the lake. The SLAM model predicted the effects of different nutrient loads to the lake on phytoplankton concentrations (as chlorophyll *a*) in the water column. We showed that phosphorus is the key nutrient to target with stormwater treatment, and that provided at least 70% removal can be achieved during both the development phase and when the urban catchment is mature, water quality of Lake Rotokauri should not deteriorate and may even improve.

KEYWORDS

water quality, limits, phosphorus, nitrogen, phytoplankton, stormwater quality treatment

PRESENTER PROFILE

Dr Jim Cooke is a water quality specialist with 40 years' experience in environmental science, principally directed towards the management of receiving waters. He has specialised in non-point (diffuse) pollution both in respect to rural and urban land uses, as well as incorporating science knowledge within National and Regional Planning processes.

1 INTRODUCTION

Streamlined Environmental Ltd was commissioned by the Hamilton City Council (HCC) to undertake a broad-scale water quality assessment to support the development of the Rotokauri 'Integrated Catchment Management Plan' (ICMP). The Rotokauri Catchment is substantially 'greenfield' and the main purpose of the ICMP is to help inform the implementation of the HCC Rotokauri Structure Plan[1] (three waters) in a sustainable and integrated manner. Another purpose is to ensure consistency with relevant statutory, policy and planning provisions, including the condition requirements of the HCC Comprehensive Stormwater Discharge Consent.[2]

The broad-scale water quality assessment forms part of a suite of technical investigations and assessments which have been undertaken to inform an 'evidence based approach' in the development of the ICMP. These assessments have helped to inform robust design parameters for stormwater management and the development of Best Practicable Options, including a comprehensive water quality treatment concept for the catchment.[3] This is informed via the water quality targets and contaminant load limits determined through the assessment work detailed below.

Development of the Rotokauri Catchment has more environmental implications than is typical for urban development, because Lake Rotokauri is located at the downstream end of the main development area (~550 ha) (Figure 1)[4]. Additional receiving waters (not included in this paper) are Lake Waiwhakareke (Horseshoe Lake), Ohote Stream (outlet of Lake Rotokauri), and the Waipa and Waikato Rivers.

Lake Rotokauri currently has degraded water quality; the origin of which can be traced to the collapse of macrophytes beds (*Egeria densa)* in the summer of 1996-97 (Edwards et al. 2007). It was classified as hypertrophic by Barnes (2002), indicative of very poor water quality (turbid, frequent algal blooms, very high levels of nitrogen (N) and phosphorus (P)). More recent data presented in Sharma (2011) indicates it may have improved slightly, however water quality remains poor with indices spanning the supertrophic-hypertrophic boundary.

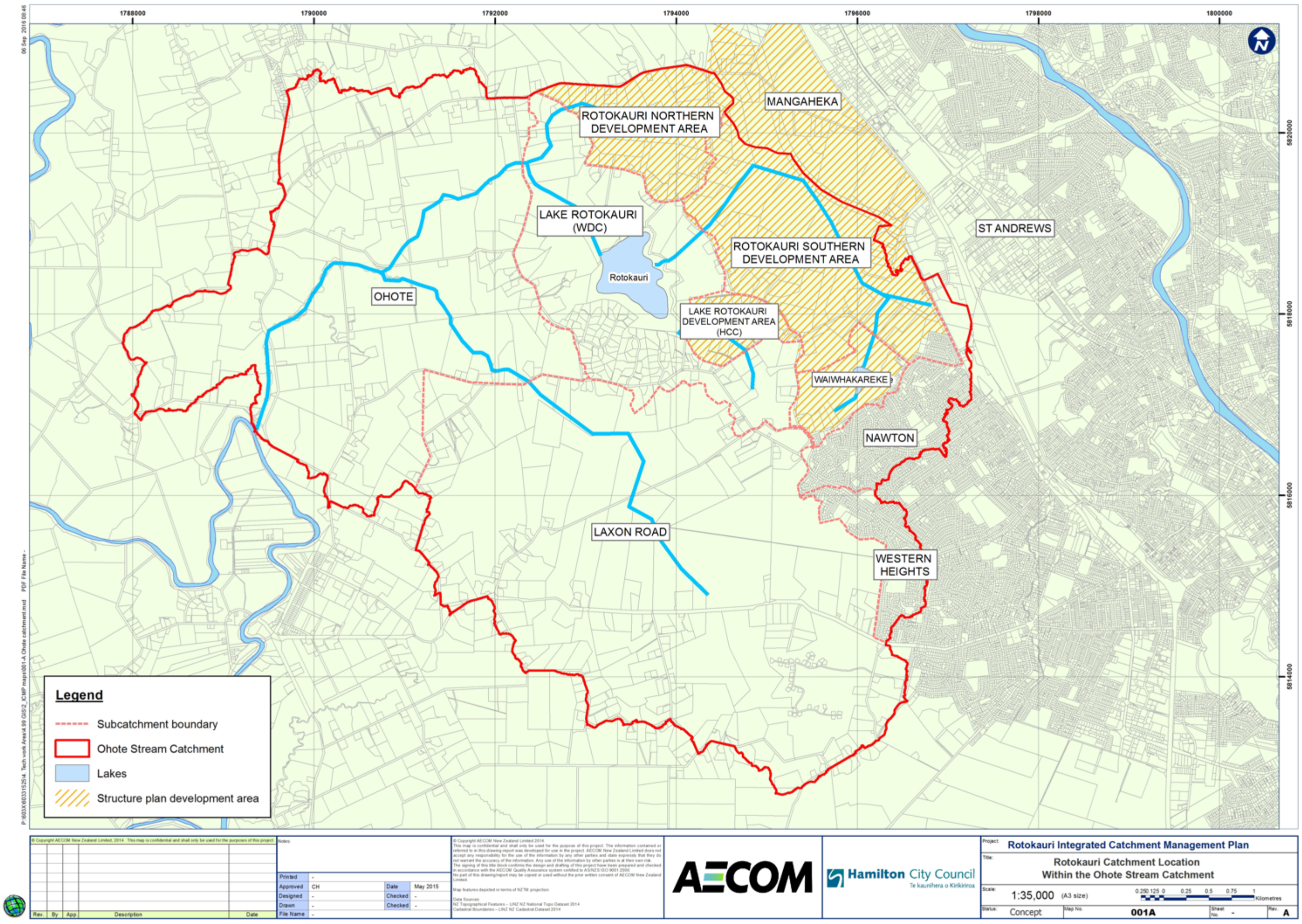
Whilst the lake has poor water quality, it is highly valued because of its proximity to Hamilton. Local residents, District and Regional Councils, Waikato-Tainui, and NGOs all aspire to improve the water quality of the lake. This desire for improvement is also encapsulated within the Waikato Raupatu Claims (Waikato River) Settlement Act 2010, which provides the highest policy direction for environmental improvement.

There is therefore real concern for the potential of the Rotokauri urban development to degrade lake water quality further. This concern is not only due to the potential for further nutrient enrichment, but also 'effects' from known urban contaminants such as metals (e.g. copper, zinc, lead), petroleum hydrocarbons, and emerging organic contaminants associated with population increases.

---

[1] HCC Partly Operative District Plan, 21st October 2016.
[2] HCC Comprehensive Stormwater Discharge Consent #105279 / Condition 3(c) and 30 (Catchment Management Plans).
[3] 'Concept Development Report – Rotokauri ICMP Water Quality Treatment' (Morphum Environmental Ltd, 2016).
[4] The main development area as referred to in this paper includes the 'Rotokauri Southern Development Area' and the 'Lake Rotokauri Development Area' (Figure 1).

Figure 1: Rotokauri ICMP area showing Lake Rotokauri, other receiving waters and proximity to Hamilton City. Once completed the area will house ~20,000 people.



The purpose of this study was to: (i) provide defensible water quality targets for Lake Rotokauri consistent with planning documents, existing state, and water and sediment guidelines, (ii) identify the contaminants that are most limiting (i.e. will require the greatest treatment to ensure that water quality targets are not breached), and (iii) quantify the stormwater treatment required both during the development phase and when the urbanized area is 'mature'.

We assessed these effects through a combination of field work, desktop modelling, and simulation modelling. Our first objective was to predict potential deterioration in water quality from the urban development without any mitigations in place. From a comparison to current state data we developed realistic water quality targets and load limits for Lake Rotokauri. We used these targets and limits to advise consultants designing mitigation infrastructure as to which contaminant(s) are most limiting (i.e. which contaminant(s) will require the greatest treatment to meet the limits and ensure that the water quality targets are not breached) and the likely quantum of treatment required to ensure the limits are not breached and the targets met.

2 DATA ON EXISTING STATE

2.1 NUTRIENTS

There were sufficient nutrient data (and flows) on the main inflow stream (Table 1) and the Lake (Sharma, 2011) from studies undertaken in 2009. Cooke (2010) showed that there were significant relationships with flow for several nutrient forms (particularly nitrate and dissolved phosphorus, Figure 2) whereas relationships with particulate forms (e.g.

particulate phosphorus and nitrogen) were not significant. This is the opposite trend to that reported in other catchment studies where particulate nutrient concentrations often increase markedly with flow rate as mobilization of surface-entrained nutrients increases with flow rate (e.g. Cooke, 1988). The situation at Rotokauri reflects (i) the current stable nature of the catchment and low-intensity land use (mainly lifestyle blocks), and (ii) the dominance of subsurface flow as a source of runoff during and after storm events. Water balance studies (Sharma, 2011) also identified large subsurface (groundwater) inputs to the lake as being necessary to achieve a water balance.

A feature of the inflow water quality was the relatively high concentrations of nitrate-N (Figure 2) consistent with a groundwater source, which comprised ~ half the TN load. The nitrate-N concentrations are higher than one would expect from low-stocking lifestyle blocks and may reflect a legacy landuse such a dairying.

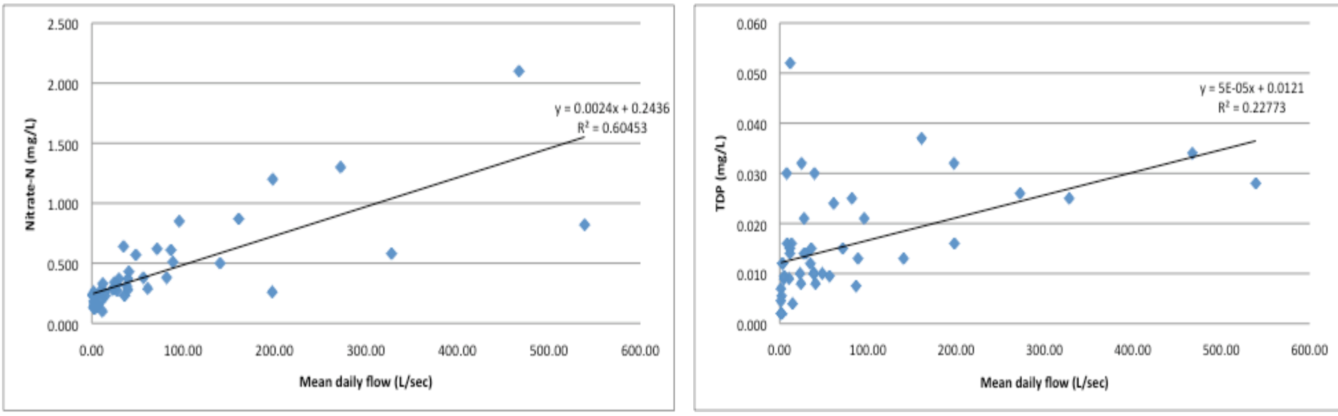
During and after urbanisation the degree of imperviousness will increase, and the risk of lake contamination from urban sources will mainly arise from surface processes (i.e. surface runoff → Rotokauri Drain → Lake Rotokauri).

Table 1: Annual load (2009) estimates for suspended solids, and nitrogen and phosphorus forms monitored in the Rotokauri Stream (Cooke, 2010).

	TSS	NH_4-N	NO_2-N	NO_3-N	TKN	TN	DRP	TDP	TP
Annual load (kg/y)	20860	374	11.9	1782	1862	3643	22.0	51.6	121
Standard error (%)	45	13	57	45	23	20	7.4	65	5.9
Specific load (kg/ha/y) ± SE	37 ± 17	0.66 ± 0.09	0.021 ± 0.012	3.2 ± 1.4	3.3 ± 0.8	6.5 ± 1.3	0.039 ± 0.003	0.09 ± 0.06	0.21 ± 0.01

We also undertook additional sampling of lake sediments. Shallow sediment grab samples were collected from six (6) site locations distributed across the lake. GPS was used to record the location of each sampling site. Samples were collected from a boat using a "petite" Ponar grab sampler. Collected samples included approximately the top 15 cm of the lake bed sediments and were relatively intact upon retrieval. Sediment nutrient concentrations exhibited uniformity for all sites, with total phosphorus ranging from 690 to 870 mg kg^{-1} and total nitrogen ranging from 6800 to 10900 mg kg^{-1}.

Figure 2: Scatter plots of significant (95% confidence) relationships between water quality parameters and mean daily flow with regression equations derived from weekly sampling (n=49) of Rotokauri Stream during 2009 (Cooke, 2010)



2.2 "URBAN" CONTAMINANTS

In contrast to the relatively abundant nutrient dataset, there were few historical measurements of urban contaminants in lake sediments or inflows (to form a baseline) and no data on emerging contaminants. To redress this situation, we analysed composite sediment samples from the Ponar dredge sampling discussed above for a range of metals, as well as persistent organic pollutants (POPs) (including organochlorine pesticides, polychlorinated biphenyls, plasticisers, polybrominated diphenyl ether (PBDE) flame retardants and total petroleum hydrocarbons). PAHs were not analysed as these had been recently as part of the monitoring requirements for the Comprehensive Stormwater Discharge Consent.

Sediment metal concentrations within the lake were generally low and consistent with historic results. Zinc was the exception, with moderately high concentrations (~250 mg/kg). POP concentrations were very low and generally below analytical detection limits. We note that 16 USEPA priority PAHs measured in 2014 were also below detection limits in Lake Rotokauri sediments (Tonkin & Taylor, 2014).

We also deployed passive sampling devices (PSDs) in both the main inlet (Rotokauri Drain) and outlet (Ohote Stream) to Lake Rotokauri, namely the Polar Organic Chemical Integrative Sampler (POCIS) and Diffuse Gradients in Thin Films (DGTs). These PSDs (Stewart et al., 2016), which are specific to contaminant types (polar wastewater markers and metals, respectively), provide averaged dissolved contaminant concentrations over a sustained period (in this case, 1 week - metals, 3 weeks - organics).

For most dissolved metals, there was a significant reduction in concentration between the inlet and outlet, suggesting that the lake acts as a sink for metals.

Of the 9 wastewater markers analysed, carbamazepine and the fluorescence whitening agent, FWA-1, could not be reported due to analytical problems. Three of the remaining 7, paracetamol, caffeine and cotinine (nicotine breakdown product) could be quantified (Figure 4). Only caffeine showed a significant difference between inlet and outlet concentrations with an approximate 3-fold reduction.

The POCIS provided evidence of some wastewater contamination of the lake, most likely from septic tank leachate. With urbanisation, we would expect this contamination to decrease because all new properties will be connected to a modern sewerage system and pumped away from the catchment, whilst existing septic tanks should be progressively decommissioned.

Figure 3: Average (±1 SD) concentration of metals measured using DGTs at a site in the Rotokauri Drain (inlet) and Ohote Stream (outlet).

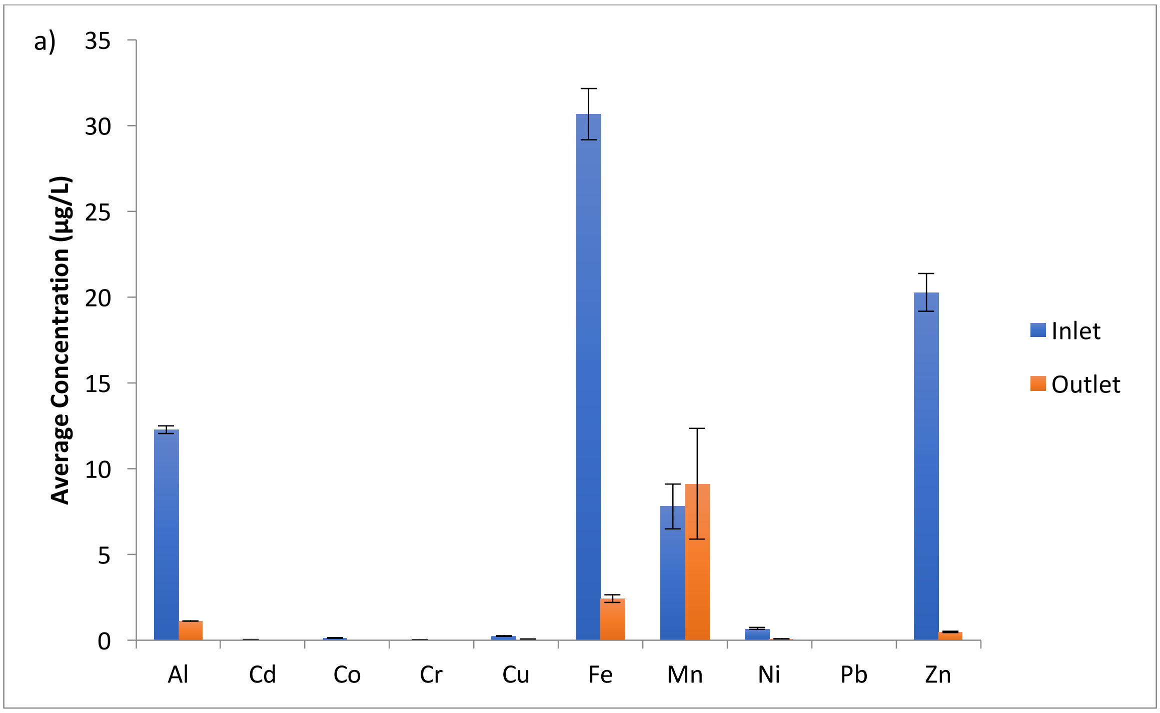
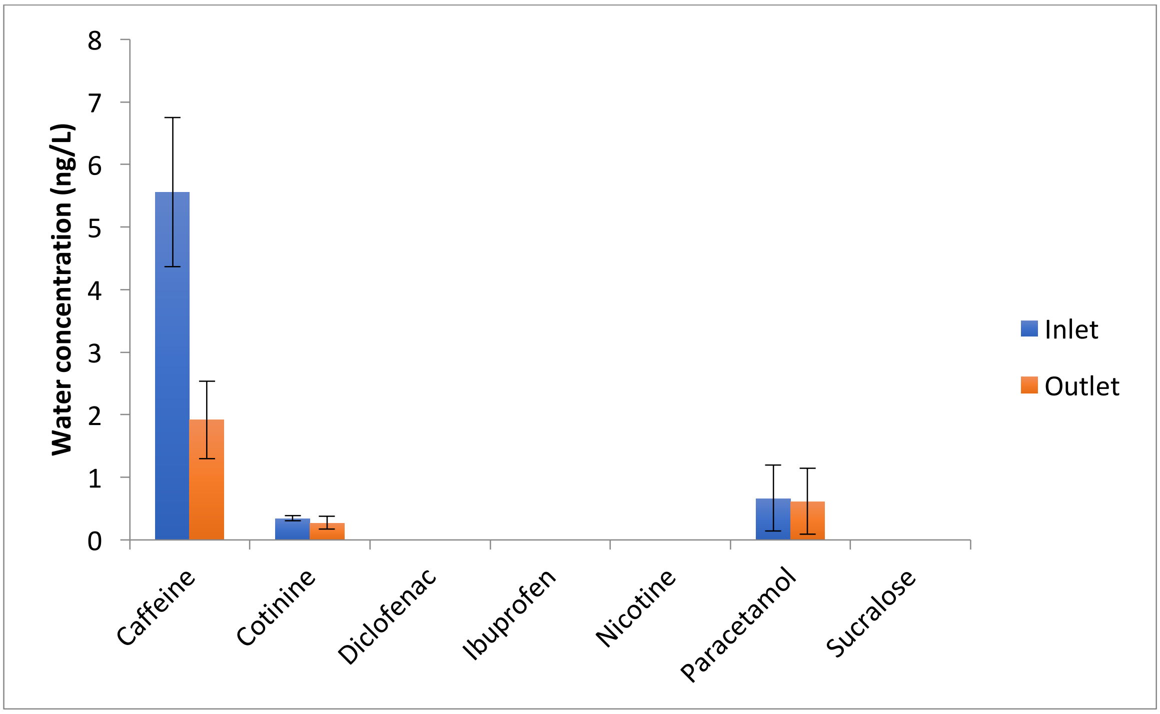


Figure 4: Average (±1 SD) concentration of wastewater markers measured using POCIS at a site in the Rotokauri Drain (inlet) and Ohote Stream (outlet).



3 WATER QUALTY TARGETS

3.1 POLICY AND PLANNING CONSIDERATIONS

There has been a stepwise change in the approach to consents affecting the catchment of the Waikato River in recent times, as a consequence of recent legislative and policy changes affecting freshwater management (Dean-Spiers and Nielson, 2014a). These include:

- Waikato Raupatu Claims (Waikato River) Settlement Act 2010 (Vision and Strategy for the Waikato River);
- Ngati Tuwharetoa, Raukawa and Te Arawa River Iwi Waikato River Act 2010;
- Nga wai o Maniapoto (Waipā River) Act 2012;
- Waikato-Tainui Environmental Plan which identifies objectives, policies and methods for the future co-management of water, wetlands, and land; and
- Ngati Tahu-Ngati Whaoa Iwi Environmental Management Plan; Ngati Raukawa Fisheries Management Plan, Ngati Tuwharetoa Iwi EMP.

An important concept inherent in the above approaches is the requirement to restore and protect the health and wellbeing of the Waikato River, rather than simply to maintain current status. Restoration and protection goes beyond avoiding effects and includes preservation for the future and restoration from past damage. This point was emphasized in a recent Environment Court finding[5], which noted that the Settlement Act (2010) included all tributaries, streams and watercourses in its definition of the Waikato River. Further, it noted that in applications affecting the Waikato catchment, the applicant would need to show that, in proportion to the impact of the proposal, there was real benefit to the river catchment. This finding is relevant to both stormwater discharge consents and to any ICMPs approved in accordance with the conditions of those consent. It is also relevant to new resource use activities requiring resource consents from local and regional authorities.

3.2 NUTRIENTS

As noted previously, Lake Rotokauri is already classified as hypertrophic, which is the most 'polluted' on the trophic scale. However even within this category there are 'degrees' of enrichment. A more enriched lake, while still hypertrophic, can result in increased incidence of algal blooms and a change in dominant algal type. Blue-green algal blooms, can lead to adverse effects on stock and public health. The policy direction (particularly the Vision and Strategy) is that water quality should be improved. Therefore, the targets for the ICMP should at the very least be that the intent of the policy is met and that there should be some improvement predicted. We use this criterion in our lake modelling and determination of stormwater treatment requirements.

3.3 URBAN CONTAMINANTS

Our assessment of current state showed that (i) metals and toxic organics in lake water were low and well below any relevant guidelines. However, the difference between lake inlet and outlet concentrations (Figure 3) as well as sediment concentrations showed that

---

[5] Environment Court (2014). 3201096-Environment Court Appeal 2014. NZEnvC223 Puke Coal & Ors v Waikato Regional & District Councils (decision). Date of decision: 23 October 2014.

lake sediments were a sink for metals. There was evidence for accumulation of toxic organics in sediment, but the concentrations were low.

Sediment POP concentrations were assessed against the ANZECC Interim Sediment Quality Guidelines (ISQG) (ANZECC, 2000), or in the case of PBDEs, Environment Canada Guidelines[6]. The ISQG define two values for each toxicant: 'low' (trigger value) and 'high' (Long et al. 1995). The ISQG-low value indicates a possible biological effect and is intended as a trigger value for further investigation, while the ISQG-high value indicates a probable biological effect. All POPs were normalised to 1% organic carbon for comparison with ANZECC ISQG trigger values (where applicable).

Numerical sediment quality guidelines to assess potential effects on sediment dwelling organisms are presented in Table 2.

Table 2: Numerical sediment quality guidelines used to assess effects on the receiving environment

Parameter	Units	ANZECC ISQG-Low	ANZECC ISQG-High	Environment Canada
Arsenic	mg/kg	20	70	
Cadmium	mg/kg	1.5	10	
Chromium	mg/kg	80	370	
Copper	mg/kg	65	270	
Lead	mg/kg	50	220	
Mercury	mg/kg	0.15	1	
Nickel	mg/kg	21	52	
Zinc	mg/kg	200	410	
Total DDT	µg/kg	1.6	46	
Total PAH	µg/kg	4000	45,000	
Total PCB	µg/kg	23	NV	
TPH	µg/kg	280	550	
PBDE	µg/kg	-	-	0.4-19[7]

NV = No value given. No guidelines available for plasticisers or wastewater markers

Chronic sediment guidelines provided by ANZECC are acceptable to use for assessment of potential effects arising from accumulation of contaminants in sediments. However, for potential effects on water column dwelling organisms, two assessment scenarios can be applied, i.e. effects under stormflow and baseflow conditions. Stormflow events are short-term and intermittent with potential effects likely to be acute, whereas baseflow conditions are more likely to be associated with chronic effects. It is important to note that PSDs used in the current assessment provided time-weighted average concentrations over the deployment time (1-3 weeks), which are relevant to chronic (baseflow) rather than acute (stormflow) effects. Numerical water quality guidelines used to assess potential effects on water column dwelling organisms were also assessed (not presented here).

Metal concentrations were compared against both acute and chronic guidelines. USEPA provide criterion maximum concentrations (CMC) guidelines to protect against acute effects (USEPA, 2014), while ANZECC provide water quality guidelines to protect against

[6] http://www.ccme.ca/en/resources/canadian_environmental_quality_guidelines/index.html

[7] A range is given as Canadian guidelines are for individual PBDE congeners, not total PBDEs

chronic effects (ANZECC, 2000). The main purpose of this baseline assessment was to establish the existing quality of the environment, not impacts from specific stormflow events. Therefore, although both acute and chronic guidelines have been included, assessments of measured data were only made against chronic (ANZECC) guidelines.

Lake sediment metal concentrations were generally well below ANZECC (2000) ISQG-Low, other than for zinc, with a value of 250 mg/kg. This exceeded the 'Low' guideline (200 mg/kg) but not 'High' (410 mg/kg, Figure 5).

Based on a preliminary CLM model, Morphum Environmental Ltd (Sam Blackbourn, pers. comm. 2015) predicted that copper and zinc concentrations will increase in the Rotokauri catchment 'without treatment', with concentrations exceeding USEPA acute guidelines for copper and zinc. In addition, based on existing baseline data, dissolved copper and zinc concentrations exceed ANZECC chronic guidelines (but not the USEPA acute guidelines) in the Rotokauri Drain and in the Ohote Stream. We therefore recommend that water quality targets for all receiving waters be set to meet both acute and chronic effects, as defined in Table 3. As previously stated, our investigations indicate that Lake Rotokauri acts as a sink for both copper and zinc. We therefore recommended that sediment quality targets (ISQG low and high) be set. Setting both low and high sediment quality targets allows for identification of early triggers (between low and high ISQG values).

Figure 5: Metal concentrations in Lake Rotokauri sediments compared with ANZECC sediment guidelines

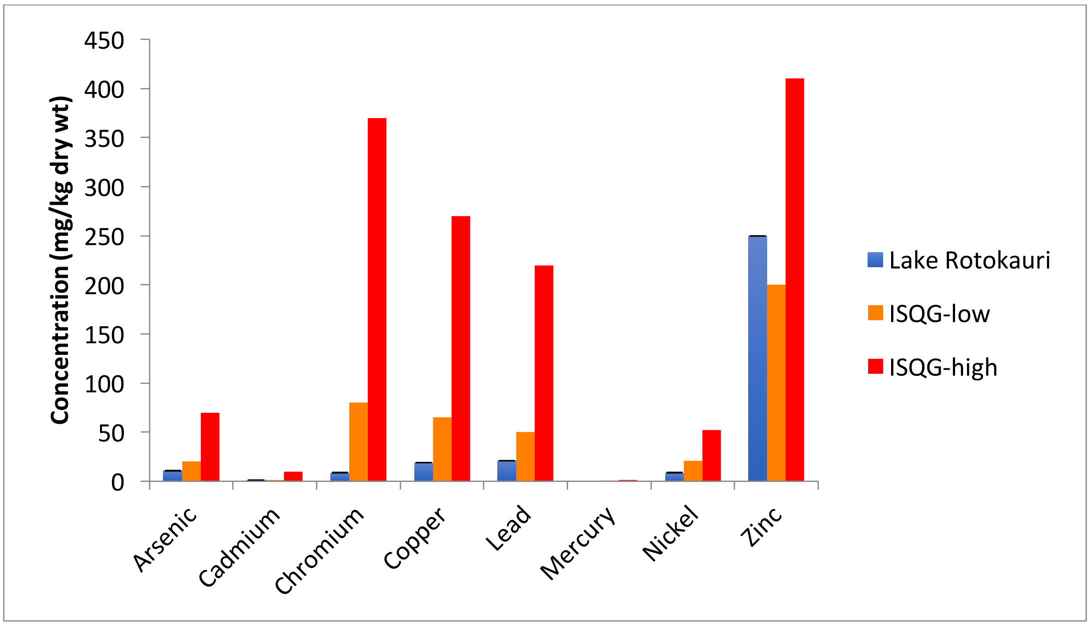


Table 3: Water and sediment quality targets for receiving waters in the Rotokauri catchment

Parameter	Units	Cu	Zn
Water quality targets			
USEPA CMC (acute)	µg/L	4.3	42
ANZECC (chronic)	µg/L	1.4	8
Sediment quality targets			
ISQG Low	mg/kg	65	270
ISQG High	mg/kg	200	410

4 MODELLING EFFECTS OF STRUCTURE PLAN ON CHANGES IN TROPHIC STATE DURING CATCHMENT DEVELOPMENT

We set up and calibrated a water quality model for the lake (Simplified Lake Analysis Model, SLAM) primarily to predict the effects of implementing the structure plan (i.e. urbanisation) on the trophic state of the lake. We used a spreadsheet model to predict changes in nutrient (N and P) inputs to the lake arising from implementation of the structure plan.

4.1 SLAM MODEL

SLAM (CDM Smith, 2012) was used in this study to simulate nutrient and phytoplankton dynamics in Lake Rotokauri and to evaluate the impacts of several proposed development scenarios on lake water quality. The SLAM software was originally developed by one of the authors (Tim Cox) to address an identified need for a practical water quality modeling tool focused on lake eutrophication that could be easily and simply applied in planning studies by a wide range of end-users. SLAM calculates lake mass and flow balances on a daily timestep, assuming one or more well-mixed lake zones. Each zone follows the conceptual model often referred to as a "continuously stirred tank reactor" (CSTR), whereby complete and immediate mixing is assumed for each zone in both the vertical and horizontal directions. This assumption makes the model particularly well suited for lakes that are generally well-mixed and can justifiably be divided into a limited number of small and/or shallow zones. SLAM targets the key parameters important for eutrophic lakes: phytoplankton (as Chl *a*), phosphorus (P), and nitrogen (N). An established empirical model is used to describe the relationship between summer phytoplankton levels and lake nutrient concentrations and hydraulics.

The model allows for quick and easy simulations of a variety of in-lake best management practices (BMPs), including: sediment dredging, hypolimnetic oxygenation, supplemental water inputs, pump and treat systems, alum application, and re-circulating off-channel wetlands treatment. Lastly, the model includes a state-of-the-art dynamic sediment nutrient flux module. This module calculates internal nutrient loads from the sediments to the water column as a function of shallow sediment nutrient dynamics and diffusive exchanges between sediment porewater and the overlying water column. Internal nutrient loads are a key component of many eutrophic lakes.

The water quality and hydrologic data described above were used to construct and calibrate a Lake Rotokauri water quality model using the SLAM software. The baseline calibration model was constructed to simulate a continuous period for 1 year (2009) on a daily timestep. The best available information and data were used to support the model construction and calibration. This includes historical data, previous studies, and the sediment sampling described above. Details on model parameterization and calibration are found in Cooke et al (2015).

Excellent agreement between modelled and measured nutrient water chemistry was achieved in terms of both average annual values and patterns of variability. Modelled sediment nutrient concentrations also agreed very well with the measured data. Sediment nutrient flux rates agreed well with known published rates for similarly impacted lakes. Lastly, predicted seasonal average phytoplankton concentrations (as chlorophyll *a*) agree well with measured values on an annual average basis and during the critical summer months. A summary of the calibration results is given in Table 4.

Table 4: Summary of SLAM model calibration results (NA= not available)

Output Parameter	Measured Value	Modelled Value	% Difference
Average annual TP (mg L^{-1})	0.05	0.05	0%
Average annual TN (mg L^{-1})	1.1	1.1	0%
Average annual Chl *a* (ug L^{-1})	24	25	4%
Average sediment P (mg g^{-1})	0.8	0.8	0%
Average sediment N (mg g^{-1})	9.2	9.0	-2%
Sediment P flux (mg m^{-2} d^{-1})	NA	4 - 9	NA
Sediment N flux (mg m^{-2} d^{-1})	NA	40 - 70	NA

4.2 SPREADSHEET MODEL OF NUTRIENT LOSS FROM THE DEVELOPING CATCHMENT

The calibrated SLAM model was used to simulate a series of future "what if" scenarios associated with the projected urban development of the Lake Rotokauri catchment. To support this analysis, a spreadsheet model was developed to predict soil-associated nutrient loss from the site during construction. Two development scenarios were modelled: one assuming a 10-year growth period and the other a 20-year growth period. Each also included a 4-year final "maturation" period, for total simulation periods of 14 and 24 years, respectively. For each 'block' developed, we assume a 25% drop in sediment load per year as infrastructure is installed and cover re-established.

The 10-year growth development path assumed that 10% of the main development area (550ha) would be developed each year (i.e. 55 ha/year). During this development phase, additional N and P could be flushed off site due to exposed bare earth (DSL, 2012). The same assumptions are made in the 20 year development phase as for 10 year development phase, with the exception that only 5% of the catchment (27.5 ha) is developed in any one year.

We used sediment yield relationships established by Elliott et al. (2010) as a function of rainfall, soil type and slope angle. We used these relationships to establish likely sediment yields from the main development area. Soil type within the area was predominantly Hamilton Silt/Clay Loam, for which we obtained published soil chemistry information[8]. The distribution of slope angles on the area was estimated from LIDAR data (Hardy, pers. comm.). In addition, we used the 10th %ile, median, and 90th %ile 12-month rainfall for Hamilton (Chapple, 2011) to establish low, likely and high estimates of sediment yield from the area. The values of parameters used are summarised in Table 5.

Using the above parameter values, we predicted the 10%ile, median, and 90%ile load of N and P exported from the structure plan area under the 10 and 20-year development scenario. The 20-year predictions are presented in Figure 6. The points to note from Figure 6 is that for nitrogen, we predict only a small increase above current surface water loads under the most likely (median) conditions, and that load is expected to decline to current conditions or less once development is complete. Under 90%ile rainfall conditions, predicted N load nearly doubles under a 10-year development scenario, with about half that increase (but for a longer time) with a 20-year development scenario. Under 10%ile rainfall conditions, the N load could be expected to decline under both scenarios. In contrast, we predict that phosphorus load would increase under all rainfall conditions for both development scenarios, with the maximum increase ranging from 6-14 times (10-year scenario) and 5.5– 9 times (20-year scenario). The difference between N and P can be attributed to: (1) the high proportion of the current N load as nitrate-N which is of

[8] New Zealand Soil Bureau (1968) Soils of New Zealand (Part 3)

groundwater origin and would not be expected to increase with urban development, (2) the low current P load (Cooke, 2010) which is attributed to very low stocking rates (mainly lifestyle blocks), and (3) the relative enrichment of P c.f. N in the subsoil (Table 5).

Table 5: Values of parameters used to calculate nutrient loads generated from the main development area

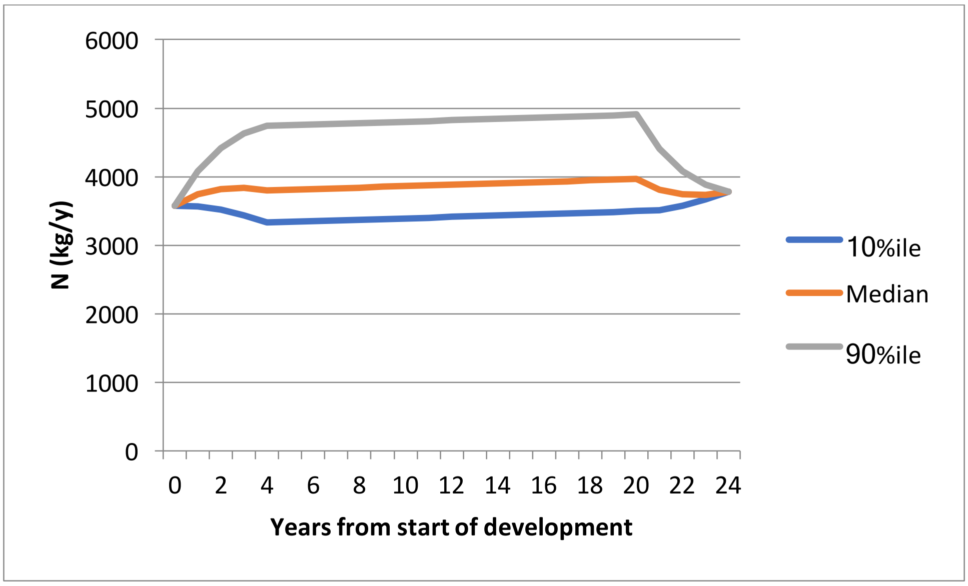
Parameter	Value
Soil type	Hamilton silt/clay loam
Slope angle	Class 1 75% flattish (slope < 5^{o}) Class 2 25% rolling (slope 5-15^{o})
Sediment-yield (T ha/y) Pasture cover, average rainfall	Class 1 0.2 Class 2 1.0
Multiplier (compared to pasture) for bare earth, no treatment controls	43.3
Multiplier for 10%ile , 90%ile rainfall (compared to median)	10%ile 900 mm/y = 0.5 90%ile 1600 mm/y = 2.0
Phosphorus in Hamilton silt/clay loam (NZ soil Bureau, 1968)	A horizon 0.5g/kg B horizon 0.17 g/kg
Nitrogen in Hamilton silt/clay loam (NZ soil Bureau, 1968)	A horizon 3.4 g/kg B horizon 0.5 g/kg

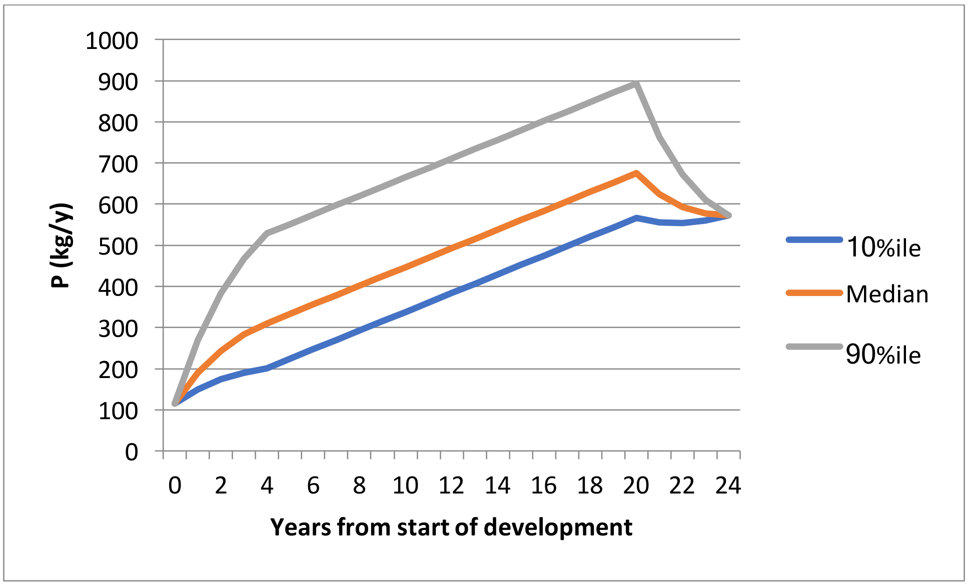
4.3 PREDICTED EFFECTS ON LAKE ROTOKAURI WITHOUT APPROPRIATE EROSION AND SEDIMENT CONTROLS

The above predicted annual N and P loads were used as input to SLAM using the same 2009 hydrologic data. Rainfall in 2009 was very close to the long-term median (Chapple 2011). Whilst it is likely that flows would be significantly less than 2009 flows under the 10%ile scenario and significantly more under the 90%ile scenario we have assumed that only nutrient loads will change.

The predicted average annual chlorophyll *a* levels in the lake as a consequence of the range of loads (10%ile, 50%ile, and 90%ile) over 20-year development scenarios presented in Figure 6 is shown in Figure 7.

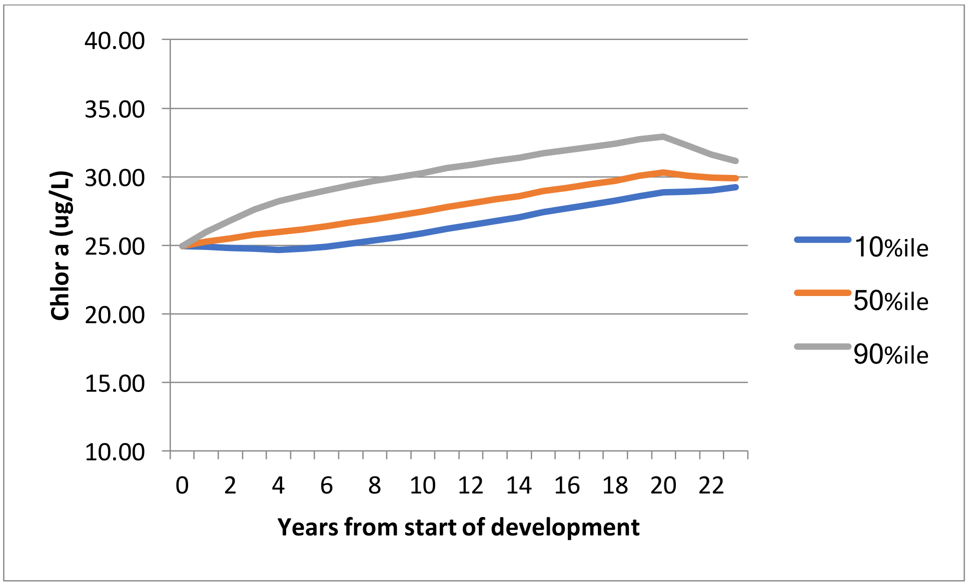
Figure 6: Predicted N (top) and P (bottom) loads from the main development area with a 20-year development period





Our SLAM model predicts that average annual phytoplankton concentrations will increase in the lake during development (without treatment) under all load (10-90%ile) and development (10 or 20 years) scenarios. Under median (most likely) conditions we predict that chlorophyll *a* could increase from the current 25 µg/L to a maximum 31.5 µg/L (10-year development) and 30.3 µg/L (20-year development). Whilst this level of increase would probably not be noticeable to the casual observer it still constitutes deterioration, which is contrary to the policy directive. It will therefore be necessary to treat sediment-laden runoff to ensure lake water quality does not deteriorate, and if possible, improves.

Figure 7: Predicted annual average chlorophyll *a* concentrations in Lake Rotokauri for different nutrient loads over a 20-year development period.



5 PREDICTING THE EFFECTS OF STORMWATER TREATMENT

5.1 DEVELOPING URBAN CATCHMENT

To assist with the selection of erosion and sediment controls (developing catchment) and stormwater treatment devices (mature urban catchment), we modelled the effects of various levels of treatment to predict the actual loads entering the lake. These were in turn used as input to SLAM to predict the resulting annual average phytoplankton concentrations. From the analysis of likely treatment efficacy carried out by DSL (2012) we chose 3 different levels of treatment, viz; 50%, 70%, and 90% treatment. As before, modelling was done for three different scenarios of nutrient load generation, being low (10%ile), likely (median), and high (90%ile). Because the 20-year scenario is the most likely, and that the difference between 10 and 20-year scenarios previously were mainly due to timing, we made the decision to model treatment options for the 20-year scenario only.

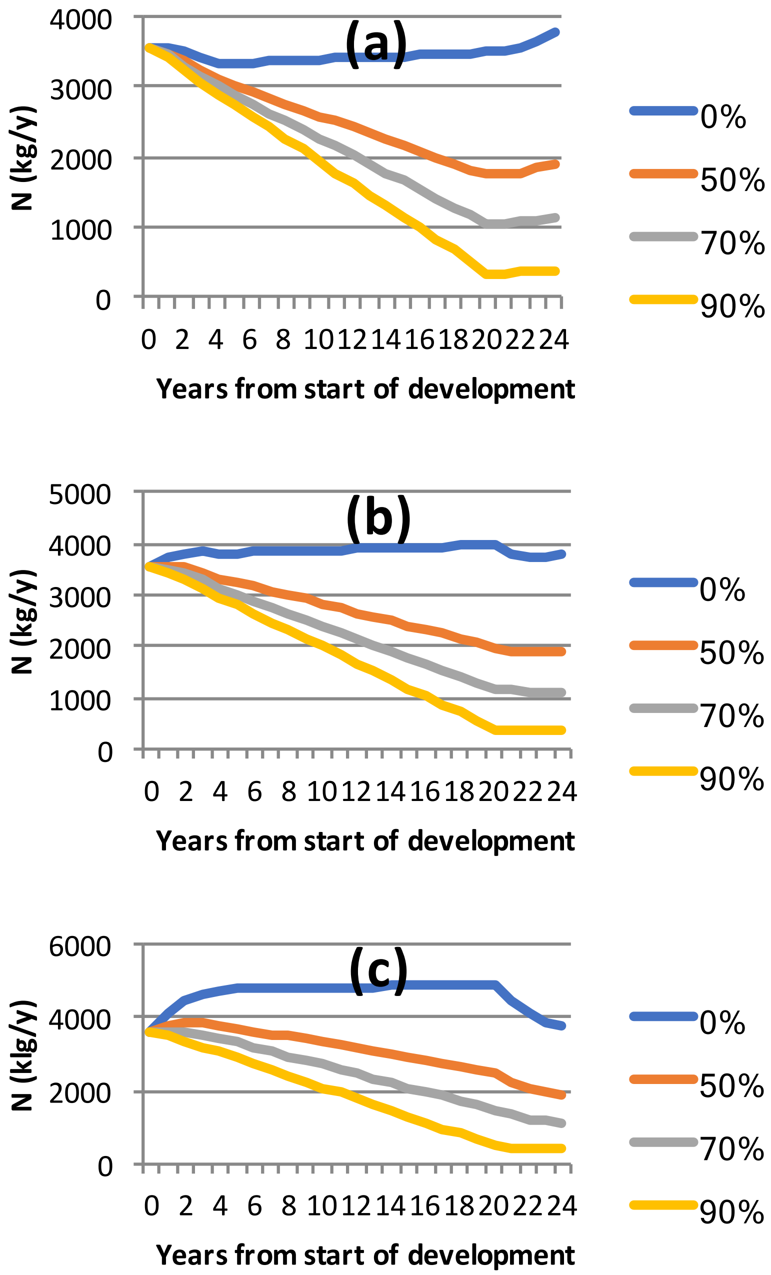
The predictions of N and P loads associated with different levels of treatment are given in Figures 8 and 9. The predicted annual average chlorophyll *a* concentration in the lake are given in Figure 10.

We predict that N loads will decrease well-below current levels with even 50% treatment Figure 8. In contrast, P load will still be greater than current levels with all except 90% treatment (Figure 9). These results are consistent with the conclusions of DSL (2012) that N loads would decrease but that P loads would increase “despite an expected 61% removal in urban infrastructure”. We have shown that between 70 and 90% removal is necessary to affect a net decrease.

However, the important environmental effect of concern here is the trophic state of the lake. Our SLAM modelling (Figure 10) shows that for both median and 90%ile base loads, a treatment efficiency >70% should result in predicted annual average chlorophyll *a* concentrations at or below current levels.

The above results indicate that phosphorus is the key nutrient to target with stormwater treatment, and that provided at least 70% removal can be achieved during the development phase of urbanisation, lake water quality should not deteriorate and may even improve.[9]

Figure 8: Predicted N load from structure plan area with a range of stormwater treatment efficiencies (given in legend) for (a) 10%ile, (b) median, and (c) 90%ile base loads



[9] The development of stormwater treatment solutions was beyond the scope of this work. However, the application of appropriately selected erosion and sediment controls throughout catchment development, including flocculation, is considered imperative.

Figure 9: Predicted P load from structure plan area with a range of stormwater treatment efficiencies (given in legend) for (a) 10%ile, (b) median, and (c) 90%ile base loads

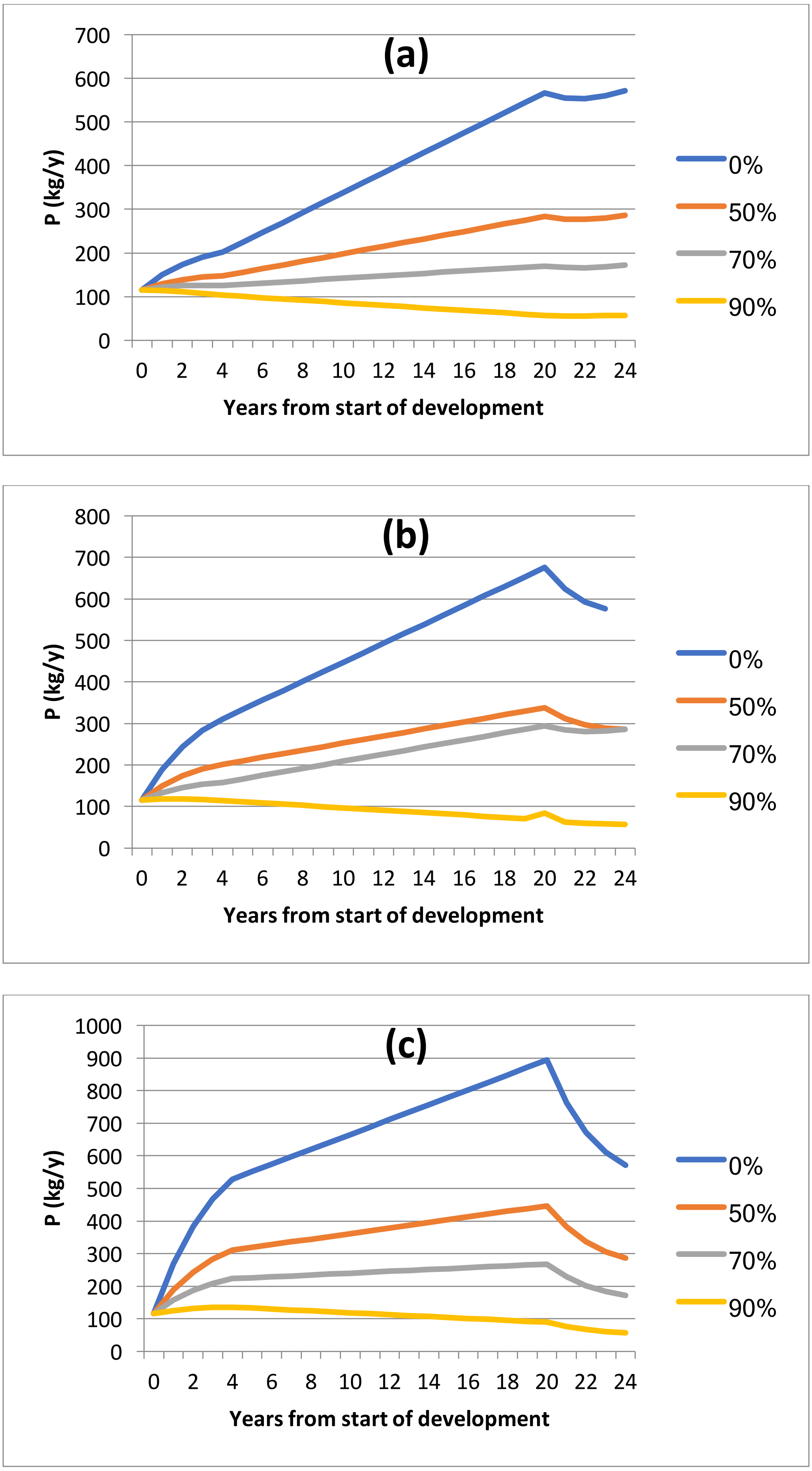
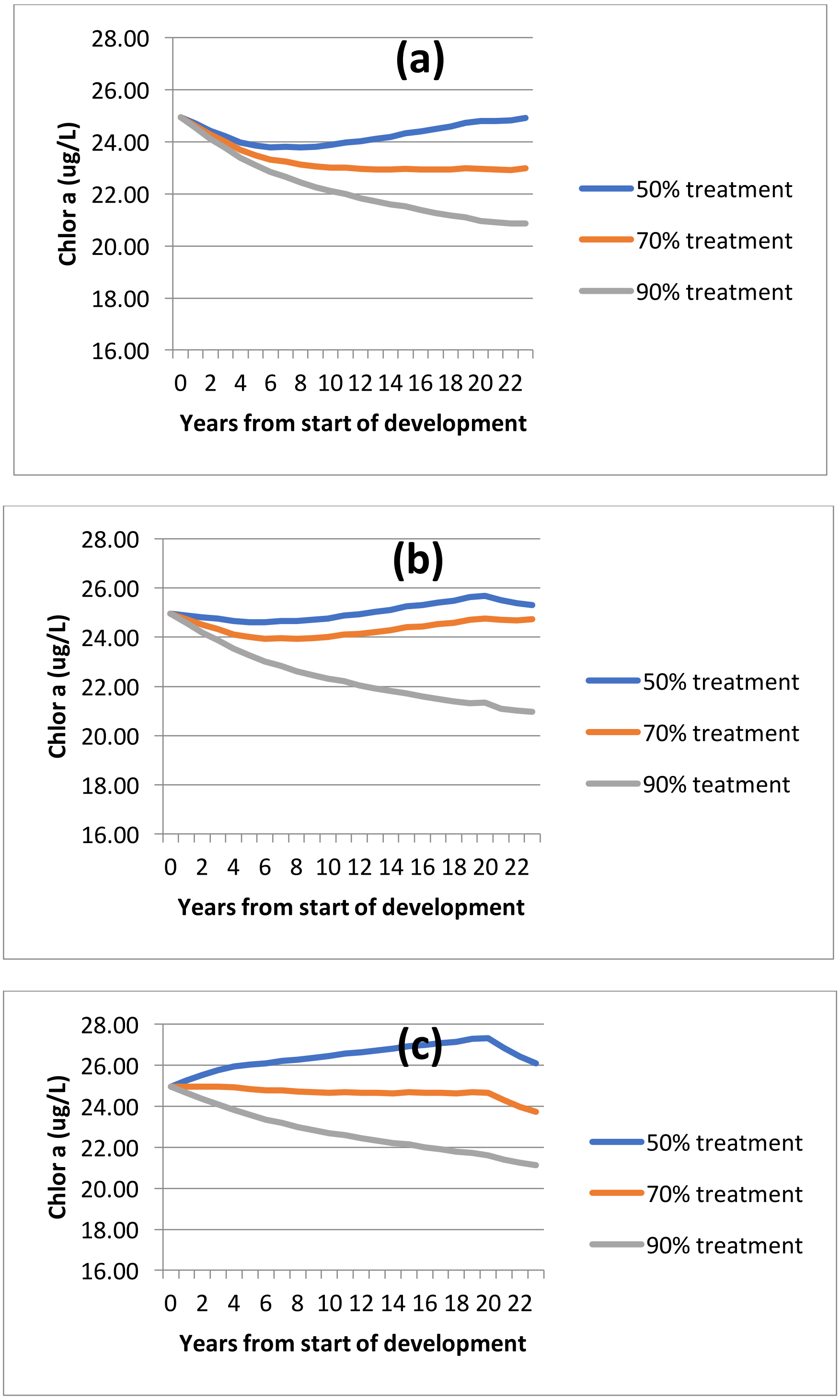


Figure 10: Predicted average annual chlorophyll a concentrations in Lake Rotokauri as a consequence of stormwater treatment (given in legend) following 10%ile (a), median (b) and 90%ile nutrient load inputs (defined in text)



5.2 MATURE URBAN CATCHMENT

For the developing urban catchment, we estimated the effects on Lake Rotokauri as the 'endpoint' in simulating a development sequence whereby sediment transport (and hence N and P loads) decreased by 25% per year following initial clearing of the site. The 'endpoint' of this simulation was very close to the values that DSL (2012) estimated for a mature mainly residential catchment, such as envisaged at Rotokauri (8.9 kg N/ha/y, and 1.2 kg P/ha/y). These estimates were derived initially from Williamson's (1993) Urban

Water Quality Databook[10]. This databook is currently under revision and whilst it is not yet published the authors have released their recommended estimates, which are presented as event-based percentile concentrations. The new urban water databook will state that for phosphorus; *"The New Zealand and global median were similar and used to recommend a median of 0.300 mg/L for use in New Zealand. The value is lower than that recommended by Williamson (1993); 0.420 mg/L, and reflects more recent collations of data (Smullen 1999, Mitchel 2014; Duncan 1999). We recommend using the 10th and 90th percentile of the international dataset (0.100 and 1.100 mg/L; n = 454) for New Zealand."* (S Trowbridge, B Williamson, pers. comm. 2015). *Similarly, for nitrogen "we recommend a median value of 1.98 mg/L and the 10th and 90th percentiles (1.00 and 3.50 mg/L) for use in New Zealand (the latter being c.75th percentile of the international dataset)".*

We used the average annual flow at Rotokauri Drain for 2009 (2009 being close to the long-term average rainfall for Hamilton (Chapple, 2011)) to calculate the estimated specific yield for each of the recommended percentile values. These values are given in Table 6.

Table 6: Specific yields (kg/ha/y) of N and P calculated from recommended values in new urban water databook (S. Trowbridge, B Williamson, pers. comm.).

Nutrient	10%ile	Median	90%ile	DSL (2012)
Nitrogen	3.5	6.9	12.2	8.9
Phosphorus	0.35	1.0	3.8	1.2

We used the above 10%ile, median and 90%ile yields as input to SLAM. The results are presented in Table 7.

Table 7: Predicted Lake Rotokauri Water Quality (annual mean) arising from a mature urban catchment using the input values in Table 6

Measure	10%ile	Median	90%ile
TN (mg/L)	1.02	1.07	1.15
TP (mg/L)	0.06	0.07	0.11
Chlor a (µg/L)	26.0	28.1	33.9

The predicted average annual chlorophyll *a* concentration in the lake as a function of stormwater treatment efficiency is shown in Table 8.

By comparing Table 7 with Table 8 we predict that even 50% treatment efficiency will reduce chlorophyll *a* levels in the lake from the mature urban catchment compared with no treatment. However, compared with current levels (annual average of 25 µg/L measured in 2009) we predict that at least 70% stormwater treatment efficiency would

[10] Williamson RB. 1993. Urban runoff data book. Water Quality Centre Publication No. 20. Hamilton, DSIR Marine and Freshwater.

be required to maintain or slightly reduce lake chlorophyll *a* levels in the most likely (median load) scenario.[11]

Table 8: Predicted annual average chlorophyll *a* concentrations in Lake Rotokauri as a function of stormwater treatment efficiency

Treatment	10%ile	Median	90%ile
50% treatment	24.6	25.9	29.9
70% treatment	23.9	24.9	27.8
90% treatment	23.5	23.9	25.1

6 CONCLUSIONS

- Water quality targets need to reflect the Vision and Strategy of the Waikato River, which is to restore and protect the Waikato River. Maintaining the current state is not consistent with the Vision and Strategy.
- Based on model outputs, N and P (particularly P) are the major contaminants that will require mitigation during and post development. Phytoplankton concentrations in Lake Rotokauri will increase both during the development phase and as a result of runoff from the mature catchment without appropriate erosion and sediment controls and stormwater treatment. Our modelling suggests that treatment efficiency of at least 70% will be necessary to avoid further degradation. Any improvement on this efficiency could lead to a modest improvement of water quality (less phytoplankton), which would satisfy the policy intent.
- Changes in nutrient load inputs are predicted to have a greater effect on lake water quality than changes in catchment hydrology.
- Concentrations of most typical/priority and emerging urban-derived contaminants (i.e. metals, POPs, PBDEs, wastewater markers) were below guideline values (for both applicable sediment-associated and dissolved forms) above which ecological effects would be expected, other than for zinc in Lake Rotokauri sediment and Rotokauri Drain (dissolved).
- The use of best practice treatment devices will further ensure that urban derived zinc concentrations are maintained at a practicable minimum, and will not exceed applicable guidelines.
- Lake Rotokauri is a sink for many metals, with dissolved concentrations generally much lower downstream than upstream of the lake.

[11] The development of stormwater treatment solutions was beyond the scope of this work. However, a stormwater treatment concept has subsequently been developed which includes sub-catchment scale wetlands in conjunction with upstream source controls for enhanced phosphorus removal (Morphum Environmental Ltd, 2016).

- Aquatic metal guidelines should be retained and the target should be that water quality targets for all receiving waters be set to meet both acute and chronic effects.

ACKNOWLEDGEMENTS

We acknowledge Hamilton City Council for their support of this study, and the other partners in the ICMP process (AECOM, Morphum Environmental Ltd, Kessels Ecology and CH2M Beca) for useful interaction.

REFERENCES

ANZECC (2000). Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Volume 1. Australian and New Zealand Environment and Conservation Council, Agriculture and Resource Management Council of Australia and New Zealand. Canberra, Australia.

Barnes, G. (2002). Water Quality Trends in Selected Shallow Lakes in the Waikato Region, 1995-2001. *Environment Waikato Technical Report 2002/11*, 31p.

CDM Smith (2012). Simplified Lake Analysis Model (SLAM). Version 2.0. User's Manual.

Chapple, P.R. (2011). Climate and weather of Waikato. NIWA Science and Technology Series No. 61 http://www.niwa.co.nz/static/Waikato%20ClimateWEB.pdf

Cooke, J.G. (1988) Sources and sinks of nutrients in a hill pasture catchment – II Phosphorus. Hydrological Processes 2:123-133.

Cooke, J.G. (2010) Effects of urbanisation of the Rotokauri Catchment on nutrient loads. Phase 3 Report Rotokauri Stream Monitoring and Load Calculations. Diffuse Sources Ltd report to Hamilton City Council 14p.

Cooke, J.G., Cox, T., Stewart, M., Philips, P. (2015). Rotokauri ICMP – Broad scale water quality assessment. Streamlined Environmental Ltd Report to Hamilton City Council 64p.

Dean-Speirs, T. and Neilson, K. (2014a). Waikato region shallow lakes management plan: Volume 1. Objectives & strategies for shallow lake management Waikato Regional Council Technical Report 2014/58.

Diffuse Sources Ltd (2012). Effects of urbanisation of the Rotokauri catchment on nutrient loads Phase 4 Predicted changes to nutrient loads after implementation of structure plan. July 2012.

Edwards, T., Clayton, J., & de Winton, M. (2007). The Condition of 41 Lakes in the Waikato Region Using LakeSPI. *Environment Waikato Technical Report 2007/35*, 54p.

Elliott, S., Parshotom, A., Wadhwa, S. (2010) Tauranga Harbour Sediment Study: Catchment Model Results. NIWA Client Report 2009-046 (Amended May 2010) For Bay of Plenty Regional Council 36 pp.

Long, E.R., Bin, C., Smith, S.L., Calder, F.D., (1995). Incidence of Adverse Biological Effects Within Ranges of Chemical Concentrations in Marine and Estuarine Sediments. Environ. Manag. 19, 81–97.

Sharma, A. (2011) A modelling approach to assist with managing water quality in a catchment subject to rapid urbanisation: Lake Rotokauri, Hamilton, New Zealand. MSc thesis University of Waikato, 87p.

Stewart, M., Cameron, M., McMurtry, M., Sander, S., Benedict, B., Graham, L., Hosie, M. (2016). Development of passive sampling devices for analysis of bioavailable contaminants of current and emerging concern: Waitemata Harbour Case Study. New Zeal. J. Mar. Freshw. 50:526-548.

Tonkin & Taylor (2014). Comprehensive Stormwater Discharge Consent 105279 2013/14 Monitoring Report. Report prepared for Hamilton City Council. June 2014. 74p.