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Modelling Nutrient Loads in the Waikato and Waipa River Catchments

Development of catchment-scale models

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Prepared by:
Annette Semadeni-Davies, Sandy Elliott, Sharleen Yalden
(NIWA

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Waikato Regional Council
Private Bag 3038
Waikato Mail Centre
HAMILTON 3240

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Authors/Contributors:
Annette Semadeni-Davies
Sandy Elliott
Sharleen Yalden

For any information regarding this report please contact:

Sandy Elliott
Programme Leader
Freshwater Quality
+64-7-859 1839
Sandy.Elliott@niwa.co.nz

National Institute of Water & Atmospheric Research Ltd
PO Box 11115
Hamilton 3251

Phone +64 7 856 7026

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	Reviewed by:	Neale Hudson Group Manager, Catchment Processes
	Formatting checked by:	Alison Bartley
	Approved for release by:	David Roper Regional Manager, Hamilton

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Executive summary

This study is one of a suite of technical studies commissioned through the Healthy Rivers / Wai Ora Technical Leaders Group (TLG). The report describes two nutrient load models that were developed to provide input data to an economic model. The latter evaluates the costs associated with mitigating farm practices to reduce nutrient loads. The Waikato River catchment was divided into 74 sub-catchments, each representing the contributing area draining to a corresponding node or site. For all but ten sites, nutrient concentrations are routinely measured.

This report also describes model input and calibration data, the methods used to determine median annual nutrient concentrations and mean annual loads from monthly water quality sampling data, and sources of model uncertainty.

Nutrient load modelling

The nutrient instream load models for TN and TP are very similar in terms of their input data requirements, model set up and calculation methods. The models, particularly the TN model, make considerable use of tacit knowledge, provided by an expert panel at two workshops hosted by NIWA (see Appendix I and Appendix J). In both models, nutrient losses from point sources (including geothermal TN and sediment P) are discharged directly to the stream network. Nutrient losses from diffuse sources are calculated as a function of land use and the source yields associated with these land uses. The source yields were provided for this study by the University of Waikato and were derived from Overseer modelling. Losses from pastoral and horticultural sources are subject to catchment attenuation prior to reaching the stream network. Once within the stream network, instream loads are routed downstream (within the model) using a set of matrices which describe the connectivity of the drainage network including groundwater recharge and discharge for TN. The instream loads are subject to reservoir attenuation in sub-catchments where there are large lakes or hydro-power dams.

The models were calibrated against loads estimated from TN and TP concentration measurements. These loads were calculated for monitoring sites with paired flow data using a rating curve method, the loads for all the other sites were determined using modelled mean annual flows.

Two sets of attenuation values were determined for the TN instream load model; an *apparent* attenuation, and an expected attenuation, selected after consideration of all the information available, referred to as the *ultimate* attenuation. The difference between the two attenuation factors accounts for time lags between leaching of nitrogen from diffuse sources into groundwater, and the subsequent release of that nitrogen from groundwater storage into the stream network. The apparent attenuation was determined using an iterative process whereby the factor was first calibrated against the TN loads estimated from measurements and then assessed and adjusted using *a priori* knowledge of attenuation in the sub-catchment.

TP catchment attenuation factors were calibrated against TP loads estimated from measurements and were not further adjusted.

Concentration estimation

There are eight nodes (sites that represent eight sub-catchments) in the study area where nutrient concentrations are not currently measured. Estimates of the current and future (i.e., scenario) annual median TN, nitrate-N and TP concentrations and 95th percentile nitrate-N concentrations at these sites are required for the economic optimisation model. Models were developed to predict nutrient concentrations for the monitored sites, and these models were then used to estimate nutrient concentrations in the unmonitored sub-catchments.

Regression models were developed to estimate median annual TN and nitrate-N, and 95th percentile annual nitrate concentrations, respectively, for sites where nutrients are not currently sampled. A regression approach was not used to estimate median annual TP concentrations, which were back-calculated from the loads estimated from measurements instead.

TN load model results

The TN model is able to predict instream TN loads well with a coefficient of determination (R^2) of 0.98 and a Nash-Sutcliff efficiency (NSE) of 0.97. Key findings are:

- All of the sub-catchments have an estimated TN load within 20% of the measured load, with one exception.
- The greatest proportional difference between the measured and estimated loads and yields is observed in the Whakauru sub-catchment. The hydrology of this area is complex and it is suggested that there could be significant bypass of groundwater between Whakauru and its neighbouring sub-catchments that is not captured by the model.
- Several sub-catchments in the Waipa River catchment have modelled TN losses that are too low to account for the increase in measured load observed. This may be caused by an inability of Overseer to simulate nutrient loss from karst landforms adequately.
- The model estimates of source yields for sub-catchments downstream of Waikato at Rangiriri (e.g., Whangamarino at Island Block Rd and at Jefferies Rd Br, and Whakapipi, Whangape, Waikare) seem to be too low, leading to some underestimation of TN loads for these sub-catchments.
- The TN load in the Waiotapu at Campbell sub-catchment is underestimated by around 55% which could be due to an underestimation of the nitrogen input from geothermal sources in this sub-catchment.

TP load model results

The model is able to predict TP instream loads well with both the R^2 and NSE having a value of 0.93. Predictive ability was best for main-stem locations, but there was more error in predicting yields in tributary sub-catchments. Key findings are:

- Around half of the sub-catchments have TP losses from pastoral sources which are too low to account for the incremental increase in loads estimated from measurements. In these cases, underestimation of TP losses results in underestimation of the TP instream load for the sub-catchment. Several of these sites are associated with peat soils. Other underestimation may be due to P sources in deep old groundwater in the Taupo pumice areas, and under-estimation of P sources from steep areas in the Waipa catchment.

- In contrast, the pastoral TP losses in other sub-catchments are overestimated relative to the incremental increase in loads estimated from measurements, causing overestimation of instream loads.
- While the proportional differences in loads predicted for the tributary sub-catchments can be fairly large, the absolute differences are low relative to the instream loads measured at the main-stem sites.
- The model fit for main-stem sub-catchment TP yields is regarded as reasonable, mainly due to the cumulative compensation of under and overestimation of loads from tributary sub-catchments as the loads are routed downstream.

Sources of model uncertainty

Several sources of model error and uncertainty were identified:

- Under- or overestimation of source yields for land uses represented in the model by Overseer.
- Errors in the calibration data, e.g., due to sampling or analysis, and use of data that were not purpose-collected for the study. Moreover, the use of modelled mean annual flows to estimate loads in sub-catchments where flow data are not recorded also introduces error.
- Uncertainties in point source data, estimates of geothermal nitrogen and sediment-P.
- Spatial and temporal scaling issues.

Recommendations for further work:

- **Calibration and validation**: The models have been calibrated against estimates using monitored nutrient data, but have not been validated. Continuation and expansion of nutrient monitoring within the catchment will provide further model test and calibration data. Water quality monitoring should be concurrent with flow monitoring where possible to allow for more accurate load calculation.
- **Point sources:** The models should be updated through time to include new or changed inputs from point sources. Additionally, sources of geothermal nitrogen and sediment-bound phosphorus should be re-assessed to improve yield estimates for these sources.
- **Dynamic modelling:** Dynamic nutrient modelling in the catchment at the river reach-scale is likely to provide a better understanding of the temporal processes in operation, as well as a better representation of those processes.

1 Introduction

1.1 Preamble

Waikato and Waipa River iwi and the Waikato Regional Council (WRC) are partners in the project "Healthy Rivers: Plan for Change / Wai Ora: He Rautaki Whakapaipai" (HR/WO). This project has the objective of identifying and implementing changes to the Waikato Regional Plan that will help restore and protect the health of the Waikato and Waipa Rivers, which are key to a vibrant regional economy. These protection and restoration objectives are set out in settlement and co-management legislation for the Waikato and Waipa Rivers. The plan change will, over time, help reduce sediment, bacteria and nutrient (nitrogen and phosphorus) inputs to water bodies (including groundwater) in the Waikato and Waipa River catchments.

The total nitrogen (TN) and total phosphorus (TP) instream load models presented here are part of a suite of technical studies that have been commissioned through the HR/WO Technical Leaders Group. These assessments provide information on the current state of the streams and rivers, sources of contaminants, catchment modelling to determine how contaminants accumulate and move through the catchment, and economic catchment modelling to determine the cost of meeting water quality goals and targets.

1.2 Scope

This report describes the development of two catchment-scale models for predicting the mean annual instream loads of TN and TP in the Waikato River catchment. The models are used to estimate nutrient concentrations in the catchment for various future land use and mitigation scenarios.

This information will in turn inform the Farm Costs Model (FCM) being developed by the University of Waikato in order to investigate the economic impacts of changes in land use, farm practices and implementation of mitigations designed to improve water quality. The models build on previous work carried out for the Waikato River Joint Economic Joint Venture study (EJV; Doole, 2013; Elliott *et al.*, 2013). The report also discusses sources of model uncertainty and gives recommendations for further work. Additionally, background material used to develop and calibrate the models are provided in a series of appendices.

2 Methodology

This section presents an overview of model input and calibration data followed by descriptions of the instream load models and the concentration model.

2.1 Input data

2.1.1 Drainage network and monitoring stations

The study catchment area extends from Taupo Gates to Port Waikato inclusive of the Waipa River catchment. The area was divided into 74 sub-catchments for modelling purposes by aggregating River Environments Classification (Snelder *et al.*, 2010) drainage units between selected sites located along the drainage network (see Appendix A and Figure 2-1). Each sub-catchment represents the contributing area draining to its corresponding site. Most of the sites are water quality monitoring stations where nutrients are recorded as part of State of the Environment (SOE) reporting. There are, however, 10 sites where river water quality is not currently sampled. Three of the 10 sites — Waikato at Port Waikato (catchment terminal reach), Waikato at Karapiro, and Waipa at Waingaro Rd Bridge — represent the Waikato River mouth, the outlet of Karapiro Dam and the confluence of the Waipa and Waikato Rivers at Ngaruawahia, respectively, and are included as they are locations of interest, being terminal points of Freshwater Management Units. Concurrent flow data, required to calculate instream loads for model calibration, are available at or near 28 of the sites. Estimated annual mean flows have therefore been taken for the other sites from the model of Woods *et al.* (2006) which calculates the annual flow within a reach as a statistical function of annual rainfall and potential evapotranspiration and catchment characteristics.

Additionally, data from Waikato at Reid's Farm (NAT-RO06) near the inflow to the study area within the Ohaaki sub-catchment are used to provide flow and nutrient load data to represent input from Lake Taupo.

The instream load models include reservoir attenuation or decay terms for sub-catchments containing large lakes or reservoirs (Table 2-1); these are either hydro-lakes subject to flow regulation or shallow lakes located in the lower Waikato River catchment.

Table 2-1: Large reservoirs in the Waikato River catchment.

Type	Subcatchment	Reservoir
Hydro lake	Waikato at Ohaaki	Lake Aratiatia
	Waikato at Ohakuri	Lake Ohakuri
	Waikato at Whakamaru	Lake Whakamaru Lake Atiamuri
	Waikato at Waipapa	Lake Maraetai Lake Waipapa
	Waikato at Karapiro	Lake Karapiro Lake Arapuni
Shallow lake	Awaroa (Rotowaro) at Harris/Te Ohaki Br	Lake Waahi
	Whangape	Lake Whangape
	Waikare	Lake Waikare

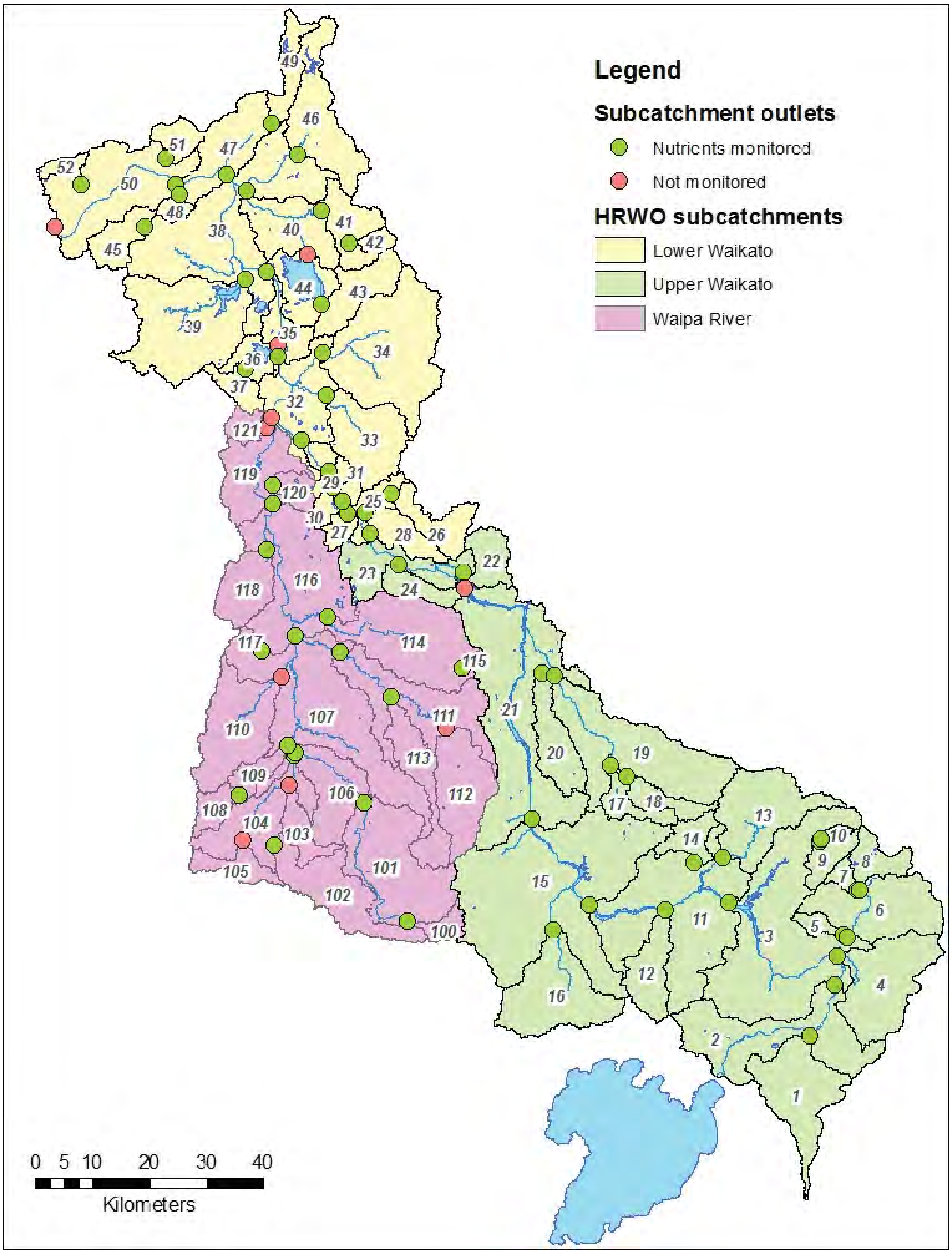


Figure 2-1: Sub-catchments and their associated monitoring sites. Catchment names are listed according to the map reference number in Table 2-2.

2.1.2 Land use

Regional land use data were supplied for this project by WRC as a polygon shapefile with the same land use classes as those used in the CLUES model (Figure 2-2). These land uses were reclassified into five land use classes by the University of Waikato (contact Graham Doole) to be compatible with the FCM, namely: dairy; dairy support; sheep and beef; forestry (i.e., plantation forest), urban, horticulture and miscellaneous (i.e., all other land uses). The breakdown of land uses by sub-catchment is given in Appendix B.

The main land uses in the study area (Table 2-2) are dairy, sheep and beef, native forest and forestry. Dairy dominates in the Waipa and Lower Waikato catchments. Native and plantation forest is mainly located in the south-eastern Upper Waikato catchment area. Urban areas account for 3%, with Hamilton being the largest centre.

Table 2-2: Summary of land use in the study area.

Land use class	Proportional cover (%)	Area (km^2)
Dairy	22	2464.1
Dairy support	6	616.0
Sheep and beef	34	3703.6
Horticulture	1	61.0
Forestry	15	1694.8
Urban	3	344.2
Miscellaneous (e.g., native forest, scrub, cropping)	19	2139.0
Total		11022.6

2.1.3 Point sources, geothermal TN and Sediment-P

WRC estimated annual nutrient loads from point sources located in the study area (Appendix C, Table C-1), such as waste water treatment plants, abattoirs and dairy factories (Vant, 2014). These are added as model inputs for the sub-catchments within which the sources are discharged respectively. The point sources do not include leachate from effluent that is discharged to land (i.e., spray irrigation).

Geothermal sources of TN (Appendix C; Table C-2) were estimated from nitrogen concentrations and flow rates given in (Gibbs, 1987). Note that because a single load was given in Gibbs for the Waiotapu Stream, the load was split between Waiotapu at Campbell and Waiotapu at Homestead as both sub-catchments are likely to have geothermal nitrogen sources. Additional geothermal nitrogen was added to Waikato at Ohaaki on the assumption that there are unmonitored geothermal inputs in this sub-catchment such as the Tauhara field opposite Wairakei.

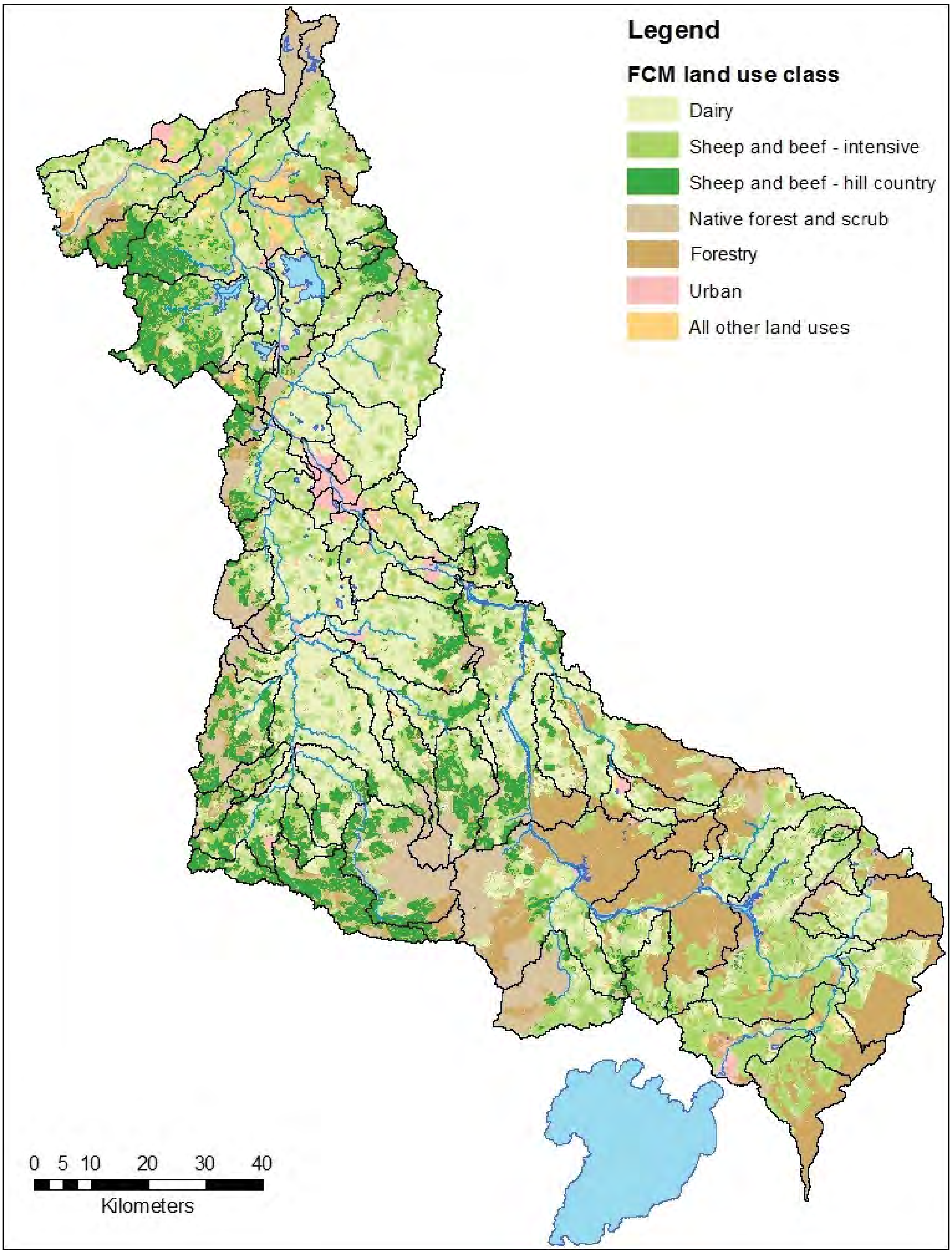


Figure 2-2: Land use from WRC classified into FCM classes. Maize, horticulture and miscellaneous land use classes have been amalgamated for display. Hill country sheep and beef also included a small area of high country sheep and beef.

Sediment loads generated in each sub-catchment are used in the TP model to estimate phosphorus losses from soil due to mass erosion (i.e., sediment-P). The sediment loads used in this study were provided by Landcare Research[1] and were estimated using the New Zealand Empirical Erosion Model (NZEEM). An application of this model to the Waipa River catchment is described in Palmer *et al.* (2013). Since the Overseer model used to assign the baseline yields already includes some sediment-P losses, the sediment load reported in Appendix D was adjusted by first calculating the sub-catchment sediment yield and then reducing this by 34 t/km^2.[2] Sub-catchments with yield below this threshold were assumed to have no extra sediment-P. The sediment-P load is calculated for each sub-catchment by multiplying the adjusted sediment load by an average phosphorus mass concentration of 15 kg/t sediment (see Appendix E).

2.2 Calibration data

This section presents the methodology used for determining the instream annual median nutrient concentrations and mean annual loads from monthly water quality data from the monitoring stations listed above. These data were obtained from NIWA's National Rivers Water Quality Network (NRWQN) database and WRC. Mean concentrations were determined for each of the stations. Instream nutrient loads estimated for Reid's Farm in the Waikato at Ohaaki sub-catchment are used as model inputs to represent loads from Lake Taupo. The calibration data are listed in Appendix F and Appendix G for concentrations and instream loads respectively. It should be recognised that these calibration data have uncertainty (see Section 4).

2.2.1 Annual median concentrations

Median TN and TP concentrations and median and 95th percentile nitrate-N concentrations were calculated for the sites where water quality is monitored. These are listed in Table F-1. It is known that nutrient concentrations have been slowly trending upward over time in the study area due to intensification of land use and farm practices. Accordingly, it had been intended to calculate long-term (2-year) de-trended median concentrations (similar to those used for nutrient modelling in Elliott et al. 2013) for sites with sufficiently long data records. However, there were concerns that the de-trending method may introduce error into the calculation. To avoid the effects of both trending data and de-trending smoothing errors, five-year median concentrations, calculated for the period from January 2010 to December 2014 from raw (not de-trended) data, were used for this study. The exceptions are Otamakokore, Waiotapu at Campbell and Waiotapu at Homestead where there were insufficient data over the five-year period to calculate the median concentration for TP; for these sites, the 2-year median TP concentrations are used instead.

In addition, TN and TP median concentrations for Lakes Waikare and Waahi, supplied by WRC[3], were used as proxy concentration data for the Waikare and Awaroa (Rotowaro) at Harris/Te Ohaki Br sub-catchments respectively.

2.2.2 Mean annual instream loads

Two calculation methods were used to determine the measured mean annual instream nutrient loads: a rating curve and a ratio method. Where possible, the rating curve method was used in preference to determine instream loads from water quality monitoring sites, using concurrent flow data from the nearest flow monitoring station. This method determines mean loads from instream

[1] Model run provided as part of the HR/WO programme (contact John Dymond)
[2] This value was calibrated concurrently with the estimation of the attenuation factor (Section 2.3.2) using the Solver tool by minimising the total difference between modelled loads and those estimated from measurements.
[3] Bill Vant, personal communication, 3 June 2015

loads calculated for each monthly water quality sampling event from the recorded nutrient concentration and flow data. The ratio method was used to estimate instream loads for sites where suitable flow data did not exist from estimated mean annual flow rates (Woods et al., 2006) and the median annual concentration described above. These methods are described in more detail below.

Rating curve method

Measured mean annual instream nutrient loads were estimated using a rating-curve method at sites where there were sufficient concurrent flow data at, or nearby, the site. In this method, a rating curve is fitted to the natural log of measured monthly nutrient concentrations against the natural log of the flow rate using the following equation:

$$\ln(C) = s(t) + s(\ln(Q)) + a\sin(2\pi t) + b\cos(2\pi t) \quad (1)$$

Where C is the nutrient concentration, s is a cubic spline smoothing function, Q is the flow at the time of the sample, t is time (in years), and a and b are coefficients. Cubic spline smoothing from the R statistical package was used, with effective degrees of freedom fixed at two to restrict curvature. Equation (1) was applied to the hourly flow time-series over the period of the flow record to derive a time-series of concentrations, which was then multiplied by flow and summed to give the mean annual instream load. To account for retransformation bias, the load was adjusted using the non-parametric smearing factor of (Duan (1983)).

The suitability of the rating curve derived instream loads for model calibration were assessed by generating confidence intervals (9%) and standard deviations for the mean annual instream loads by repeating the rating curve procedure using a boot-strapping approach. This approach repeatedly took random samples of the original water quality data and estimated the mean annual instream load for each of these. On the basis of this assessment, the rating curve-derived instream loads for all the monitoring sites with flow data were accepted for model development.

Ratio method

Measured instream nutrient loads for the sites without concurrent flow data were estimated using the ratio method from the median annual TN and TP concentrations respectively and estimated mean annual flow for the site taken from the model of Woods et al. (2006).

In this method, the median concentration was multiplied by a statistical factor to convert it to a flow-weighted concentration, and this was then multiplied by the estimated mean annual flow to derive the instream load estimate. The TN and TP conversion factors for the reaches where the monitoring sites are located were taken from the CLUES model and are listed in Appendix H. The derivation of the factors is discussed in Oehler and Elliott (2011).

2.3 Nutrient instream load models

The nutrient instream load models are very similar in terms of their input data, model set up and calculation methods. The models, particularly the TN model, make considerable use of tacit knowledge, provided by an expert panel at two workshops hosted by NIWA (see Appendix I and Appendix J). This knowledge guided the choice of model structure, including which processes are included and how they are represented or parameterised.

In both models, loads from point sources and from geothermal TN and sediment P (Section 2.1.3) are added to loads calculated from diffuse sources (i.e., leaching losses less catchment attenuation) to give a total sub-catchment load which is discharged to the stream network. Once within the drainage network, instream loads are routed downstream using a set of matrices which describe the connectivity of the sub-catchments with respect to both surface drainage and groundwater.

Leaching losses from diffuse sources within a sub-catchment are calculated for each source as the product of the source area and the source's associated TN or TP yield, derived using Overseer from the baseline scenario provided by Graeme Doole from the University of Waikato for this study. Leaching losses from pastoral and horticultural sources are multiplied by a catchment attenuation factor to give a load estimate which is added to the instream load. This includes subsurface attenuation and attenuation in small streams, but not attenuation in hydro reservoirs or the river main-stem. The estimation of catchment attenuation is discussed for each nutrient separately in Sections 2.3.1 and 2.3.2.

A fraction of the TN leaching loss is diverted to groundwater recharge in some sub-catchments (see Appendix A). Whether leaching loss to groundwater occurs in a sub-catchment and, if so, the fraction of surface runoff diverted, was determined from a water balance analysis undertaken by GNS for the HR/WO programme (personal communication Paul White, GNS), the results of which are summarised in Appendix J. The fraction of nitrogen transported via groundwater was assumed to be the same as the fraction of flow diversion, assuming that nitrogen is usually dissolved and there is an even distribution of recharge and nitrogen leaching. At this stage, groundwater is transported to the next sub-catchment in the stream drainage network and added to the instream load as a point source, although it is possible to divert ground water further afield within the model. Since the model is steady-state, it is also assumed that there is no groundwater attenuation or temporal lags. Instead, two sets of attenuation factors are determined which simulate the current and future expected instream loads.

Instream loads estimated for the sub-catchments listed in Table 2-1 are attenuated to simulate reservoir losses by multiplying the sub-catchment instream load by an attenuation factor. The reservoir attenuation factor for each lake, Att_{res}, is calculated for the outlet as:

$$Att_{res} = \frac{O_{res}}{(O_{res} + k_{res})} \tag{2}$$

Where O_{res}, the reservoir overflow (m/year), is calculated as the annual flow for the outlet reach divided by the lake area; and k_{res} is the reservoir settling coefficient for each of TN (10.26) and TP (33.31) respectively as determined by the CLUES model. In sub-catchments which have more than one lake, the sub-catchment attenuation factor is the product of the attenuation factors determined for each of the lakes.

2.3.1 TN catchment attenuation

Several key biophysical factors influence nitrogen mobilisation, attenuation and actual leaching rate losses. These factors are determined principally by catchment hydrology and hydrogeology, as well as land use. Many inter-related characteristics ultimately determine the nitrogen attenuation and loss within each sub-catchment. The data required to characterise catchment nutrient losses are not available at consistent temporal and spatial scales across all 74 sub-catchments in the Waikato and Waipa River catchments. Accordingly, a panel of experts was assembled to summarise key information for each sub-catchment (see Appendix J). This information was consulted extensively when setting nitrogen attenuation factors in particular.

Two sets of attenuation values were determined for the TN instream load model: an *apparent* attenuation calibrated against the measured instream TN loads, and an expected attenuation selected after consideration of all the information available, including the expert panel, opinion, henceforth referred to as the *ultimate* attenuation. The difference between the two sets of attenuation factors accounts for lags between leaching of nitrogen from diffuse sources and the release of that nitrogen from groundwater storage into the stream network. In sub-catchments with stable land use and little or no trend in observed instream TN concentrations and little or no leaching to groundwater, the two attenuation factors are the same. For sub-catchments assessed as having a load to come, the ultimate attenuation factor was assigned in accordance with the level of attenuation expected by the expert panel. In some cases, the factor was increased or reduced depending on the attenuation factors assigned to neighbouring sub-catchments. Whether a sub-catchment is expected to have a load to come or not was assessed by examining historical land use and leaching loss data as described by Hudson *et al.* (2015). This information is appended to Appendix J.

An iterative approach was followed to determine the apparent level of TN attenuation for each sub-catchment. The apparent attenuation factor was first calibrated for all the sub-catchments automatically using the Solver tool (GRG nonlinear) in EXCEL to minimise the sum of the absolute differences between the predicted and observed instream loads. The calibrated factors for each sub-catchment were then assessed against the information obtained during the workshops to see if the factors were credible. Where the calibrated attenuation factor could not be explained, the value was manually adjusted in line with the expected level of attenuation.

2.3.2 TP catchment attenuation

TP attenuation was estimated in a three step process using output from the CLUES model:

i. CLUES was run for the Waikato and Waipa River catchments downstream of Taupo Gates with point sources removed and reservoir attenuation set to zero. Two model runs were made: with the stream attenuation coefficient set to the CLUES nationally calibrated value, and with the coefficient set to zero.

ii. The TP loads estimated for the two model runs were extracted for the outlet reach of each sub-catchment. For non-headwater sub-catchments, the increase in the estimated loads for each sub-catchment was calculated by subtracting the instream loads from upstream sources. The ratio of the two incremental loads was then calculated and imported into the TP model. This was done to get a relative indication of the cumulative attenuation in each sub-catchment as determined by CLUES.

iii. The TP attenuation factor was estimated using a power relationship whereby attenuation is the load ratio determined for the sub-catchment outlet to the power of a calibrated exponent. The Solver tool in Excel was used to determine the exponent concurrently with the Overseer threshold for sediment-P.

The CLUES model attenuation was used here to add the losses from smaller streams that are not modelled explicitly at the catchment scale by the TP model. CLUES operates at the river reach scale and the ratio between the loads estimated in step ii for the sub-catchment outlet reaches will include the cumulative losses for all the reaches in the sub-catchment. Unlike those for the TN model, the TP attenuation factors determined for each sub-catchment were not adjusted manually for each individual sub-catchment.

2.4 Concentration estimation for unmonitored sub-catchments

There are eight sites where nutrient concentrations are not currently measured (10 sites overall minus two sites where lake concentrations were used as a proxy for stream concentrations). Estimates of the current and future (i.e., scenario) annual median TN, nitrate and TP concentrations and 95th percentile nitrate concentrations at these sites is required for the economic optimisation model. For this reason, models were developed to predict nutrient concentrations for the monitored sites. These models were then applied to the unmonitored sub-catchments to estimate nutrient concentrations.

2.4.1 TN and nitrate-N

Three regression models were developed which use the nutrient concentrations presented in Appendix F to predict TN, median nitrate-N, and 95-percentale nitrate-N concentrations as a function of catchment characteristics. These models were then used to predict the concentration of these forms of nitrogen at the sites for which no measurements exist. Data derived from Waikato River main-stem sites were excluded from development of the regressions because they are influenced by the hydro lakes and Lake Taupo outflow.

The models used predictors that were also used in the load model; they were of the form:

$$C = (1 + (c_l - 1)F_l)\big((c_D F_D + c_{SBI}F_{SBI} + c_{SBH}F_{SBH} + c_{Urb}F_{Urb} + c_T F_T + c_O F_O)\big) \quad (3)$$

where C is the concentration; F_l is the fraction of the upstream catchment that has poor to moderate drainage; F_D *to* F_O are the fractions of the upstream catchment used for dairy, intensive sheep and beef, hill or high country sheep and beef, urban, forest (native, scrub and exotic forest) or other land uses respectively; and the other coefficients are calibration constants for drainage and the different land use classes listed above respectively.

The model was fit using non-linear least squares regression, with log-transformation to better condition the residuals.

A different approach was used for the Waikato at Karapiro, Waipa confluence and Waikato at Port Waikato main-stem virtual monitoring sites. The concentration for these sites was determined from measured concentrations at nearby main-stem monitoring stations, adjusted for predicted changes in flow and load.

2.4.2 TP

A similar regression approach was trialled for TP; however, the relationship between TP and upstream catchment characteristics was too weak to continue with the approach. Median TP concentrations for non-main-stem reaches where water quality monitoring does not occur were determined from the predicted TP mean annual load. A procedure where back-calculating the ratio method of determining loads for monitoring sites with no concurrent flow data was used. In this approach, the predicted load was divided by the estimated mean annual flow to give an estimate of the mean annual TP concentration. This value was then adjusted using the statistically derived TP conversion factor taken from the CLUES model.

The TP concentrations for the Waikato at Karapiro, Waipa confluence and Waikato at Port Waikato main-stem virtual monitoring sites were determined from nearby main-stem monitoring stations in a similar fashion as that used for TN at these sites.

2.5 Model assessment method

Three metrics are used to assess model performance by comparing the modelled mean annual loads of TP and TN against those estimated from measured concentrations. These are the Root Mean Square Error (RMSE), the Nash-Sutcliffe efficiency (NSE; Nash and Sutcliffe, 1970) and the coefficient of determination (R^2).

The RMSE is a standard statistical metric to measure model performance in many fields, including meteorology, air quality, climate research and agriculture (Chai and Draxler, 2014). RMSE represents the sample standard deviation of the residuals or difference between the predicted and observed values and has the same units as the parameter. The RMSE is calculated as:

$$RMSE = \sqrt{\frac{\sum(x-y)^2}{n}} \tag{4}$$

Where *x* and *y* are the observed and predicted values and *n* is the number of samples.

The NSE is a measure of the scatter of model residuals around the 1:1 line. The value ranges from -∞ to one. A NSE of one indicates that the modelled and measured values are the same whereas a NSE of zero indicates that the modelled values are only as accurate as the mean of the measured values. A value > 0.5 indicates that the model performance is satisfactory (Moriasi *et al.*, 2007). A negative NSE means that the mean of the measured values is a better predictor than the model.

The NSE is calculated as:

$$NSE = 1 - \frac{\sum(y-f)^2}{\sum(y-\bar{y})^2} \tag{5}$$

Where y is the observed value, $\bar{y}$ is the mean of the observed values and f is the paired predicted value.

3 Results

This section presents the estimated reservoir and catchment attenuation coefficients and compares the loads and yields from the models to those estimated from measurements. It also presents the results of the concentration modelling for the unmonitored sub-catchments.

3.1 Attenuation

3.1.1 Reservoir attenuation

The reservoir attenuation factors calculated for sub-catchments containing one or more large lake or hydropower dam are given in Table 3-1. In general, the reservoir attenuation is low. During calibration, it was found that the reservoir attenuation factors for the sub-catchments containing shallow lakes in the lower Waikato River catchment resulted in underestimations of nutrient instream loads. It was therefore decided to set the reservoir attenuation factors for these sub-catchments to one (i.e., no reservoir attenuation).

Table 3-1: Reservoir attenuation factors for TN and TP in sub-catchments with one or more large lakes or hydropower dams. *The attenuation factors for the three lower Waikato River catchment sub-catchments were set to one in the model.

Sub-catchment		TN	TP
2	Waikato at Ohaaki	0.998	0.997
3	Waikato at Ohakuri	0.970	0.951
11	Waikato at Whakamaru	0.977	0.963
15	Waikato at Waipapa	0.986	0.977
21	Waikato at Karapiro	0.976	0.960
36	Awaroa (Rotowaro) at Harris/Te Ohaki Br*	0.352	0.246
39	Whangape*	0.461	0.339
44	Waikare*	0.141	0.089

3.1.2 TN catchment attenuation

The method used to determine the apparent and ultimate attenuation factors for TN was iterative. The calibrated apparent attenuation values are shown along with the adjusted and ultimate attenuation factors in Table 3-2. Generally, attenuation factors lie in the range 0-1, the higher the factor, the lower the attenuation. An attenuation factor >1 signals that either the TN leaching losses have been underestimated or that there is an unknown nitrogen source. That is, the estimated TN load reaching the stream is not enough to account for the increase in the instream TN load seen at that sub-catchment outlet. The apparent attenuation factors have been adjusted in some sub-catchments on the basis of information provided by the expert panel. For example, the calibrated apparent attenuation for Waikato at Ohaaki was 0.67 (i.e., 33% loss). The attenuation in this sub-catchment is expected to be at a medium level. The attenuation was therefore forced to an attenuation factor of 0.50. There is also likely to be a load to come in the sub-catchment, so the ultimate attenuation factor was assigned a value of 0.60. Further examples of how and why the calibrated attenuation factors were adjusted are given below:

Table 3-2: TN attenuation factors. *Load to come* and *expected level of attenuation* taken from the expert panel assessments (see Appendix I).

	Sub-catchment	Apparent attenuation		Load to come	Expected level of attenuation	Ultimate attenuation factor
		Calibrated	Adjusted			
1	Pueto	0.38	0.40	Yes	Medium	0.60
2	Waikato at Ohaaki	0.67	0.50	Yes, minor	Medium	0.60
3	Waikato at Ohakuri	0.31	0.35	Yes, considerable	Low to medium	0.70
4	Torepatutahi	0.11	0.12	Yes, considerable	Low	0.80
5	Mangakara	0.98	0.80	Yes, minor	Low	0.80
6	Waiotapu at Homestead	0.71	0.80	?	Medium	0.80
7	Kawaunui	0.87	0.80	Yes, minor?	Low to medium	0.80
8	Waiotapu at Campbell	1.23	0.80	Yes?	Low	0.80
9	Otamakokore	0.66	0.63	Yes	Low	0.80
10	Whirinaki	0.80	0.63	Yes	Low	0.80
11	Waikato at Whakamaru	0.51	0.45	Yes	Medium	0.60
12	Waipapa	0.49	0.45	Yes?	Low to medium	0.70
13	Tahunaatara	0.54	0.52	Yes	Low	0.80
14	Mangaharakeke	0.43	0.43	Maybe	Low to medium	0.70
15	Waikato at Waipapa	0.19	0.50	Yes?	Medium	0.70
16	Mangakino	0.94	0.95	Maybe	LOW	0.95
17	Mangamingi	1.34	0.90	No	Low	0.90
18	Whakauru	0.93	0.80	Yes	Low	0.95
19	Pokaiwhenua	0.30	0.50	Yes	Low to medium	0.70
20	Little Waipa	0.50	0.51	Yes	Low to medium	0.70
21	Waikato at Karapiro	0.67	0.60	Yes, minor?	Low to medium	0.70
22	Karapiro	0.35	0.60	No	Low to medium	0.60
23	Waikato at Narrows	0.53	0.60	No	Medium	0.60
24	Mangawhero	0.79	0.60	No	Medium	0.60
25	Waikato at Bridge St Br	0.00	0.60	No	Medium	0.60
26	Mangaonua	0.13	0.60	No	Medium	0.60
27	Mangakotukutuku	0.34	0.60	No	Medium	0.60
28	Mangaone	0.47	0.60	No	Medium	0.60
29	Waikato at Horotiu Br	0.13	0.50	No	Medium	0.50
30	Waitawhiriwhiri	0.51	0.50	No	Medium to high	0.50
31	Kirikiriroa	0.30	0.50	No	Medium	0.50
100	Waipa at Mangaokewa Rd	1.76	0.95	No	Low to medium	0.95
101	Waipa at Otewa	0.96	0.95	No	Low to medium	0.95
102	Mangaokewa	1.13	0.95	No	Low	0.95
103	Mangarapa	1.29	0.95	No	Low to medium	0.95

Sub-catchment		Apparent attenuation		Load to come	Expected level of attenuation	Ultimate attenuation factor
		Calibrated	Adjusted			
104	Mangapu	1.33	0.95	No	Low	0.95
105	Mangarama	1.30	0.95	No	Low	0.95
106	Waipa at Otorohanga	0.54	0.60	No	Medium	0.60
107	Waipa at Pirongia-Ngutunui Rd Br	0.77	0.75	No	Low to medium	0.75
108	Waitomo at Tumutumu Rd	2.08	0.95	No	Low to medium	0.95
109	Waitomo at SH31 Otorohanga	1.38	0.95	No	Low to medium	0.95
110	Moakurarua	1.02	0.95	No	Low	0.95
111	Puniu at Bartons Corner Rd Br	0.82	0.75	Yes, minor	Medium	0.80
112	Puniu at Wharepapa	0.87	0.85	No	Low to medium	0.85
113	Mangatutu	0.60	0.61	No	Low to medium	0.61
114	Mangapiko	0.65	0.65	No	Medium	0.65
115	Mangaohoi	0.66	0.65	No	Low	0.65
116	Waipa at SH23 Br Whatawhata	0.77	0.80	No	Medium	0.80
117	Mangauika	0.90	0.89	No	Low	0.89
118	Kaniwhaniwha	0.90	0.60	No	Medium	0.60
119	Waipa at Waingaro Rd Br	1.20	0.60	No	Medium	0.60
120	Ohote	0.55	0.55	No	Medium to high	0.55
121	Firewood	1.04	0.90	No	Low to medium	0.90
32	Waikato at Huntly-Tainui Br	1.36	0.95	No	Medium	0.95
33	Komakorau	0.57	0.95	No	Medium	0.95
34	Mangawara	0.89	0.95	No	Medium	0.95
35	Waikato at Rangiriri	0.60	0.95	No	Low to medium	0.95
36	Awaroa (Rotowaro) at Harris/Te Ohaki Br	1.09	0.95	No	Medium	0.95
37	Awaroa (Rotowaro) at Sansons Br	1.25	0.95	No	Low to medium	0.95
38	Waikato at Mercer Br	3.00	0.95	No	Low to medium	0.95
39	Whangape	2.62	0.95	No	Low to medium	0.95
40	Whangamarino at Island Block Rd	3.00	0.95	No	Low to medium	0.95
41	Whangamarino at Jefferies Rd Br	2.11	0.95	No	Medium	0.95
42	Waerenga	1.11	0.95	No	Medium	0.95
43	Matahuru	0.98	0.95	No	Low to medium	0.95
44	Waikare	1.24	0.95	No	Medium	0.95

Sub-catchment		Apparent attenuation		Load to come	Expected level of attenuation	Ultimate attenuation factor
		Calibrated	Adjusted			
45	Opuatia	1.16	0.95	No	Low	0.95
46	Mangatangi	0.62	0.65	No	Medium	0.65
47	Waikato at Tuakau Br	0.20	0.95	No	Low to medium	0.95
48	Ohaeroa	0.74	0.95	No	Low to medium	0.95
49	Mangatawhiri	0.77	0.85	No	Low	0.85
51	Whakapipi	1.22	0.95	No	Low to medium	0.95
52	Awaroa (Waiuku)	1.10	0.95	?	Medium	0.95
50	Waikato at Port Waikato	1.00	0.95	No	Medium	0.95

- There are a number of sub-catchments in the Waipa River catchment with calibrated apparent attenuation factors >1, signalling that the modelled load of nitrogen reaching the drainage network was not enough to make up the incremental increase seen in the loads estimated from measurements. These attenuation factors were adjusted with reference to the expert panel evaluations of these sub-catchments. For example, the modelled TN losses from diffuse sources in the Waitomo at Tumutumu Rd sub-catchment account for only half of the estimated TN load in this headwater sub-catchment. It is thought that the TN losses determined by the Overseer model may be too low due its inability to simulate karst landforms adequately. For this reason, the apparent attenuation factor was adjusted from 2.10 to 0.95 in keeping with the expert panel's expectation that the sub-catchment has low to medium attenuation. The apparent attenuation calibrated for the neighbouring Waitomo at SH31 Otorohanga sub-catchment was similarly adjusted.

- The complex surface and groundwater hydrology in the Whakauru, Mangamingi and Pokaiwhenua sub-catchments makes assessment of attenuation difficult in this area. The apparent attenuation factors for Whakauru and Mangmingi were adjusted in accordance with the expert panel expectation of low attenuation. Pokaiwhenua was assumed to have higher apparent attenuation in anticipation of an expected load to come.

- In some cases, it was decided to group neighbouring sub-catchments with similar catchment characteristics into a single drainage area with a single attenuation factor. For example Kawaunui and Waiotapu at Campbell were given the same attenuation factor as Waiotapu at Homestead. The attenuation factors for Komakorau and Mangawara were similarly linked to Waikato at Huntly-Tainui Br.

- The calibrated attenuation factor for Waikato at Bridge St Br was adjusted from zero (i.e., total removal of TN leaching loss from pasture and horticulture) to 0.6 on the understanding that this sub-catchment has medium attenuation. The calibrated value is likely to be due to a higher load measured upstream of the sub-catchment (i.e., Waikato at Narrows).

- With the exceptions of Waikato at Tuakau Br, Mangatangi, Matahuru, Ohaeroa and Mangatawhiri, all the sub-catchments downstream of Waikato at Rangiriri had calibrated apparent attenuation factors greater than one, signalling that the predicted diffuse source yields are likely to be too low for the lower reaches for the Waikato River catchment. According to the expert panel, these sub-catchments are expected to have low to medium attenuation. The calibrated apparent attenuation factors were adjusted accordingly.

- The high apparent attenuation factor for Torepatutahi reflects a lagged response to land use change in the sub-catchment that has caused a gradual increase in TN concentrations at the Torepatutahi monitoring site over recent years. A considerable further increase in TN loads is expected and it is likely that the concentration will continue to rise and the predicted attenuation losses will decrease. The ultimate attenuation factor was set to 0.80 on the basis of the expert panel assessment.

  Another example is Waikato at Waipapa, where the area of pasture has doubled since 1972. The sub-catchment was assessed as having moderate attenuation and was assigned an ultimate attenuation factor of 0.7. The apparent attenuation factor for this sub-catchment was adjusted from 0.19 to 0.50 as the difference between the calibrated apparent attenuation factor and the ultimate attenuation factor suggests that a tripling of nutrient loads can be expected, which is not in keeping with the increase in pastoral land.

- The sub-catchments in the lower Waikato downstream of Waikato at Huntly-Tainui Br, inclusive, are expected to have low attenuation and the loads are generally underestimated in the main-stem. For this reason, attenuation for these sub-catchments, and for Komakorau and Mangawara immediately upstream of Waikato at Huntly-Tainui Br has been set to 0.95.

3.1.3 TP attenuation

The TP attenuation factors from CLUES and the values used in the current modelling are given in Table 3-3. The calibrated exponent used to convert the ratio to the attenuation factor is 0.13. This exponent results in attenuation factors that are low compared to the CLUES ratios, with only a handful of sub-catchments having an attenuation factor less than 0.90. The lower attenuation factors could be due, for example, to different calibrated TP yields and source areas in the CLUES model compared with those used in this study and to local differences in the level of catchment attenuation in the Waikato compared with the nationally calibrated average TP attenuation. It is not unreasonable to have small amounts of attenuation, because datasets used to calibrate Overseer are based on observations in surface water and in some cases from small catchments (McDowell *et al.*, 2005).

Table 3-3: TP attenuation factors determined from the ratio of CLUES incremental loads, with and without attenuation, estimated for the sub-catchment outlet reaches..

Sub-catchment		CLUES TP load ratios	TP attenuation factor
1	Pueto	0.49	0.91
2	Waikato at Ohaaki	0.59	0.93
3	Waikato at Ohakuri	0.59	0.93
4	Torepatutahi	0.48	0.91

5	Mangakara	0.46	0.90
6	Waiotapu at Homestead	0.57	0.93
7	Kawaunui	0.46	0.90
8	Waiotapu at Campbell	0.54	0.92
9	Otamakokore	0.54	0.92
10	Whirinaki	0.70	0.95
11	Waikato at Whakamaru	0.55	0.93
12	Waipapa	0.43	0.90
13	Tahunaatara	0.61	0.94
14	Mangaharakeke	0.59	0.93
15	Waikato at Waipapa	0.64	0.94
16	Mangakino	0.69	0.95
17	Mangamingi	0.43	0.89
18	Whakauru	0.50	0.91
19	Pokaiwhenua	0.58	0.93
20	Little Waipa	0.44	0.90
21	Waikato at Karapiro	0.59	0.93
22	Karapiro	0.48	0.91
23	Waikato at Narrows	0.53	0.92
24	Mangawhero	0.44	0.90
25	Waikato at Bridge St Br	0.72	0.96
26	Mangaonua	0.43	0.90
27	Mangakotukutuku	0.49	0.91
28	Mangaone	0.37	0.88
29	Waikato at Horotiu Br	0.74	0.96
30	Waitawhiriwhiri	0.41	0.89
31	Kirikiriroa	0.63	0.94
100	Waipa at Mangaokewa Rd	0.69	0.95
101	Waipa at Otewa	0.74	0.96
102	Mangaokewa	0.59	0.93
103	Mangarapa	0.67	0.95
104	Mangapu	0.74	0.96
105	Mangarama	0.55	0.93
106	Waipa at Otorohanga	0.72	0.96
107	Waipa at Pirongia-Ngutunui Rd Br	0.71	0.96
108	Waitomo at Tumutumu Rd	0.52	0.92
109	Waitomo at SH31 Otorohanga	0.86	0.98

110	Moakurarua	0.71	0.96
111	Puniu at Bartons Corner Rd Br	0.71	0.96
112	Puniu at Wharepapa	0.48	0.91
113	Mangatutu	0.76	0.96
114	Mangapiko	0.63	0.94
115	Mangaohoi	0.73	0.96
116	Waipa at SH23 Br Whatawhata	0.57	0.93
117	Mangauika	0.64	0.94
118	Kaniwhaniwha	0.70	0.95
119	Waipa at Waingaro Rd Br	0.60	0.94
120	Ohote	0.48	0.91
121	Firewood	0.50	0.91
32	Waikato at Huntly-Tainui Br	0.70	0.95
33	Komakorau	0.44	0.90
34	Mangawara	0.49	0.91
35	Waikato at Rangiriri	0.63	0.94
36	Awaroa (Rotowaro) at Harris/Te Ohaki Br	0.75	0.96
37	Awaroa (Rotowaro) at Sansons Br	0.51	0.92
38	Waikato at Mercer Br	0.63	0.94
39	Whangape	0.57	0.93
40	Whangamarino at Island Block Rd	0.67	0.95
41	Whangamarino at Jefferies Rd Br	0.38	0.88
42	Waerenga	0.41	0.89
43	Matahuru	0.52	0.92
44	Waikare	0.70	0.95
45	Opuatia	0.44	0.90
46	Mangatangi	0.52	0.92
47	Waikato at Tuakau Br	0.59	0.93
48	Ohaeroa	0.58	0.93
49	Mangatawhiri	0.64	0.94
51	Whakapipi	0.36	0.87
52	Awaroa (Waiuku)	0.47	0.91
50	Waikato at Port Waikato	0.59	0.93

3.2 Nutrient loads and yields

This section presents instream nutrient loads and cumulative yields. The latter are provided to normalise the loads for the upstream area and are calculated as the instream load divided by the upstream drainage area, including the Lake Taupo catchment area upstream of Waikato at Ohaaki.

Model goodness of fit was assessed by comparing the log transformed modelled loads against the log transformed loads estimated from measurements. The model fit is summarised in Table 3-4 and shows that the models are able to capture nutrient loads fairly well but have substantial error. Model fit is discussed in more detail in the rest of this section.

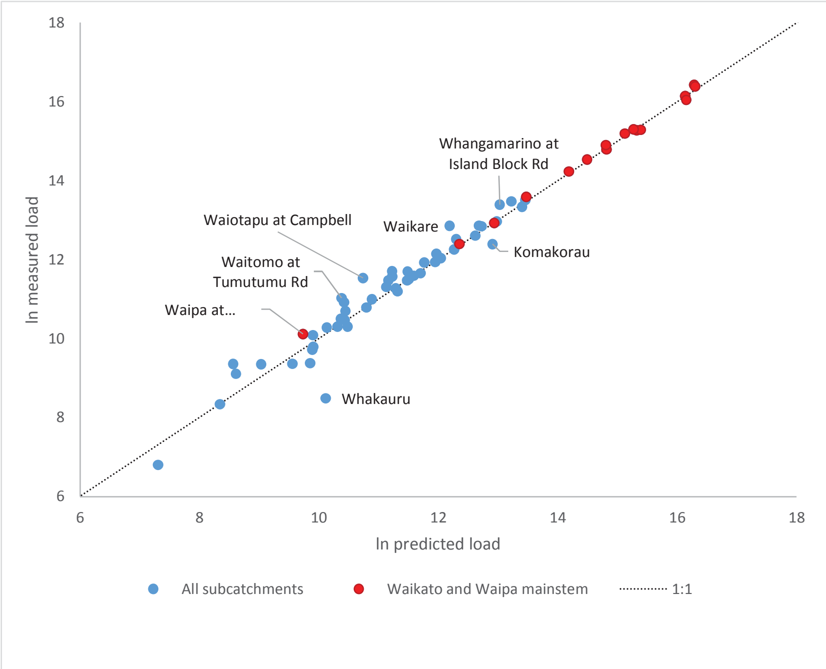
Table 3-4: Model fit indices for the log transformed modelled and estimated loads.

Model	RMSE (log transformed loads)	NSE	R^2
TN	0.33	0.97	0.98%
TP	0.56	0.93	0.93

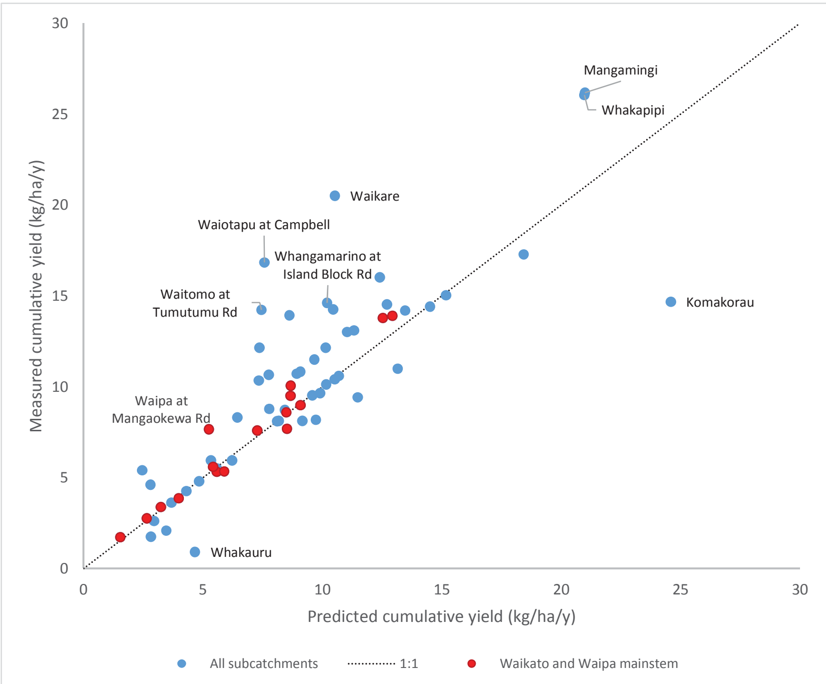
3.2.1 TN loads and yields

The modelled TN instream loads and yields are compared to those estimated from measurements in Figure 3-1 and Table 3-5. The plots in Figure 3-1 show that the model is able to predict TN instream loads fairly well for most of the sub-catchments. The model also captures the yields for main-stem sites but is less able to predict yields in tributary sub-catchments. The difference in model fit for loads and yields shows that area explains much of the model fit for loads. The key outcomes of the modelling are summarised below:

- With the exception of Waipa at Mangaokewa Rd (which is a headwater sub-catchment), all of the sub-catchments have an estimated TN load within 20% of the load estimated from the measurements. The modelled load and yield for this sub-catchment were underestimated by 32%; the unadjusted calibrated attenuation factor was >1, indicating that either the diffuse source yields are too low or there is a point source not accounted for in the model.
- The greatest proportional difference between the modelled and measurement estimated loads and yields is for Whakauru. As noted previously, the hydrology of this area is complex. The modelled TN load for Whakauru is four times that estimated from measurements (a difference of almost 20 t/y), whereas the loads modelled for Pokaiwhenua and Mangamingi are underestimated. The underestimation for Pokaiwhenua, which is downstream of both Whakauru and Mangamingi is around 12% (43 t/y), suggesting that there could be significant bypass between Whakauru and its neighbouring sub-catchments which is not captured by the model.
- The predicted load and yield for Waitomo at Tumutumu Road are each about half those estimated from measurements. As noted previously, this is probably due to an underestimation of the diffuse source yields for the sub-catchment, possibly caused by an inability of Overseer to simulate nutrient loss from karst landforms adequately.



a.



b.

Figure 3-1: Comparision of modelled TN loads and yields against those estimated from measurments. a. natural log of mean annual TN instream loads; b. mean annual TN cumulative yields. Outliers are labelled.

Table 3-5: Modelled TN instream loads and cumulative yields compared to those estimated from measurements by sub-catchment.

Subcatchment		Instream TN load (t/y)			Cumulative yield (kg/ha/y)	
		Modelled	Measured	Difference	Modelled	Measured
1	Pueto	96.8	96.4	0%	4.83	4.81
2	Waikato at Ohaaki	709.8	801.4	-11%	1.53	1.73
3	Waikato at Ohakuri	1453.3	1519.8	-4%	2.65	2.77
4	Torepatutahi	79.9	79.0	1%	3.68	3.64
5	Mangakara	20.0	24.0	-17%	8.93	10.73
6	Waiotapu at Homestead	301.7	298.7	1%	10.51	10.41
7	Kawaunui	5.2	11.6	-55%	2.45	5.42
8	Waiotapu at Campbell	46.0	102.4	-55%	7.57	16.84
9	Otamakokore	48.9	48.5	1%	10.68	10.61
10	Whirinaki	8.4	11.5	-27%	7.76	10.66
11	Waikato at Whakamaru	1965.6	2059.4	-5%	3.23	3.39
12	Waipapa	53.5	59.9	-11%	5.33	5.96
13	Tahunaatara	170.1	169.3	0%	8.17	8.13
14	Mangaharakeke	30.2	29.8	1%	5.57	5.51
15	Waikato at Waipapa	2728.5	2653.7	3%	3.99	3.88
16	Mangakino	212.5	211.5	0%	9.58	9.53
17	Mangamingi	219.9	274.4	-20%	20.99	26.19
18	Whakauru	24.7	4.9	408%	4.66	0.92
19	Pokaiwhenua	335.7	379.4	-12%	7.77	8.79
20	Little Waipa	154.5	153.6	1%	14.51	14.42
21	Waikato at Karapiro	3951.4			5.18	
22	Karapiro	19.0	11.8	61%	2.82	1.75
23	Waikato at Narrows	4273.8	4414.0	-3%	5.42	5.60
24	Mangawhero	34.4	44.5	-23%	6.44	8.32
25	Waikato at Bridge St Br	4520.8	4322.6	5%	5.58	5.33
26	Mangaonua	80.1	78.2	2%	9.90	9.66
27	Mangakotukutuku	35.6	29.8	19%	13.15	11.01
28	Mangaone	70.6	96.4	-27%	10.45	14.26
29	Waikato at Horotiu Br	4822.5	4384.7	10%	5.89	5.35
30	Waitawhiriwhiri	25.2	29.1	-14%	11.32	13.11
31	Kirikiriroa	14.2	11.6	22%	11.48	9.43
100	Waipa at Mangaokewa Rd	16.9	24.7	-32%	5.24	7.68
101	Waipa at Otewa	232.0	242.2	-4%	7.27	7.60
102	Mangaokewa	158.1	188.7	-16%	9.08	10.83

Subcatchment		Instream TN load (t/y)			Cumulative yield (kg/ha/y)	
		Modelled	Measured	Difference	Modelled	Measured
103	Mangarapa	71.5			13.13	
104	Mangapu	552.7	714.2	-23%	12.40	16.03
105	Mangarama	71.9			13.00	
106	Waipa at Otorohanga	416.0	411.7	1%	9.09	8.99
107	Waipa at Pirongia-Ngutunui Rd Br	2696.3	2967.7	-9%	12.53	13.79
108	Waitomo at Tumutumu Rd	32.1	61.5	-48%	7.44	14.24
109	Waitomo at SH31 Otorohanga	75.1	121.4	-38%	8.62	13.93
110	Moakurarua	200.5			9.72	
111	Puniu at Bartons Corner Rd Br	698.7	737.3	-5%	13.46	14.20
112	Puniu at Wharepapa	188.8			11.20	
113	Mangatutu	99.4	99.6	0%	8.10	8.12
114	Mangapiko	432.4	428.6	1%	15.17	15.04
115	Mangaohoi	1.5	0.9	66%	3.46	2.09
116	Waipa at SH23 Br Whatawhata	3703.2	3985.5	-7%	12.93	13.91
117	Mangauika	4.2	4.2	1%	4.31	4.27
118	Kaniwhaniwha	75.3	106.3	-29%	7.34	10.36
119	Waipa at Waingaro Rd Br	3887.3			12.57	
120	Ohote	34.0	35.3	-3%	8.43	8.73
121	Firewood	25.1			7.45	
32	Waikato at Huntly-Tainui Br	10174.2	10300.8	-1%	8.49	8.60
33	Komakorau	403.3	240.7	68%	24.59	14.68
34	Mangawara	661.4	620.4	7%	18.43	17.29
35	Waikato at Rangiriri	10344.7	9350.5	11%	8.52	7.70
36	Awaroa (Rotowaro) at Harris/ Te Ohaki Br	82.3	73.0	13%	9.16	8.13
37	Awaroa (Rotowaro) at Sansons Br	33.6	55.4	-39%	7.36	12.15
38	Waikato at Mercer Br	11816.9	13705.7	-14%	8.67	10.06
39	Whangape	322.0	386.3	-17%	10.14	12.16
40	Whangamarino at Island Block Rd	456.3	654.5	-30%	10.20	14.63
41	Whangamarino at Jefferies Rd Br	128.7	151.8	-15%	11.04	13.02
42	Waerenga	5.5	9.0	-39%	2.80	4.61
43	Matahuru	108.0	107.9	0%	10.15	10.14
44	Waikare	197.1	384.1	-49%	10.53	20.51
45	Opuatia	68.3	81.3	-16%	9.66	11.51
46	Mangatangi	120.9	115.8	4%	6.22	5.95
47	Waikato at Tuakau Br	12016.3	13191.2	-9%	8.67	9.52

Subcatchment		Instream TN load (t/y)			Cumulative yield (kg/ha/y)	
		Modelled	Measured	Difference	Modelled	Measured
48	Ohaeroa	19.8	16.7	19%	9.73	8.19
49	Mangatawhiri	20.1	17.9	12%	2.95	2.63
51	Whakapipi	97.4	121.1	-20%	20.97	26.05
52	Awaroa (Waiuku)	31.8	36.4	-13%	12.70	14.54
50	Waikato at Port Waikato	12542.5			8.82	

- The source yields for sub-catchments downstream of Waikato at Rangiriri (e.g., Whangamarino at Island Block Rd and at Jefferies Rd Br, and Whakapipi, Whangape, Waikare) in general seem to be too low, leading to underestimation of TN loads for these sub-catchments.

- The TN load in the Waiotapu at Campbell sub-catchment is underestimated by around 55% which could be due to an underestimation of the nitrogen from geothermal sources in this sub-catchment.

- The TN load for Komakorau is overestimated by 68%. The attenuation factor for this sub-catchment was linked to that at Waikato at Huntly-Tainui Br downstream of Komakorau. Both sub-catchments are expected to have moderate attenuation. However, the calibrated apparent attenuation for Waikato at Huntly-Tainui Br indicated that the source yields in this sub-catchment are too low. The apparent attenuation factor was therefore increased to 0.95 in both sub-catchments, leading to the overestimation of TN loads for Komokorau. Also, the measured load at this site was only estimated using the ratio method, rather than from a full rating curve.

3.2.2 TP loads and yields

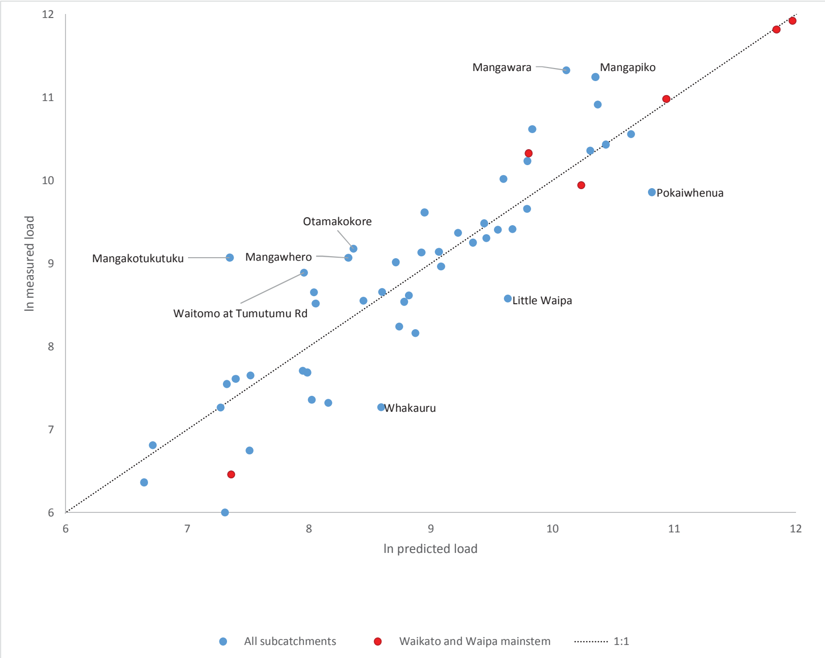
The modelled TP instream loads and yields are compared to those estimated from measurements in Figure 3-2 and Table 3-6. The plots in Figure 3-2 show that the TP model does not perform as well as the TN model which reflects the greater uncertainly surrounding TP sources and attenuation. The key outcomes of the modelling are summarised below:

- While the model is able to capture TP instream loads, it is less able to estimate TP instream yields. The poorer fit relative to that obtained for TN largely reflects the greater level of uncertainty in determining the yields from diffuse sources of TP in the different sub-catchments and in determining the contribution of sediment-P. Sources of model uncertainty are discussed in more detail in Section 4.

- Thirty-three sub-catchments have TP losses from pastoral sources which are too low to account for the incremental increase in loads estimated from measurements. For example, Waitomo at Tumutumu Road, which is a headwater sub-catchment, has an instream load estimated from measurements that is more than three times greater than the Overseer derived TP losses from pastoral sources provided by the University of Waikato. Otamakokore, Mangatukutuku, Mangapiko, Mangawara and Waikare require similarly large increases in TP losses to match the observed loads.

- In contrast, the Overseer pastoral TP losses in other sub-catchments are overestimated compared to the incremental increase in loads causing an overestimation of instream loads by the TP model. The load at Little Waipa, for instance is overestimated by 187%.
- The under-prediction of TP in some of the upper Waikato sub-catchments (i.e., Otamakokore, Mangakara, Whirinaki, Waiotapu at Homestead and at Campbell and Kawaunui) may be due in part to weathering of pumice. Timperley (1983) suggested that spring waters within the Taupo Volcanic Zone contains elevated TP concentrations due to a reaction of deep groundwater with the rhyolitic substrate of the aquifer. The expert panel notes (Appendix J) state that groundwater age in these sub-catchments is generally old which would allow time for dissolution of the substrate.
- Agricultural lowlands on peat soils can have elevated levels of P-loss following re-wetting due to the geo-chemistry of the soils (Simmons *et al.*, 2013; Forsmann and Kjaergaard, 2014). The loads estimated from measurements from some lower Waikato sub-catchments may be due to peaty soils in these sub-catchments (e.g., Mangawhero, Mangawara). The Mangatukutuku sub-catchment, for example, has a high measured phosphorus load and the ratio of TP to TN is very high. Mangapiko in the Waipa catchment may also have high P loads from peat.
- Sediment-P in the Waipa River catchment may be underestimated, for example, Waitomo at Tumutumu Rd has a high sediment yield which could result in the high TP loads measured for this sub-catchment that is not captured by the model. We were reluctant to increase the sediment P concentration further, as it was already set at quite a high level. We expect that Overseer may be under-predicting losses from this area, perhaps because of under-estimation of slope or contributions from surficial sediment loss.
- While the proportional differences in loads predicted for the tributary sub-catchments can be fairly large, the absolute difference is low compared to the in-stream loads at the main stem sites.
- The model fit for main stem sub-catchments TP yields is reasonable due to the cumulative compensation of under and overestimation of loads from tributary sub-catchments as the loads are routed downstream. The load estimated for Waikato at Tuakau Br, which is the most downstream water quality monitoring station, is within 3% of that measured. However, the loads are overestimated by over 20% for Waikato at Horotiu Br, Waikato at Narrows, Waikato at Waipapa and Waipa at Otorohanga. Waipa at Mangaokewa Rd is a headwater catchment and the load is overestimated by 147%. Two main stem sub-catchments, both in the Waipa River catchment (SH23 Br Whatawhata and Otewa) have loads which are under predicted by more than 20%.

a.



b.

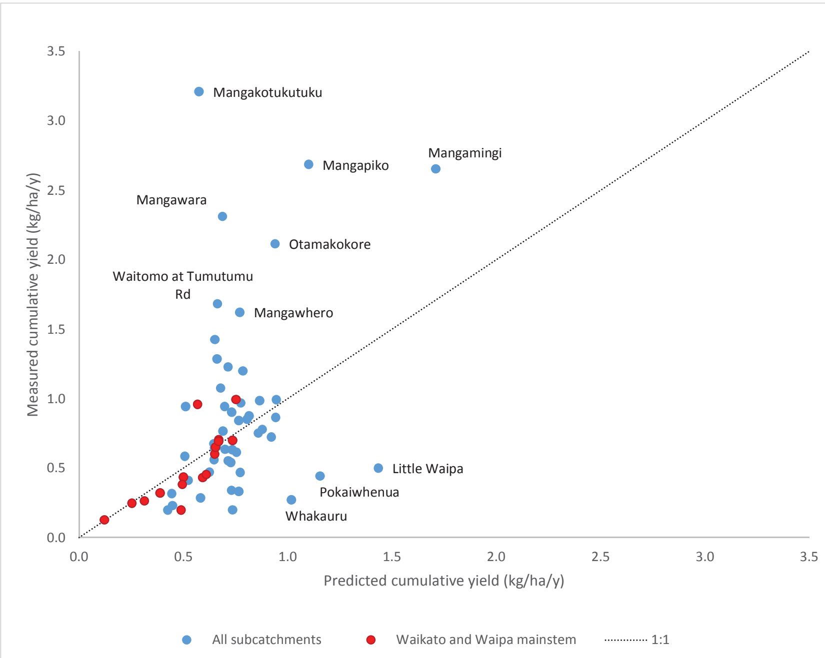


Figure 3-2: Comparison of modelled TP loads and yields against those estimated from measurements. . a. natural log of mean annual TP instream loads; b. mean annual TP cumulative yields. Outliers are labelled

Table 3-6: Modelled TP instream loads and cumulative yields compared to those estimated from measurements by sub-catchment.

Sub-catchment		Instream load (t/y)			Cumulative yield (kg/ha/y)	
		Estimated	Measured	Difference	Estimated	Measured
1	Pueto	10.1	11.7	-13%	0.51	0.6
2	Waikato at Ohaaki	56.2	58.8	-4%	0.12	0.1
3	Waikato at Ohakuri	138.7	135.4	2%	0.25	0.2
4	Torepatutahi	14.1	12.1	16%	0.65	0.6
5	Mangakara	1.6	2.0	-19%	0.73	0.9
6	Waiotapu at Homestead	18.7	40.9	-54%	0.65	1.4
7	Kawaunui	1.8	2.1	-12%	0.86	1.0
8	Waiotapu at Campbell	3.1	5.7	-46%	0.51	0.9
9	Otamakokore	4.3	9.7	-56%	0.94	2.1
10	Whirinaki	0.8	0.9	-9%	0.77	0.8
11	Waikato at Whakamaru	190.7	160.3	19%	0.31	0.3
12	Waipapa	8.8	7.8	13%	0.88	0.8
13	Tahunaatara	17.9	15.6	14%	0.86	0.8
14	Mangaharakeke	2.8	2.2	27%	0.52	0.4
15	Waikato at Waipapa	265.9	218.8	21%	0.39	0.3
16	Mangakino	15.9	12.2	30%	0.72	0.6
17	Mangamingi	17.9	27.8	-36%	1.71	2.7
18	Whakauru	5.4	1.4	276%	1.02	0.3
19	Pokaiwhenua	49.9	19.1	161%	1.15	0.4
20	Little Waipa	15.3	5.3	187%	1.43	0.5
21	Waikato at Karapiro	361.7			0.47	
22	Karapiro	5.4	5.7	-5%	0.81	0.9
23	Waikato at Narrows	389.6	301.5	29%	0.49	0.4
24	Mangawhero	4.1	8.7	-52%	0.77	1.6
25	Waikato at Bridge St Br	405.7	351.9	15%	0.50	0.4
26	Mangaonua	6.2	3.8	65%	0.77	0.5
27	Mangakotukutuku	1.6	8.7	-82%	0.57	3.2
28	Mangaone	4.7	5.2	-10%	0.69	0.8
29	Waikato at Horotiu Br	485.2	353.2	37%	0.59	0.4
30	Waitawhiriwhiri	1.4	1.4	1%	0.65	0.6
31	Kirikiriroa	0.8	0.6	33%	0.62	0.5
100	Waipa at Mangaokewa Rd	1.6	0.6	147%	0.49	0.2
101	Waipa at Otewa	18.1	30.5	-41%	0.57	1.0
102	Mangaokewa	12.8	11.0	16%	0.73	0.6

Sub-catchment		Instream load (t/y)			Cumulative yield (kg/ha/y)	
		Estimated	Measured	Difference	Estimated	Measured
103	Mangarapa	6.0			1.10	
104	Mangapu	42.0	38.5	9%	0.94	0.9
105	Mangarama	5.9			1.07	
106	Waipa at Otorohanga	27.9	20.8	34%	0.61	0.5
107	Waipa at Pirongia-Ngutunui Rd Br	158.2	150.5	5%	0.74	0.7
108	Waitomo at Tumutumu Rd	2.9	7.3	-61%	0.66	1.7
109	Waitomo at SH31 Otorohanga	6.1	8.2	-26%	0.70	0.9
110	Moakurarua	16.4			0.79	
111	Puniu at Bartons Corner Rd Br	34.2	33.9	1%	0.66	0.7
112	Puniu at Wharepapa	10.9			0.65	
113	Mangatutu	7.1	3.5	104%	0.58	0.3
114	Mangapiko	31.4	76.5	-59%	1.10	2.7
115	Mangaohoi	0.2	0.1	41%	0.44	0.3
116	Waipa at SH23 Br Whatawhata	215.5	284.6	-24%	0.75	1.0
117	Mangauika	0.4	0.2	116%	0.43	0.2
118	Kaniwhaniwha	7.5	9.2	-19%	0.73	0.9
119	Waipa at Waingaro Rd Br	230.9			0.75	
120	Ohote	2.9	2.2	35%	0.73	0.5
121	Firewood	2.4			0.71	
32	Waikato at Huntly-Tainui Br	778.4	719.8	8%	0.65	0.6
33	Komakorau	11.5	10.4	10%	0.70	0.6
34	Mangawara	24.7	82.9	-70%	0.69	2.3
35	Waikato at Rangiriri	794.2	788.5	1%	0.65	0.6
36	Awaroa (Rotowaro) at Harris/ Te Ohaki Br	6.8	5.5	23%	0.75	0.6
37	Awaroa (Rotowaro) at Sansons Br	3.5	1.5	131%	0.77	0.3
38	Waikato at Mercer Br	912.4	960.5	-5%	0.67	0.7
39	Whangape	30.0	31.5	-5%	0.94	1.0
40	Whangamarino at Island Block Rd	31.9	54.9	-42%	0.71	1.2
41	Whangamarino at Jefferies Rd Br	7.7	15.0	-49%	0.66	1.3
42	Waerenga	1.5	1.9	-20%	0.77	1.0
43	Matahuru	8.7	9.3	-7%	0.81	0.9
44	Waikare	14.7	22.5	-34%	0.79	1.2
45	Opuatia	6.5	5.1	27%	0.92	0.7
46	Mangatangi	12.6	13.1	-4%	0.65	0.7
47	Waikato at Tuakau Br	926.7	958.7	-3%	0.67	0.7

Sub-catchment		Instream load (t/y)			Cumulative yield (kg/ha/y)	
		Estimated	Measured	Difference	Estimated	Measured
48	Ohaeroa	1.5	0.4	270%	0.74	0.2
49	Mangatawhiri	3.1	1.6	94%	0.45	0.2
51	Whakapipi	3.2	5.0	-37%	0.68	1.1
52	Awaroa (Waiuku)	1.8	0.9	115%	0.73	0.3
50	Waikato at Port Waikato	972.4			0.68	0

3.3 Concentrations at unmonitored sites

3.3.1 TN concentrations

The regression models described in Section 2.4.1 were used to predict current concentrations for sites TN or nitrate-N monitoring does not occur at present. The model coefficients and their standard errors are presented in Table 3-7 along with the coefficient of determination (R^2) and the overall model standard error.

Table 3-7: Regression model output for current TN and nitrate annual concentrations.

Coefficient	TN median		Nitrate-N median		Nitrate 95th percentile	
	Value	SE of coefficient	Value	SE of coefficient	Value	SE of coefficient
c_l	-1.4789	0.6197	0.302	0.278	1.5451	0.4288
c_D	3.4593	1.1169	2.1125	0.5583	2.7059	0.5298
c_{SBI}	2.4082	0.8788	0.7608	0.4059	1.3362	0.4255
c_{SBH}	1.8799	0.849	0.7737	0.2987	1.2095	0.3113
c_{Urb}	3.0214	1.6112	1.5012	1.158	0.7484	0.6959
c_O	0.592	0.3611	5.33E-12	0.0708	0.2058	0.0969
R^2	0.642		0.576		0.714	
SE of estimate	0.4313		0.6439		0.3762	

The predicted TN and nitrate-N concentrations are shown in Table 3-8. As noted earlier, the concentrations for the virtual sites, Waikato at Karapiro, Waipa at Waingaro Rd Br and Waikato at Port Waikato were estimated from adjacent sites rather than from the concentration model. The concentration for Port Waikato was estimated by adjusting the median concentration for Tuakau Bridge by the ratios of the annual loads and flow rates between the two sites. The concentration for Waipa at Waingaro was similarly determined from the measured median concentration at Waipa at Whatawhata and Lake Karapiro was adjusted using data from the Narrows.

Table 3-8: Predicted current TN and nitrate-N annual concentrations (g/m^3) for sites where concentrations are not measured.

Map ID	Site Name	TN median	Nitrate median	Nitrate 95th Percentile
21	Waikato at Karapiro	0.384	0.220	0.506
50	Waikato at Port Waikato	0.617	0.329	0.904
103	Mangarapa	1.486	0.876	1.531
105	Mangarama	1.336	0.863	1.553
110	Moakurarua	1.567	0.644	1.023
112	Puniu at Wharepapa	1.981	0.877	1.295
119	Waipa at Waingaro Rd Br	0.929	0.673	1.577
121	Firewood	1.446	0.518	0.898

3.3.2 TP concentrations

As noted in Section 2.4.2, it was not appropriate to use a regression approach to estimate TP median annual concentrations from upstream catchment characteristics. For this reason, TP median concentrations were calculated from the loads estimated from measurements for the non-mainstem sites using the same method as is used by the CLUES model (see Oehler and Elliott, 2011). The TP concentrations for Waikato at Karapiro, Waipa at Waingaro Rd Br and Waikato at Port Waikato were estimated from adjacent sites in the same way as was done to estimate TN and nitrate-N concentrations. The estimated median annual concentrations are given in Table 3-9.

Table 3-9: Predicted current TP median annual concentrations (g/m^3) for sites where concentrations are not measured.

Map ID	Site Name	TP median concentration
21	Waikato at Karapiro	0.027
50	Waikato at Port Waikato	0.058
103	Mangarapa	0.047
105	Mangarama	0.056
110	Moakurarua	0.021
112	Puniu at Wharepapa	0.045
119	Waipa at Waingaro Rd Br	0.072
121	Firewood	0.032

4 Limitations, uncertainties and recommendations for further work

A general discussion on the sources of model uncertainty and error can be found in Walker *et al.* (2003). Identified sources of model uncertainty and error include:

- **Underlying yield estimations** for diffuse nutrient sources. The yields associated with different land uses within each sub-catchment were determined by the University of Waikato for this project using the Overseer model. Uncertainties within Overseer are discussed in Shepherd *et al.* (2013). They note that the Overseer pastoral N leaching model has had a significant amount of validation, whereas the P loss model is based on a calibration process. It is inherently more difficult to model TP as there is a higher complexity in the processes in operation. This point has also been made with respect to SPARROW modelling of TN and TP (Elliot *et al.*, 2005).

- **Calibration data:** nutrient concentration data from 65 sampling sites was used to estimate mean annual loads for calibration. These data are subject to error in sampling and analysis and measured concentrations vary considerably over time. It is assumed that the SOE data are representative of the full range of nutrient concentrations.

  The loads estimated from measurements were determined using concurrent flow data where flow data were available (i.e., the rating curve method). For other sites, estimated annual mean flows were used (i.e., the ratio method) and it is assumed that there is a relationship between the median and mean annual nutrient concentrations that is a function of the mean annual flow. It is possible to estimate the error associated with the rating curve method and the confidence intervals for the loads are provided in Appendix G. However, it is not possible to estimate the error associated with the ratio method.

- **Point sources:** nutrient point source data used in the model include estimates of mean annual nutrient loads from industrial and municipal sources that are directly discharged to water. The point source characteristics vary over time in response to improvements in treatment performance, making it difficult to assess mean annual loads. For example, some sources may have new processes in place to reduce contaminant discharge that may not be reflected in the historical water quality record and cannot be accounted for in a steady-state model. There may also be other point sources that have not been accounted for.

- **Diffuse sources:** The nutrient losses from diffuse sources are calculated as a function of land use. Land use is represented by a limited number of land cover classes and the nutrient yields associated for these were derived from Overseer modelling. These data were provided by WRC and were derived from a number of sources. The derivation and interpretation of the underlying land use data are subject to sampling precision - and ground-truthing errors. Also, recent land use changes, such as those that have occurred in the Pueto sub-catchment may not be represented in the model. The model results suggest that the source yields for TP are not as representative of TP losses from pastoral land uses as those for TN.

- **Additional sources**: The TN model includes geothermal nitrogen and the TP model includes sediment-bound P. The contributions from these sources are uncertain and will require further investigation to improve the accuracy of estimates.
- **Spatial resolution:** the models operate at the catchment scale and are subject to spatial smoothing of heterogeneous input data (i.e. scaling effects). It is impossible for these models to represent the complexity of interactions between land use and biophysical characteristics perfectly.
- **Temporal resolution:** Similarly, the load models are steady-state models which predict mean annual nutrient loads. This means that seasonal changes in nutrient generation and transport are not captured by the models. Adding seasonality would require more complexity in the load models and is outside the project scope. Moreover, there are too few data at some monitoring sites to allow seasonal modelling. Dynamic modelling may also be possible but would increase the input data needs and model complexity.
- **Ultimate catchment attenuation for N.** There is uncertainty in the ultimate value of N. This relied on semi-quantitative information from a range of experts, including information on water ages in relation to development, trajectories of development, groundwater oxic state, and concentration time series. While this provides guidance, quantification of ultimate attenuation (and the difference between apparent and ultimate attenuation) is still imprecise.

4.1 Further work

Based discussion of uncertainty and error above, recommendations for further work include:

- **Reappraisal of diffuse source yields.** The source yields for pastoral and horticultural land uses were provided for this study and were derived from Overseer and should be re-assessed in some sub-catchments in light of this study. The model results suggest that TN losses are underestimated for sub-catchments with karst landscapes and TP is underestimated for sub-catchments with peaty soils, springs from aquifers with rhyolitic substrates or high rates of soil erosion. Additionally, sources of geothermal nitrogen need to be assessed and improved yield estimates derived for these sources.
- **Calibration and validation.** The models have been calibrated using SOE monitoring data, but have not been validated. Continuation and expansion of nutrient monitoring within the catchment will provide further data for model calibration and testing. Water quality monitoring should be concurrent with flow monitoring where possible to allow for better calculation of loads. See Davies-Colley *et al.* (2011) for a discussion of the requirements of national (and regional) water quality monitoring programmes to provide data suitable for modelling.
- **Point sources:** The models should be updated to include new or changed inputs from point sources. Additionally, sources of geothermal nitrogen and sediment-bound phosphorus need to be assessed and improved yield estimates derived for these sources.
- **Annual dynamic modelling:** The models presented here are steady-state annual models. Dynamic modelling would take the historical time series of catchment loading

into account, include representation of pathways and lag-time distribution, and subsurface attenuation, and be based on at least and an annual time-step. It is proposed that a dynamic model should be pursued in the next phase of catchment modelling for the Waikato catchment, particularly in the upper Waikato catchment, to better evaluate the load to come and the time trajectory of response to interventions relating to N.

- **Sub-annual and reach-scale modelling.** Detailed dynamic nutrient modelling in the catchment at the river reach-scale is likely to provide a better understanding of the temporal processes in operation, as well as a better representation of those processes. Such a model could be coupled with a dynamic model of the reservoir system, including phytoplankton growth dynamics.

5 Summary and conclusions

This report describes two steady-state catchment models used to estimate TN and TP loads in the Waikato and Waipa River catchments. The study area was divided into 74 sub-catchments for modelling, such that each sub-catchment represents the contributing area draining to its corresponding site. Sixty-four of the sites are water quality monitoring stations where nutrients are recorded; at a further 10 sites where river water quality is not currently sampled, but where a logical break-point occurs in the drainage network (e.g., just above the confluence of two streams). In addition to the load models, the report also presents three regression models which were developed to estimate median annual TN and nitrate-N and 95th percentile annual nitrate-N concentrations, respectively, for sites where nutrients are not currently sampled. A regression approach was not used to estimate median annual TP concentrations, which were instead calculated from the modelled loads. The water quality models were developed to inform an economic model which will be used to assess the economic impact of mitigations to improve water quality in the catchment.

The load models estimate nutrient mean annual loads from diffuse sources on the basis of land use. Point sources, including geothermal nitrogen and sediment-P are added to the instream load. Once within the drainage network, the instream loads are routed downstream. Nutrient losses from pastoral and horticultural land uses are subject to catchment attenuation before discharge into the river main-stem. The methods used to determine the degree of catchment attenuation differed between TN and TP. Two sets of attenuation values were determined for the TN instream load model; an *apparent* attenuation calibrated against the measured instream TN loads, and an expected future attenuation which accounts for lags between leaching of nitrogen from diffuse sources and the release of that nitrogen from groundwater storage into the stream network. The TP catchment attenuation factors were calibrated against TP loads estimated from measurements.

Both load models are able to capture the variability in mean annual nutrient loads across the catchment, whilst the models were less able to predict nutrient yields. The fit for the TN model was better than that for TP, which is consistent with the increased complexity of phosphorus transport processes.

Sources of uncertainty and error in the models include: errors in the source loads provided for each land use and sub-catchment; the assumption that monthly water quality concentration sampling is representative of the range of nutrient concentrations in the stream network; the use of estimated annual mean flows to determine mean annual loads for monitoring sites without concurrent flow sampling; spatial and temporal scaling issues; and uncertain estimates of loads from point sources, geothermal nitrogen and sediment P.

It is recommended that an annual dynamic model should be developed, along with further work to address some of the other uncertainties.

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Appendix A Sub-catchments and connectivity

The following table lists the sub-catchment names and provides unique map reference identifier numbers which are used throughout this report.

Connectivity describes the downstream flow of surface and groundwater. Note that flow diversion to groundwater is only simulated for TN, it is assumed that all TP transport is via surface water. Similarly, the flow factors refer to the relative proportion of the load from diffuse sources transported via each of surface and groundwater. Groundwater diversions and flow factors were derived from a water balance analysis undertaken for this project by GNS.

Table A-1: List of sub-catchments and their connectivity. The LOC is the WRC identification number of the monitoring site used to delineate the sub-catchment. The NZ reach number is the reach containing the monitoring site, i.e., the outlet reach. Sub-catchments which do not currently have nutrient monitoring are marked with an asterisk. Blue shading denotes sub-catchments with concurrent flow monitoring.

Map ID	Sub-catchment	Area (ha)	Connectivity			Monitoring site	
			Map ID of Downstream sub-catchment	Surface flow factor	Groundwater diversion factor	LOC	NZ reach
1	Pueto	20029	2	1	0	EW-0802-001	3042044
2	Waikato at Ohaaki	29009	3	1	0	EW-1131-105	3039804
3	Waikato at Ohakuri	53139	11	1	0	EW-1131-107	3035123
4	Torepatutahi	21721	3	1	0	EW-1057-006	3038300
5	Mangakara	2235	3	1	0	EW-0380-002	3037027
6	Waiotapu at Homestead	20478	3	1	0	EW-1186-004	3037105
7	Kawaunui	2134	6	0.2	0.8	EW-0240-005	3034452
8	Waiotapu at Campbell	6079	6	1	0	EW-1186-002	3034280
9	Otamakokore	4573	3	1	0	EW-0683-004	3031549
10	Whirinaki	1080	3	1	0	EW-1323-001	3031392
11	Waikato at Whakamaru	44665	15	1	0	EW-1131-147	3035301
12	Waipapa	10049	11	0.7	0.3	EW-1202-007	3035556
13	Tahunaatara	20816	11	1	0	EW-0934-001	3032435
14	Mangaharakeke	5415	11	1	0	EW-0359-001	3032678
15	Waikato at Waipapa	69392	21	1	0	EW-1131-143	3030247
16	Mangakino	22186	15	1	0	EW-0388-001	3036710
17	Mangamingi	5175	19	1	0	EW-0407-001	3027230
18	Whakauru	5302	17	0.3	0.7	EW-1287-007	3027821
19	Pokaiwhenua	32701	21	0.37	0.63	EW-0786-002	3023849
20	Little Waipa	10649	21	1	0	EW-0335-001	3023862
21	Waikato at Karapiro*	53969	23	1	0	EW-1131-081	3020656

Map ID	Sub-catchment	Area (ha)	Connectivity			Monitoring site	
			Map ID of Downstream sub-catchment	Surface flow factor	Groundwater diversion factor	LOC	NZ reach
22	Karapiro	6741	23	0.33	0.67	EW-0230-005	3020352
23	Waikato at Narrows	12987	25	1	0	EW-1131-101	3018977
24	Mangawhero	5347	23	0.57	0.43	EW-0488-001	3020102
25	Waikato at Bridge St Br (Hamilton Traffic Br)	5072	29	1	0	NAT-HM03	3017901
26	Mangaonua	8096	25	1	0	EW-0421-010	3017726
27	Mangakotukutuku	2708	25	1	0	EW-0398-001	3018237
28	Mangaone	6760	25	1	0	EW-0417-007	3018213
29	Waikato at Horotiu Br	5405	32	1	0	EW-1131-069	3015830
30	Waitawhiriwhiri	2223	29	1	0	EW-1236-002	3017487
31	Kirikiriroa	1233	29	1	0	EW-0253-004	3016924
32	Waikato at Huntly-Tainui Br	17322	35	1	0	EW-1131-077	3013160
33	Komakorau	16399	32	1	0	EW-0258-004	3014466
34	Mangawara	35884	32	1	0	EW-0481-007	3013137
35	Waikato at Rangiriri	6853	38	1	0	NAT-HM04	3010604
36	Awaroa (Rotowaro) at Harris/ Te Ohaki Br	4730	35	1	0	1097_1	3012631
37	Awaroa (Rotowaro) at Sansons Br*	4561	36	1	0	EW-0039-011	3013581
38	Waikato at Mercer Br	45168	47	1	0	EW-1131-091	3006806
39	Whangape	31767	38	1	0	EW-1302-001	3010847
40	Whangamarino at Island Block Rd	14365	38	1	0	EW-1293-007	3007681
41	Whangamarino at Jefferies Rd Br	9701	40	1	0	EW-1293-009	3008369
42	Waerenga	1959	41	0.33	0.67	EW-1098-001	3009556
43	Matahuru	10637	44	1	0	EW-0516-005	3010952
44	Waikare*	10418	40	1	0	EW-326-10	3010071

Map ID	Sub-catchment	Area (ha)	Connectivity			Monitoring site	
			Map ID of Downstream sub-catchment	Surface flow factor	Groundwater diversion factor	LOC	NZ reach
45	Opuatia	7067	38	1	0	EW-0665-005	3008985
46	Mangatangi	19452	38	1	0	EW-0453-006	3006132
47	Waikato at Tuakau Br	15178	50	1	0	EW-1131-133	3007421
48	Ohaeroa	2033	47	0.7	0.3	EW-0612-009	3007733
49	Mangatawhiri	6808	47	1	0	EW-0459-006	3005110
50	Waikato at Port Waikato*	28148	50	1	0	Terminal	3009006
51	Whakapipi	4648	50	1	0	EW-1282-008	3006346
52	Awaroa (Waiuku)	2506	50	1	0	EW-0041-009	3007434
100	Waipa at Mangaokewa Rd	3221	101	1	0	EW-1191-005	3036214
101	Waipa at Otewa	28665	106	1	0	NAT-HM01	3029370
102	Mangaokewa	17419	104	1	0	EW-0414-012	3031564
103	Mangarapa*	5443	104	1	0	444_4	3028468
104	Mangapu	16170	107	1	0	EW-0443-003	3027166
105	Mangarama*	5528	104	1	0	EW-1391-001	3031371
106	Waipa at Otorohanga	13889	107	1	0	EW-1191-012	3027129
107	Waipa at Pirongia-Ngutunui Rd Br	43607	116	1	0	EW-1191-010	3022669
108	Waitomo at Tumutumu Rd	4318	109	1	0	EW-1253-007	3028966
109	Waitomo at SH31 Otorohanga	4393	107	1	0	EW-1253-005	3026779
110	Moakurarua*	20630	107	1	0	553_5	3023962
111	Puniu at Bartons Corner Rd Br	22785	107	1	0	EW-0818-002	3023180
112	Puniu at Wharepapa*	16853	111	1	0	818_40	3025988
113	Mangatutu	12269	111	1	0	EW-0476-007	3024473
114	Mangapiko	28069	116	1	0	EW-0438-003	3022010
115	Mangaohoi	431	114	1	0	EW-0411-009	3023476

Map ID	Sub-catchment	Area (ha)	Connectivity			Monitoring site	
			Map ID of Downstream sub-catchment	Surface flow factor	Groundwater diversion factor	LOC	NZ reach
116	Waipa at SH23 Br Whatawhata	31506	119	1	0	NAT-HM02	3017829
117	Mangauika	978	116	1	0	EW-0477-010	3023179
118	Kaniwhaniwha	10259	116	1	0	EW-0222-016	3019566
119	Waipa at Waingaro Rd Br*	15484	32	1	0	Confluence	3015066
12	Ohote	4041	119	1	0	EW-0624-005	3017348
121	Firewood*	3372		1	0	124_8	3015451

* Nutrients not currently monitored at site.

Appendix B Baseline land use areas by sub-catchment

Table B-1: Baseline land use areas (ha) by sub-catchment.

Sub-catchment	Dairy	Dairy support	Sheep and beef	Forestry	Horticulture	Miscellaneous	Urban
1 Pueto	162	41	8147	10173	11	1352.8	140
2 Waikato at Ohaaki	2184	546	12646	8006	130	3557.2	1938
3 Waikato at Ohakuri	9240	2310	24290	10385	0	6364.8	550
4 Torepatutahi	4174	1043	4279	11270	0	760.2	189
5 Mangakara	242	61	1109	310	0	492.5	21
6 Waiotapu at Homestead	4579	1145	2224	10356	0	1969.8	203
7 Kawaunui	626	157	704	199	0	442.8	6
8 Waiotapu at Campbell	314	79	1919	2838	0	806.4	49
9 Otamakokore	1453	363	1805	176	0	791.3	57
10 Whirinaki	135	34	614	45	0	247.9	4
11 Waikato at Whakamaru	5137	1284	9586	24690	0	3612.0	356
12 Waipapa	1645	411	4783	2580	25	523.1	83
13 Tahunaatara	3743	936	5599	5938	0	4466.8	133
14 Mangaharakeke	456	114	371	4324	0	92.5	58
15 Waikato at Waipapa	8122	2030	11340	26890	0	19861.3	1128
16 Mangakino	2020	505	7137	1593	0	10812.1	116
17 Mangamingi	1803	451	827	1106	0	250.0	738
18 Whakauru	1436	359	1315	1757	0	87.1	349
19 Pokaiwhenua	8475	2119	6623	12313	0	2810.6	360
20 Little Waipa	5114	1279	2616	1283	0	239.8	117
21 Waikato at Karapiro	15771	3943	17163	6550	323	9450.2	770
22 Karapiro	1294	323	4179	277	36	563.6	68
23 Waikato at Narrows	3975	994	4268	173	124	1850.4	1603
24 Mangawhero	2247	562	2004	10	46	334.9	143
25 Waikato at Bridge St Br	1221	305	1725	10	200	612.7	999
26 Mangaonua	2579	645	3333	55	90	1231.8	162
27 Mangakotukutuku	1164	291	571	6	1	172.4	502
28 Mangaone	1811	453	2199	39	113	930.6	1214
29 Waikato at Horotiu Br	740	185	422	9	2	262.9	3784
30 Waitawhiriwhiri	460	115	334	16	0	101.1	1197
31 Kirikiriroa	207	52	80	0	0	93.7	800
100 Waipa at Mangaokewa Rd	0	0	950	1208	0	1038.6	20
101 Waipa at Otewa	2150	538	8973	1524	0	15188.6	292
102 Mangaokewa	928	232	10722	1484	0	3705.1	346
103 Mangarapa	925	231	3523	123	0	578.8	61

Sub-catchment	Dairy	Dairy support	Sheep and beef	Forestry	Horticulture	Miscellaneous	Urban
104 Mangapu	3253	813	9247	420	0	1714.5	656
105 Mangarama	850	212	3932	91	0	392.8	49
106 Waipa at Otorohanga	6260	1565	4521	173	0	988.4	446
107 Waipa at Pirongia-Ngutunui Rd Br	21296	5324	9933	547	156	5410.6	940
108 Waitomo at Tumutumu Rd	224	56	1673	545	0	1736.2	84
109 Waitomo at SH31 Otorohanga	447	112	2142	313	0	1301.9	77
110 Moakurarua	2396	599	8454	1441	0	7347.3	394
111 Puniu at Bartons Corner Rd Br	11301	2825	6863	526	304	459.2	507
112 Puniu at Wharepapa	3075	769	8242	327	0	4233.2	206
113 Mangatutu	2691	673	2765	243	0	5700.1	197
114 Mangapiko	12823	3206	8021	651	34	2181.0	1154
115 Mangaohoi	8	2	44	0	0	373.7	2
116 Waipa at SH23 Br Whatawhata	13752	3438	7842	745	122	4405.3	1202
117 Mangauika	46	12	28	29	0	856.5	7
118 Kaniwhaniwha	1841	460	2924	70	0	4837.1	127
119 Waipa at Waingaro Rd Br	2823	706	5521	1360	106	4160.5	809
120 Ohote	1067	267	1987	18	12	300.2	390
121 Firewood	144	36	1672	400	0	1068.3	52
32 Waikato at Huntly-Tainui Br	6999	1750	3115	136	77	3846.8	1398
33 Komakorau	10547	2637	2488	27	23	442.6	235
34 Mangawara	15054	3764	11079	459	0	5127.6	400
35 Waikato at Rangiriri	1500	375	2096	120	0	2165.1	597
36 Awaroa (Rotowaro) at Harris	800	200	2264	36	0	1318.7	112
37 Awaroa (Rotowaro) at Sansons Br	206	51	2100	770	0	1363.6	70
38 Waikato at Mercer Br	6718	1679	23091	2431	977	8869.0	1152
39 Whangape	3250	813	21722	1083	0	4516.1	383
40 Whangamarino at Island Block Rd	1907	477	5140	918	204	5270.2	449
41 Whangamarino at Jefferies Rd Br	2912	728	3517	1581	30	784.1	150
42 Waerenga	95	24	1267	367	0	190.0	16
43 Matahuru	1722	430	6474	316	0	1532.6	163
44 Waikare	1817	454	2774	110	72	4874.7	317
45 Opuatia	206	51	4750	1450	94	684.7	84
46 Mangatangi	3524	881	6750	1100	6	7023.0	168
47 Waikato at Tuakau Br	1138	284	5163	350	684	6828.1	687
48 Ohaeroa	286	72	1142	60	123	301.6	47
49 Mangatawhiri	2	0	376	420	0	5990.1	7
51 Whakapipi	131	33	1783	40	1000	677.2	1000
52 Awaroa (Waiuku)	442	110	1500	26	27	153.8	248

Sub-catchment	Dairy	Dairy support	Sheep and beef	Forestry	Horticulture	Miscellaneous	Urban
50 Waikato at Port Waikato	6322	1581	7575	2065	950	8812.8	878

Appendix C Nutrient point sources and geothermal sources of TN

Table C-1: Nutrient loads estimated for point sources in the study area (t/year). From Vant (2014).

Source	Discharge sub-catchment	TN	TP
Wairakei Power Station and Taupo	Waikato at Ohaaki	395.7	0.0
Ohaaki Power Station	Waikato at Ohakuri	1.0	0.7
Kinleith pulp mill	Waikato at Waipapa	145.0	19.1
Tokoroa sewage	Mangamingi	32.0	6.5
Hautapu dairy factory* and Cambridge sewage	Waikato at Narrows	71.0	9.0
Te Rapa dairy and Hamilton sewage	Waikato at Horotiu Br	200.0	73.9
Te Kuiti sewage	Mangapu	26.0	4.0
Otorohanga sewage	Waipa at Pirongia-Ngutunui Rd Br	14.0	2.1
Te Awamutu dairy and sewage	Mangapiko	26.0	11.8
Horotiu meatworks and Ngaruawahia sewage	Waikato at Huntly-Tainui Br	98.0	16.3
Huntly sewage	Waikato at Rangiriri	14.0	4.2
Te Kauwhata sewage	Whangamarino at Island Block Rd	2.0	0.9
Meremere sewage	Waikato at Mercer Br	1.0	0.2
Tuakau rendering and Tuakau/Pukekohe sewage	Waikato at Port Waikato	51.0	22.1

* While the Hautapu dairy factory is located in the Mangaone sub-catchment, effluent is discharged to the Waikato River via a 6 km long pipeline.

Table C-2: Geothermal sources and estimated annual loads of nitrogen Adapted from Gibbs (1987)

Sub-catchment		Source	NH_4	TN
1	Pueto	Pueto	2	1
2	Waikato at Ohaaki	Otumuheki	4	4
2	Waikato at Ohaaki	Pararikiki	34	36
2	Waikato at Ohaaki	Wairakei (power station)	Included as point source	
4	Torepatutahi	Torepatutahi		7
6	Waiotapu at Homestead	Waiotapu	23.4	31.2
8	Waiotapu at Campbell	Waiotapu (part)	3.9	5.2

Appendix D NZEEM modelled sediment loads

Table D-1: Estimated mass erosion sediment loads estimated using NZEEM. Provided by Landcare Research.

Sub-catchment		Total load (t/yr)
1	Pueto	10347.6
2	Waikato at Ohaaki	12672.2
3	Waikato at Ohakuri	29766.9
4	Torepatutahi	4606.9
5	Mangakara	1758.9
6	Waiotapu at Homestead	4075.2
7	Kawaunui	893.2
8	Waiotapu at Campbell	1681.0
9	Otamakokore	1925.4
10	Whirinaki	491.7
11	Waikato at Whakamaru	16880.0
12	Waipapa	5208.6
13	Tahunaatara	8310.4
14	Mangaharakeke	932.7
15	Waikato at Waipapa	23066.0
16	Mangakino	10127.0
17	Mangamingi	1536.0
18	Whakauru	1826.6
19	Pokaiwhenua	8557.6
2	Little Waipa	2877.9
21	Waikato at Karapiro	17458.1
22	Karapiro	5595.5
23	Waikato at Narrows	3918.7
24	Mangawhero	2000.2
25	Waikato at Bridge St Br	1142.5
26	Mangaonua	5242.4
27	Mangakotukutuku	426.7
28	Mangaone	1673.0
29	Waikato at Horotiu Br	367.1
30	Waitawhiriwhiri	26.2
31	Kirikiriroa	85.5
32	Waikato at Huntly-Tainui Br	7592.5
114	Mangapiko	12720.7
115	Mangaohoi	36.1
116	Waipa at SH23 Br Whatawhata	14209.8
117	Mangauika	189.8

Sub-catchment		Total load (t/yr)
35	Waikato at Rangiriri	4005.7
36	Awaroa (Rotowaro) at Harrisr	1098.9
37	Awaroa (Rotowaro) at Sansons Br	6758.4
38	Waikato at Mercer Br	53988.6
39	Whangape	59029.9
40	Whangamarino at Island Block Rd	2944.6
41	Whangamarino at Jefferies Rd Br	5321.9
42	Waerenga	2440.0
43	Matahuru	12241.7
44	Waikare	3147.2
45	Opuatia	14985.9
46	Mangatangi	12016.4
47	Waikato at Tuakau Br	7212.4
48	Ohaeroa	522.8
49	Mangatawhiri	3721.5
50	Waikato at Port Waikato	9769.5
51	Whakapipi	1245.1
52	Awaroa (Waiuku)	594.4
100	Waipa at Mangaokewa Rd	937.4
101	Waipa at Otewa	14337.7
102	Mangaokewa	15712.6
103	Mangarapa	15843.4
104	Mangapu	17541.3
105	Mangarama	15111.5
106	Waipa at Otorohanga	5606.3
107	Waipa at Pirongia-Ngutunui Rd	18253.2
108	Waitomo at Tumutumu Rd	4541.9
109	Waitomo at SH31 Otorohanga	4033.7
110	Moakurarua	32976.9
111	Puniu at Bartons Corner Rd Br	7990.7
112	Puniu at Wharepapa	7270.2
113	Mangatutu	5004.8
118	Kaniwhaniwha	13949.5
119	Waipa at Waingaro Rd Br	13488.7
120	Ohote	782.4
121	Firewood	3986.1

Appendix E Phosphorus from mass soil erosion

In some parts of New Zealand, such as the soft East Cape geologies, TP yields are high due to the large amount of mass erosion (gullies, sediment) and phosphorus associated with this sediment. In national CLUES modelling (Parshotam *et al.*, 2012), an additional phosphorus source term, beyond the OVERSEER source in CLUES, is introduced to account for this mass erosion, because OVERSEER does not address this source itself. The question is whether it is necessary to include such an additional sediment-P term for the Waikato. It is most likely that sediment-P would be relevant to the Waipa River catchment, where there is steep erodible hill country.

The high end of the range of measured sediment specific yields in the Waikato River catchment is 165.5 t/km^2 for Waipa at Otewa, and 149.7 t/km^2 for Waitomo at Aranui Caves, all of which are in the Waipa River catchment. The yield for Waipa at Whatawhata, the most downstream monitoring sited in the Waipa River catchment, is 59.3 t/km^2. For flat areas the yield is approximately 2 t/km^2, and for the mid-mainstem Waikato monitoring sites, the yields are in the order of 1 t/km^2, reflecting the relatively stable morphology and the influence of lakes and reservoirs. In the context of sediment yields nationally, the yield from the Waipa River catchment are not particularly large.

In the national SPARROW model, the concentration of phosphorus on sediment was calibrated to be 16 kg/t (kg phosphorus per tonne of sediment), or 16%. From LENZ base layers[4], the concentration of acid-soluble phosphorus in soil material in the Waipa lies in the low to moderate range (LENZ technical documentation Table 2.10, Leathwick *et al.*, 2002), at about 15 kg/t. Applying 15 kg/t to a representative sediment yield of 15 t/km^2 gives a corresponding phosphorus yield of 22 kg/ha. Some sediment enrichment from soil source to stream monitoring location could be expected (because fines have higher phosphorus concentration per mass of sediment).

Measured phosphorus yields analysed as part of development of the SPARROW model are 1.2 kg/ha for Matahuru at Waiterimu Road (which is close to the Myjers site, but has lower sediment yield), 1.3 kg/ha for Waipa at Otewa, and 1 kg/ha for Waipa at Whatawhata. Therefore the contribution of mass erosion to phosphorus yields seems to be less than 2%. This does not imply that erosion processes do not contribute to TP loads. However, the sediment contribution is likely to be related to erosion of relatively P-enriched surficial soil, which is captured to some degree by OVERSEER.

[4] https://lris.scinfo.org.nz/layer/89-lenz-acid-soluble-phosphorous/ (date of last access, 5 June 2015)

Appendix F Calibration data: Concentration of TN, NO_3 and TP

Table F-1: Five-year measured annual nutrient concentrations (g/m^3) calculated for water quality monitoring sites in the study area.

	Monitoring site	Median TN	Median nitrate-N	95th percentile nitrate-N	TP
1	Pueto	0.55	0.45	0.54	0.10
2	Waikato at Ohaaki	0.14	0.04	0.08	0.01
3	Waikato at Ohakuri	0.22	0.08	0.17	0.02
4	Torepatutahi	0.63	0.50	0.83	0.10
5	Mangakara	1.58	1.30	1.68	0.08
6	Waiotapu at Homestead*	1.86	1.29	1.67	0.14
7	Kawaunui	2.99	2.60	3.10	0.09
8	Waiotapu at Campbell*	1.96	0.92	1.14	0.11
9	Otamakokore*	0.99	0.74	1.36	0.17
10	Whirinaki	0.86	0.77	0.89	0.06
11	Waikato at Whakamaru	0.27	0.10	0.25	0.02
12	Waipapa	1.36	1.21	1.56	0.14
13	Tahunaatara	0.78	0.56	0.85	0.05
14	Mangaharakeke	0.69	0.53	0.80	0.05
15	Waikato at Waipapa	0.34	0.16	0.32	0.03
16	Mangakino	0.76	0.65	0.88	0.05
17	Mangamingi	3.50	2.80	3.40	0.36
18	Whakauru	0.47	0.26	0.46	0.04
19	Pokaiwhenua	2.01	1.76	2.20	0.11
20	Little Waipa	1.79	1.58	2.15	0.07
22	Karapiro	0.86	0.52	1.76	0.09
23	Waikato at Narrows	0.41	0.24	0.54	0.03
24	Mangawhero	2.93	2.10	2.72	0.21
25	Waikato at Bridge St Br	0.44	0.24	0.58	0.04
26	Mangaonua	1.91	1.51	2.10	0.05
27	Mangakotukutuku	1.88	0.80	2.35	0.50
28	Mangaone	3.06	2.60	3.20	0.13
29	Waikato at Horotiu Br	0.44	0.26	0.54	0.04
30	Waitawhiriwhiri	2.11	0.88	1.27	0.10
31	Kirikiriroa	1.49	0.82	1.98	0.07
32	Waikato at Huntly-Tainui Br	0.59	0.36	1.00	0.05
33	Komakorau	2.90	1.31	5.30	0.10
34	Mangawara	1.89	0.77	3.35	0.23
35	Waikato at Rangiriri	0.60	0.36	0.96	0.06
36	Awaroa at Harris/Te Ohaki Br#	1.06	0.01	0.48	0.07

Monitoring site		Median TN	Median nitrate-N	95th percentile nitrate-N	TP
37	Awaroa at Sansons Br	0.99	0.70	1.39	0.01
38	Waikato at Mercer Br	0.66	0.37	0.89	0.05
39	Whangape	1.94	0.00	0.80	0.13
40	Whangamarino at Island Block Rd	1.98	0.07	0.87	0.16
41	Whangamarino at Jefferies Rd Br	1.09	0.63	2.50	0.10
42	Waerenga	1.12	0.82	1.42	0.05
43	Matahuru	1.31	0.72	1.91	0.11
44	Waikare#	2.50	0.00	0.25	0.15
45	Opuatia	1.07	0.74	1.08	0.03
46	Mangatangi	0.51	0.11	1.29	0.08
47	Waikato at Tuakau Br	0.60	0.32	0.88	0.06
48	Ohaeroa	1.83	1.53	1.92	0.03
49	Mangatawhiri	0.20	0.01	0.40	0.02
51	Whakapipi	3.88	3.50	5.35	0.04
52	Awaroa (Waiuku)	2.10	1.41	2.50	0.05
100	Waipa at Mangaokewa Rd	0.59	0.38	0.71	0.02
101	Waipa at Otewa	0.35	0.23	0.50	0.02
102	Mangaokewa	0.78	0.53	1.06	0.04
104	Mangapu	1.24	0.86	1.43	0.08
106	Waipa at Otorohanga	0.60	0.37	1.15	0.03
107	Waipa at Pirongia-Ngutunui Rd	0.86	0.57	1.54	0.06
108	Waitomo at Tumutumu Rd	0.77	0.63	0.83	0.02
109	Waitomo at SH31 Otorohanga	0.76	0.52	0.93	0.04
111	Puniu at Bartons Corner Rd Br	0.91	0.65	1.31	0.05
113	Mangatutu	0.51	0.38	0.91	0.02
114	Mangapiko	2.10	1.41	2.65	0.26
115	Mangaohoi	0.37	0.23	0.42	0.05
116	Waipa at SH23 Br Whatawhata	0.94	0.68	1.60	0.07
117	Mangauika	0.32	0.21	0.29	0.01
118	Kaniwhaniwha	0.59	0.35	1.00	0.03
120	Ohote	1.32	0.50	1.39	0.08

*2-year median annual TP concentration

#No river sampling, lake median concentrations from WRC: Awaroa at Harris/Te Oharki Br = Lake Waahi and Waikare = Lake Waikare

Appendix G Calibration data: Loads TN and TP

Table G-1: Measured TN mean annual loads (t / year) calculated using the Rating Curve method for water quality monitoring sites with concurrent flow data. Results of the boot-strapping assessment also provided.

Map ID	Monitoring site	Mean annual load	Boot-strapping results			
			Lower 90%	Upper 90%	SD	Mean of mean annual loads
Input	Waikato at Reids Farm	345.7	331.4	366.5	9.9	345.2
2	Waikato at Ohaaki	801.4	731.2	886.2	42.6	801.0
3	Waikato at Ohakuri	1519.8	1376.2	1719.7	95.4	1532.4
6	Waiotapu at Homestead	298.7	290.3	313.3	7.1	300.3
9	Otamakokore	48.5	46.0	58.1	6.5	50.4
11	Waikato at Whakamaru	2059.4	1844.9	2514.1	172.9	2090.5
13	Tahunaatara	169.3	154.9	182.9	8.5	169.8
15	Waikato at Waipapa	2653.7	2537.0	2788.4	74.9	2664.0
16	Mangakino	211.5	204.0	223.0	5.4	212.2
19	Pokaiwhenua	379.4	369.6	390.0	6.3	379.0
23	Waikato at Narrows	4414.0	4127.0	4748.8	167.1	4391.2
25	Waikato at Bridge St Br	4322.6	4110.3	4499.5	106.3	4325.6
26	Mangaonua*	78.2	74.0	85.7	7.3	78.2
29	Waikato at Horotiu Br	4384.7	4093.5	4620.6	146.7	4342.2
32	Waikato at Huntly-Tainui Br	10300.8	9543.1	10988.5	408.3	10283.2
35	Waikato at Rangiriri	9350.5	8813.4	9893.6	320.9	9274.0
38	Waikato at Mercer Br	13705.7	12885.2	14724.6	558.4	13800.0
43	Matahuru	107.9	101.6	121.5	6.0	109.5
46	Mangatangi	115.8	102.3	127.1	7.5	115.9
47	Waikato at Tuakau Br	13191.2	12512.0	14099.2	474.1	13247.5
49	Mangatawhiri	17.9	15.2	24.6	2.9	18.7
51	Whakapipi	121.1	114.1	127.2	3.5	121.3
11	Waipa at Otewa	242.2	230.3	257.8	7.4	243.4
12	Mangaokewa	188.7	182.0	197.9	4.6	188.9
14	Mangapu	714.2	662.2	771.0	31.5	711.3
17	Waipa at Pirongia-Ngutunui Rd Br	2967.7	2784.5	3146.1	108.4	2956.7
18	Waitomo at Tumutumu Rd	61.5	58.3	65.1	1.8	61.1
111	Puniu at Bartons Corner Rd Br	737.3	681.8	779.5	28.9	732.2
113	Mangatutu	99.6	86.0	111.9	7.8	99.3
116	Waipa at SH23 Br Whatawhata	3985.5	3792.0	4164.6	108.6	3960.6

*Flow adjusted by ratio of Wood's et al flow estimated for the Mangaonua at Dreadnought flow monitoring station and the water quality monitoring site.

Table G-2: Measured TP mean annual loads (t/year) calculated using the Rating Curve method for water quality monitoring sites where concurrent flow data exists. Results of the boot-strapping assessment also provided..

Map ID	Monitoring site	Mean annual load	Boot-strapping results			
			Lower 90%	Upper 90%	SD	Mean of mean annual loads
Input	Waikato at Reids Farm	27.6	26.4	29.2	0.9	27.7
2	Waikato at Ohaaki	58.8	52.8	68.0	4.5	58.9
3	Waikato at Ohakuri	135.4	123.5	144.1	5.5	134.8
6	Waiotapu at Homestead	40.9	32.6	58.7	8.2	42.8
9	Otamakokore	9.7	7.7	12.4	1.3	9.6
11	Waikato at Whakamaru	160.3	149.3	182.0	10.1	163.0
13	Tahunaatara	15.6	11.1	19.7	2.4	15.9
15	Waikato at Waipapa	218.8	198.0	239.3	12.0	218.1
16	Mangakino	12.2	11.4	13.4	0.5	12.2
19	Pokaiwhenua	19.1	18.0	21.0	0.9	19.2
23	Waikato at Narrows	301.5	270.7	334.5	18.4	301.4
25	Waikato at Bridge St Br	351.9	327.0	372.4	12.9	349.9
26	Mangaonua*	3.8	3.3	4.9	0.5	3.9
29	Waikato at Horotiu Br	353.2	317.4	392.8	19.9	351.9
32	Waikato at Huntly-Tainui Br	719.8	667.2	776.2	33.3	719.9
35	Waikato at Rangiriri	788.5	729.8	847.5	35.8	790.2
38	Waikato at Mercer Br	960.5	875.1	1026.4	41.3	953.0
43	Matahuru	9.3	6.6	13.2	1.9	9.5
46	Mangatangi	13.1	11.7	15.6	1.0	13.3
47	Waikato at Tuakau Br	958.7	871.3	1047.7	50.7	957.9
49	Mangatawhiri	1.6	1.2	2.3	0.3	1.7
51	Whakapipi	5.0	4.2	5.7	0.4	5.0
11	Waipa at Otewa	30.5	24.5	38.1	4.1	30.9
12	Mangaokewa	11.0	9.5	12.8	1.0	11.0
14	Mangapu	38.5	34.4	45.4	2.9	38.4
17	Waipa at Pirongia-Ngutunui Rd Br	150.5	123.1	183.3	16.0	152.2
18	Waitomo at Tumutumu Rd	7.3	4.7	10.6	1.6	7.3
111	Puniu at Bartons Corner Rd Br	33.9	30.9	38.0	2.2	33.9
113	Mangatutu	3.5	2.9	4.4	0.4	3.6
116	Waipa at SH23 Br Whatawhata	284.6	254.1	308.0	14.1	285.5

*Flow adjusted by ratio of Wood's et al. flow estimated for the Mangaonua at Dreadnought flow monitoring station and the water quality monitoring site.

Table G-3: Mean annual loads (t/year) calculated from measurements using the ratio method for sites without suitable flow data..

Monitoring site		TN	TP
1	Pueto	96.4	11.7
4	Torepatutahi	79.0	12.1
5	Mangakara	24.0	2.0
7	Kawaunui	11.6	2.1
8	Waiotapu at Campbell	102.4	5.7
10	Whirinaki	11.5	0.9
12	Waipapa	59.9	7.8
14	Mangaharakeke	29.8	2.2
17	Mangamingi	274.4	27.8
18	Whakauru	4.9	1.4
20	Little Waipa	153.6	5.3
22	Karapiro	11.8	5.7
24	Mangawhero	44.5	8.7
27	Mangakotukutuku	29.8	8.7
28	Mangaone	96.4	5.2
3	Waitawhiriwhiri	29.1	1.4
31	Kirikiriroa	11.6	0.6
33	Komakorau	240.7	10.4
34	Mangawara	620.4	82.9
36	Awaroa (Rotowaro) at Harris/ Te Ohaki Br	73.0	5.5
39	Whangape	386.3	31.5
40	Whangamarino at Island Block Rd	654.5	54.9
41	Whangamarino at Jefferies Rd Br	151.8	15.0
42	Waerenga	9.0	1.9
45	Opuatia	81.3	5.1
48	Ohaeroa	16.7	0.4
52	Awaroa (Waiuku)	36.4	0.9
100	Waipa at Mangaokewa Rd	24.7	0.6
106	Waipa at Otorohanga	411.7	20.8
109	Waitomo at SH31 Otorohanga	121.4	8.2
114	Mangapiko	428.6	76.5
115	Mangaohoi	0.9	0.1
117	Mangauika	4.2	0.2
118	Kaniwhaniwha	106.3	9.2
120	Ohote	35.3	2.2

Appendix H Concentration conversion factors TN and TP

Table H-1: Concentration conversion factors for the determination of nutrient loads using the ratio method. The factors were taken from the CLUES model, their derivation is discussed in (Oehler and Elliott, 2011).

Subcatchment		Concentration conversion factors	
		TN	TP
1	Pueto	0.99	0.83
4	Torepatutahi	0.98	0.88
5	Mangakara	0.78	0.55
7	Kawaunui	0.78	0.66
8	Waiotapu at Campbell	0.91	0.80
10	Whirinaki	0.61	0.57
12	Waipapa	0.91	0.84
14	Mangaharakeke	0.93	0.89
17	Mangamingi	0.76	0.78
18	Whakauru	0.95	0.96
20	Little Waipa	0.81	0.86
21	Waikato at Karapiro	0.86	0.85
22	Karapiro	0.82	0.51
24	Mangawhero	0.89	0.57
27	Mangakotukutuku	0.77	0.70
28	Mangaone	0.87	0.70
30	Waitawhiriwhiri	0.74	0.70
31	Kirikiriroa	0.74	0.70
33	Komakorau	0.88	0.70
34	Mangawara	0.62	0.57
36	Awaroa (Rotowaro) at Harris/Te Ohaki Br	0.91	0.75
37	Awaroa (Rotowaro) at Sansons Br	0.59	0.31
39	Whangape	0.93	0.75
40	Whangamarino at Island Block Rd	0.74	0.72
41	Whangamarino at Jefferies Rd Br	0.49	0.45
42	Waerenga	0.48	0.28
44	Waikare	0.73	0.73
45	Opuatia	0.59	0.28
48	Ohaeroa	0.73	0.61
50	Waikato at Port Waikato	0.84	0.83
52	Awaroa (Waiuku)	0.68	0.72
100	Waipa at Mangaokewa Rd	0.94	0.94

Subcatchment		Concentration conversion factors	
		TN	TP
103	Mangarapa	0.65	0.41
105	Mangarama	0.54	0.59
106	Waipa at Otorohanga	0.74	0.61
109	Waitomo at SH31 Otorohanga	0.66	0.53
110	Moakurarua	0.69	0.37
112	Puniu at Wharepapa	0.76	0.67
114	Mangapiko	0.70	0.49
115	Mangaohoi	0.96	0.87
117	Mangauika	0.94	0.57
118	Kaniwhaniwha	0.61	0.41
119	Waipa at Waingaro Rd Br	0.67	0.63
120	Ohote	0.75	0.70
121	Firewood	0.67	0.36

Appendix I Expert panel workshops

The nutrient models were developed using data from a range of sources and were calibrated, at least in part, according to *a priori* expert knowledge of the study area. To ensure that inferred information was as robust as possible, NIWA hosted two expert panel workshops (15th and 22nd May 2015) where independent experts from a number of organisations provided their considered opinion on key areas where data and information are limited. The process is described in this appendix, a summary of the knowledge gained is given in Appendix J.

Pre-workshop data summaries

Several key biophysical factors influence nitrogen mobilisation, attenuation and actual leaching rate losses. These factors are determined principally by catchment hydrology and hydrogeology, as well as land use. Many inter-related characteristics ultimately determine the nitrogen attenuation and loss within each sub-catchment. The data required to characterise catchment nutrient losses are not available at consistent temporal and spatial scales across all 74 sub-catchments in the Waikato and Waipa River catchments. For example, more information regarding groundwater age is available for the upper Waikato sub-catchments than those in the lower Waikato or Waipa River catchments, and similar differences in information exist regarding the likelihood and extent of reducing conditions. Despite these limitations in the homogeneity of data, inferences can be made regarding groundwater age, the existence of reducing conditions and therefore of the likelihood of nitrogen attenuation and lags in terms of delivery of nitrogen to surface waters. These inferences obviously rely on interpretation using expert opinion.

To assist with the process, NIWA:

- sourced key data from a range of organisations
- created a database to store, manage and retrieve these data
- queried the data in the database to prepare a two-page hardcopy summary for each sub-catchment
- provided these summaries to the expert panel ahead of the workshops to provide a context for their review.

Key sources of information included:

- Data collected as part of WRC routine surface and groundwater monitoring, including:
  - Regional surface water quality monitoring.
  - Regional groundwater quality monitoring.
  - Regional hydrometric monitoring.
- Data derived from specific surface and groundwater monitoring campaigns undertaken by WRC to address specific information gaps.
- Review of data collected as components of routine WRC monitoring activities (such as gauging surveys undertaken as components of surface water hydrology), and use of these data to assess relative contributions of groundwater to base flow; and

- Water quality data collected by NIWA as part of the National River Water Quality Monitoring Network (NRWQN).

In addition to summarising key data, the data review also identified areas where data were limited (or absent), allowed cross-referencing of nomenclature that exists across several agencies for the various subcatchment and monitoring locations, summarised subcatchment land use, and visually summarised trends in measured concentrations of TP and TN. An example summary is included in Figure I-1.

Expert panel

Attendees at the workshops were selected because of their recognised knowledge and expertise, with respect to the Healthy Rivers subcatchments, in the areas of: geology; hydrogeology; attenuation of nitrogen in the vadose zone; shallow and deep groundwater systems; and land use and trends in land use change over previous decades. The attendees are listed in Table 5-1 along with their affiliation and contribution.

Table 5-1: Attendees at the expert panel workshops. The initial workshop was held on 15/5/2015, and a follow up workshop was held on 22/5/2015. Attendees in bold attended both workshops.

Name	Organisation	Role
Channa Rajanayaka	Aqualinc	Hydrogeology
Murray Close	ESR	Hydrogeology/groundwater chemistry
Paul White	**GNS**	**Geology/hydrogeology**
Roland Stenger	Lincoln Agritech	Hydrogeology/groundwater chemistry
David Payne	MRP	Hydrology
Neale Hudson	**NIWA**	**Documentation**
Sandy Elliott	**NIWA**	**Facilitator/modeller**
Tony Petch	**Tony Petch Consultants**	**Hydrogeology/geology/land use change**
Bevan Jenkins	WRC	Hydrogeology/hydrology
Dan Borman	WRC	Land use change/geospatial analysis
John Hadfield	**WRC**	**Hydrogeology/hydrology**
Jonathan Cowie	**WRC**	**Project manager**
Evelien van de Ven	WRC	Documentation

Waikato at Bridge St Br

Zone: LMW **Group:** Lower Middle Waikato: above Taupiri **Map ID:** 25

Catchment area (km²): 5072.38 (this catchment)
830735.92 (upstream incl. Taupo)
487783.8 (upstream excl. Taupo)

NZReach: 3017901 **u/s km:** 119.2
WRC ID: HM3 **Order:** 7
LAWA ID: **NEMaR ID:** NAT-HM03

Upstream_catchment(s)
28 Mangaone
26 Mangaonua
27 Mangakotukutuku
23 Waikato at Narrows

Catchment summary

Water budget	Flux m³/s	Depth mm/y
Rainfall	1.9	1179
Actual evaporation	1.3	797
Groundwater inflow	0.2	124
Surface inflow	0.5	311
Quickflow surface outflow	0.6	373
Baseflow outflow	0.7	435

Land use	%	cum %
Dairy	28.66	23.13
SB Intensive	32.38	24.35
SB Hill	0.02	4.81
Other Pasture	0.16	0.17
Forestry	0.20	29.35
Native Forest	4.34	10.12
Maize	3.02	0.38
Horticulture	3.95	0.30
Urban	19.69	2.47
Miscellaneous	7.58	4.92

Hydrogeology descriptors	
Dominant surface geology	Tauranga Group
Geology water table aquifer	Tauranga Group
Geology principal aquifer	Tauranga Group
Geomorphology comment	River plain dissected by Waikato River
Principal aquifer transmissivity	247 m²/d
Principal aquifer velocity estimate	0.00988 m/d
Fraction low drainage	0.3744 (raw)
Fraction low drainage	0.0475 (cumulative)

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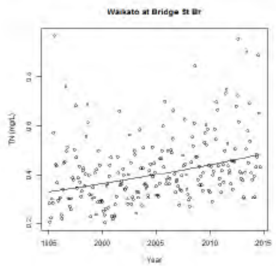
Waikato at Bridge St Br

Water quality data	
Apparent attenuation fraction	0.5626
Cumulative N sources t/year	7683.86
Groundwater Fe g/m³	no data
Groundwater N concentration g/m³	no data
Groundwater N concentration trend g/m³/decade	insufficient data
Groundwater P g/m³	no data
Measured N load t/year	4322.57
Stream TN concentration g/m³	0.437



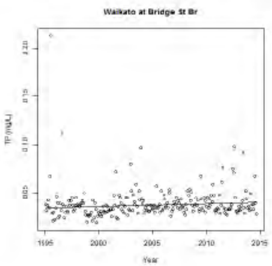


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Figure I-1: Example sub-catchment two-page data summary sheets. Waikato at Bridge St Br.

Several workshop attendees contributed the data used to populate the database and create the individual sub-catchment summaries – they brought this detailed knowledge to the workshop. Other attendees have considerable knowledge of the relationships between land use, groundwater processes and surface water quality in the Waikato region - they critically evaluated the information provided, and contributed their expert knowledge at the workshop.

Each of the workshops commenced with a summary of the objectives of the Healthy Rivers project, as well as clear direction in terms of expectations from the workshop. The following approach was followed to provide the information required:

1. The first workshop session covered the information available and provided a consensus of expert opinion regarding key information that was most lacking for 13 representative sub-catchments:
   i. groundwater age
   ii. the relative proportions of surface and groundwater within a catchment, hydrological response to rainfall, and the likelihood that groundwater is lost directly from the sub-catchment
   iii. the likelihood that geological materials favoured attenuation of nitrate in groundwater
   iv. land use, recent and historical trends in land use and the impact of land use (including point source, urban and industrial activities) on surface and groundwater quality (e.g., could recent land use change result in higher future nitrogen loads not currently seen in the sub-catchment), and
   v. the possibilities of inferring information from neighbouring sub-catchments, or sub-catchments having similar conditions was also explored.
2. Notes, opinions and other information were recorded while the attendees deliberated and debated the processes within each catchment, allowing a consensus view to be captured during the workshop.
3. The remaining 61 sub-catchments were considered outside of the workshop by groups of experts who focussed on the following areas of information:
   i. Drs Stenger and Close - redox potential and implications for attenuation.
   ii. Drs Stenger, Rajanayaka and Hadfield – groundwater age (expressed as mean residence time, MRT) and related matters.
   iii. Mr White - hydrology, hydrogeology, piezometric surfaces, geology.
   iv. Their expert opinions were captured and combined in a single spreadsheet with the outcomes from the first workshop.
4. During the second workshop, the combined materials were reviewed by attendees on a sub-catchment by sub-catchment basis; additional details were added to the expert opinions, and where necessary, previously expressed opinions were modified. Once again, notes were recorded, and these were reviewed and modified to provide a consensus view during the workshop.

5. Following the workshop, the notes that were recorded for all sub-catchments by all attendees were combined to create a single record which represented the consensus view (reproduced in Appendix J). The process used to combine the opinions allowed the change history to be documented as well.

Appendix J Expert panel workshops: Summary of sub-catchment knowledge

The expert knowledge obtained during the workshops and in post-workshop evaluation, summarised in this appendix, has been used extensively during the development of the nitrogen and phosphorus models.

In the following table summarises the state of knowledge for each sub-catchment. Key information includes:

- Sub-catchment location reference (river catchment and downstream NZ reach number).
- Hydrology e.g.,
  - Amount of groundwater outflow as a percentage of the total runoff generated and the number of gaugings used to assess this.
  - Surface and groundwater age.
  - Approximate groundwater depth.
  - A comparison of the estimation of catchment runoff derived during the project with that derived from earlier estimates (Woods et al., 2006).
- Catchment characteristics, e.g., slope, soil, underlying geology.
- Land use and historical land use change.
- Likely catchment attenuation rates (low, moderate or high).
- Whether flow data are available allowing loads to be assessed using the rating method.
- The likelihood of extra nitrogen loads to come due to the delayed response to historical land use change (i.e., nitrogen held in groundwater).

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Sub-Catchment:	1. Pueto
Catchment Group:	Upper Waikato: above Ohakuri
Comments:	Surface flow is dominated by baseflow, and groundwater outflow from the catchment is unlikely. The water table is typically in the Oruanui Formation. Water tables are typically deeper than 3 m. Aquifers drain the Kaingaroa Plateau and this recharge flows to Pueto Stream. Indicative age is likely to be about ~25 yr , and some private dating data may become available. A private flow recorder exists, data not accessed. Baseflow dominated, stable, no quickflow. Land use tending to S&B, forestry removal ongoing, potential for dairying. Catchment has responded to land use to date (30% of the catchment converted to pasture since 1996) with nitrate concentration increasing since 2000, indicating a quick component of catchment response. Increase in TN concentration is likely to continue, considering that concentrations have not yet reached levels expected of the intensive land use. The dairy fraction may be under-reported due to lags in capturing land use information, and intensification since c2011 around Tauhara Forest. Major historical point source = land based disposal (effluent from MDF plant). Shallow groundwater has mixed oxic and anoxic groundwater, denitrification occurring. Overall moderate attenuation expected, with considerable load to come.
Groundwater outflow:	-
Flow monitored:	-
Likely attenuation:	Moderate
Load to come:	Yes
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	2. Waikato at Ohaaki
Catchment Group:	Upper Waikato: above Ohakuri
Comments:	Surface flow is dominated by baseflow, and groundwater outflow from the catchment is unlikely. The water table is typically in the Oruanui Formation. Water tables are typically deeper than 3 m. Many small valleys are dry above the Waikato River. The catchment includes geothermal fields (Wairakei, Taupo, Rotokawa). A single groundwater age value exists for well 68_162 (62 yr), and a surface water age at Taupo Gates (site 1131_027) (8 yr). Although the increment of flow from this sub-catchment to the main stem is relatively minor, the lag from the catchment is likely to be moderate to long given the baseflow domination and similar character to surrounding catchments. There has been a small amount of dairy conversion in the subcatchment over the last two decades prior to 2012, but rapid conversion recently around Broadlands Forest not likely to be reflected in 2012 land use layer. The medium depth is nearly all oxic except for some reducing zones along the river at the lower end of the catchment. The shallow depth is about 60:40 reducing zones:oxic throughout the catchment. Attenuation is likely to be low to moderate depending on the groundwater flow path. Moderate to long lag and moderate attenuation is anticipated, which should be compared with apparent attenuation from other streams.
Groundwater outflow:	-
Flow monitored:	Yes
Likely attenuation:	Moderate
Load to come:	Yes. Minor for pre 2012
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	3. Waikato at Ohakuri
Catchment Group:	Upper Waikato: above Ohakuri
Comments:	Surface flow is dominated by baseflow, and groundwater outflow from the catchment is unlikely. The water table is typically in the Tauranga Group and volcanic lithologies. Water tables are typically deeper than 3 m. Many small streams flow into the Waikato River. Many small valleys are dry above the Waikato River. The catchment includes geothermal fields (Orakei Korako and Ngatamariki). There is 1 groundwater age at well 72_3318 of >150 years and a surface water age for site 672_1 of 95 years. A long lag is indicated by available data and the hydrogeologic setting. Gradual removal of forest over past decades. Large scale deforestation over since 1972 adn recently, coupled with moderately long lag and moderate attenuation suggests that the load from the catchment will increase considerably in the future from past changes. There has been additional recent (post 2012) landuse change around Tahorakuri that may not yet have been captured in landuse layers, and this will bring additional load. The medium groundwater depth is nearly all oxic; the shallow depth is a mixture of reducing zones and oxic. Attenuation is likely to be low to moderate depending on the groundwater flow paths.

Groundwater outflow:	-
Flow monitored:	Yes
Likely attenuation:	Low Moderate
Load to come:	Yes, considerable
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	4. Torepatutahi
Catchment Group:	Upper Waikato: above Ohakuri
Comments:	Surface flow is dominated by baseflow, and groundwater outflow from the catchment is unlikely. The water table is typically in the Whakamaru Group. Water tables are typically deeper than 3 m. Many small valleys are dry above the Reporoa Basin. Aquifers drain the Kaingaroa Plateau and spring-fed streams cross the Basin. Several groundwater ages exist: 80-120 yr, occasional young shallow groundwater influencing springs. Surface water age 125 yr, vadose zone age 77 yr. Baseflow dominated (>95%). Groundwater flow through deep ignimbritic material -which is fractured, with limited storage; large volume groundwater stored in unwelded ignimbritic lithologies. Sequences of paleosols impede vertical recharge, promote short flow paths to springs. The catchment is spring dominated, gaining flow in lower half of catchment. Thermal measurements of water temperature provide good delineation of groundwater inflows. Mix of younger and older groundwater influenced by upstream land use. Redox indicates most medium depth oxidised, Land use has intensified over previous 50 years. Gradual TN increase since 1995 probably reflects past land use change, as there has been little land use change in the last two decades. Current concentrations are a bit low considering the catchment is about half dairy and intensive sheep and beef, suggesting (in conjunction with the large ages) that concentrations will continue to increase . Groundwater denitrification potential is at the low end of the range. Overall, attenuation is likely to be low and there is likely to be considerable load to come.
Groundwater outflow:	-
Flow monitored:	-
Likely attenuation:	Low
Load to come:	Yes, considerable
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	5. Mangakara
Catchment Group:	Upper Waikato: above Ohakuri
Comments:	Surface flow is dominated by baseflow, and groundwater outflow from the catchment is likely. The water table is typically in the Tauranga Group . Water tables are typically deeper than 3 m. The catchment drains from the Paeroa Range to the Reporoa Basin. A single surface water age value of 38 years exists for site 0380_002. Stream age and hydrogeology information infers moderate lag. TN concentrations have increased by less than 50% since 2000, and there has not been much recent conversion of land use. Current high concentrations probably largely reflect current land use, with minor adjustment to past catchment changes expected. Medium groundwater depth is largely oxic with some reducing zones near outlet; shallow has much more reducing zones. Attenuation will depend on groundwater flow paths and is likely to be low (~=Waiotapu).
Groundwater outflow:	Y, 60%, but only 9 gaugings so neglect
Flow monitored:	-
Likely attenuation:	Low
Load to come:	Minor
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	6. Waiotapu at Homestead
Catchment Group:	Upper Waikato: above Ohakuri

Comments:	Surface flow is dominated by baseflow, and groundwater outflow from the catchment is likely. The water table is typically in the Tauranga Group. Water tables are typically deeper than 3 m. Aquifers drain the Kaingaroa Plateau to the east and the Paeroa Range to the west. Spring-fed streams cross the Reporoa Basin. Groundwater age estimates range from 48-170 years. Reporoa Spring at the end of Handcock Rd has an age of 11 years. Most quickflow is generated on flats, with peaky flow. There is a tendency to short lag times due to artificial drainage. Redox status - medium depth = oxidised, band of reducing material through catchment (along river course). Much reduced groundwater at shallow depth, peat pockets, reducing conditions in shallow pumice sediments, with reducing conditions adjacent to stream. TN concentrations are high given the land use, but this is in part due to a geothermal influence, although they are only about 1/8 of the estimated total generated in the upstream catchment. Concentrations are increasing slightly despite stable land use, suggesting a response to historical land use change or intensification. Overall attenuation regarded as moderate.
Groundwater outflow:	Y, 40%. However, model-measurement comparison suggests most load appears at the catchment outlet already. Potentially, lower-concentration inputs are bypassing.
Flow monitored:	Yes
Likely attenuation:	Moderate
Load to come:	?
Flow comparison (Woods et al., 2006):	Woods flow larger than measured. Only 25% forest, so unlikely that Woods underestimating forest aet is the cause.

Sub-Catchment:	7. Kawaunui
Catchment Group:	Upper Waikato: above Ohakuri
Comments:	Surface flow is dominated by baseflow, and groundwater outflow from the catchment is likely. The water table is typically in the Tauranga Group . Water tables are typically deeper than 3 m. The catchment drains from the Paeroa Range to the Reporoa Basin. Modelled age distribution 78 yr for whole catchment, 48 yr for developed areas. Stream flows are low, with groundwater discharge at base of catchment. Part of catchment underlain by old lakebed, therefore expect reasonable denitrification through shallow sediments. Significant possibility that deeper, older groundwater is bypassing the monitoring site; the monitoring site therefore is likely to reflect younger quickflow discharge, which may explain scatter in TN and TP. These has been an approximate doubling of TN concentrations since 2000, and concentrations are high and may now be levelling off at a concentration reflecting the land use. The land use has not intensified much in that period, suggests a response to development in the preceding decades. Overall summary of attenuation - Oxic for medium depth; some reducing zones for shallow depth. Attenuation likely to be low to moderate, and little further response to current land use is expected.
Groundwater outflow:	Y, 80%, 10 gaugings
Flow monitored:	-
Likely attenuation:	Low Moderate
Load to come:	Minor?
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	8. Waiotapu at Campbell
Catchment Group:	Upper Waikato: above Ohakuri
Comments:	Surface flow is dominated by baseflow, and groundwater outflow from the catchment is unlikely. The water table is typically in the Rotoiti Formation. Water tables are typically deeper than 3 m. The catchment drains Rotoiti Formation (in the north) and the Kaingaroa Plateau (in the east). The Waiotapu Geothermal field is located in the catchment. There is a surface water age for site 1303_4 of 29 years MRT and there are 2 groundwater ages (well 72_3577 of 105 years and 72_3566 of 131 years). Available information and the hydrogeologic setting indicate the lag is moderately long. The catchment is baseflow dominated with geothermal inflows, which could be significant N input. Low denitrification in the recent pumice soils likely. TN concentrations have increased from about 1.5 to 2.0 g/m3 since 1996 despite the modest changes in land use in the cumulative upstream catchment. The concentrations are high considering the land use, and probably reflects a geothermal influence. Older concentration data are available from previous studies (1970s). Potential exists for denitrification of shallow groundwater through paleosols, deeper groundwater has relatively limited potential for denitrification. There is some uncertainty about the load to come, given the difficulty in interpreting concentration trends and values and the geothermal influence.
Groundwater outflow:	-
Flow monitored:	-

Likely attenuation:	Low
Load to come:	Yes?
Flow comparison (Woods et al., 2006):	Comparison with Woods is OK, even though nearly 50% forest

Sub-Catchment:	9. Otamakokore
Catchment Group:	Upper Waikato: above Ohakuri
Comments:	Surface flow is dominated by baseflow, and groundwater outflow from the catchment is unlikely. The water table is typically in the Rotoiti Formation. Water tables are typically deeper than 3 m. The catchment drains Rotoiti Formation and Whakamaru ignimbrite. The Waikiti geothermal field is within this catchment One groundwater age result for well 66_6 (30 yr), and a surface water age of 140 years at site 0683_004 exist. The latter data and hydrologic setting suggests lag is likely to be at least moderately long. TN concentrations have increased gradually, but there has not been much land use change. The long surface ages and fairly low concentrations given the land use suggest some load to come in response to past land use change. Both depths mainly oxic with some reducing zones in Shallow depth, mainly in upper catchment. Overall, lag likely to be long, attenuation likely to be low.
Groundwater outflow:	-
Flow monitored:	Yes
Likely attenuation:	Low
Load to come:	Yes
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	10. Whirinaki
Catchment Group:	Upper Waikato: above Ohakuri
Comments:	Surface flow is dominated by baseflow, and groundwater outflow from the catchment is likely. The water table is typically in the Rotoiti Formation. Water tables are typically deeper than 3 m. The catchment drains Rotoiti Formation. There is a surface water age of 72 years for site 1323_1. This and the hydrogeologic character of the sub-catchment indicates a long lag time. Hydrogeology character from surrounding catchments suggests long lag time. Medium depth is all oxic; Shallow depth has some reducing zones in upper catchment (~30-40%). TN concentrations are increasing gradually, and are probably low considering current land use, suggesting some further adjustment to come from historical land use change (mainly prior to 2000) and ongoing gradual intensification. Attenuation is likely to be low.
Groundwater outflow:	Y? Only one gauging. Set to zero
Flow monitored:	-
Likely attenuation:	Low
Load to come:	Yes
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	11. Waikato at Whakamaru
Catchment Group:	Upper Waikato: above Wakamaru
Comments:	Surface flow is dominated by baseflow, and groundwater outflow from the catchment is unlikely. The water table is typically in the ignimbrite. Water tables are typically deeper than 3 m. Many small stream valley are dry above the Waikato River. The catchment includes many domes of the Maroa Volcanic Centre. There is a surface water age for site 1303_4 of 29 years MRT and there are 2 groundwater ages (well 72_3577 of 105 years and 72_3566 of 131 years). Available information and the hydrogeologic setting indicate the lag is moderately long. Considerable land use change has occurred recently, with conversion of forest and S&B to irrigated dairy - currently 25% dairy. Medium depth is nearly all oxic, with a small component of reducing zones around the river; shallow depth is mostly reducing zones. Attenuation will depend on groundwater flow path and is likely to be moderate.
Groundwater outflow:	-
Flow monitored:	Yes
Likely attenuation:	Moderate
Load to come:	Yes

Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	12. Waipapa
Catchment Group:	Upper Waikato: above Wakamaru
Comments:	Surface flow is dominated by baseflow, and groundwater outflow from the catchment is likely. The water table is typically in the Mokai Formation. Water tables are typically deeper than 3 m. Many small stream valley are dry above approximately the elevation of Mokai. The catchment includes the Mokai geothermal field. A single stream age for site 1202_6 (48 yr) exists. A moderately long lag time is indicated. Currently land use is being actively converted to dairying; TN concentrations have increased markedly from 2000, reflecting a short term response to the fairly modest increase in dairy and intensive sheep and beef, and the concentrations may even be levelling off. The lag times suggest that there will be some load to come, however. Medium depth is nearly all OX; Shallow depth is mostly reducing zones. Attenuation is likely to be low to moderate depending on groundwater flow paths.
Groundwater outflow:	Y, 30%, continous flow record (although we did not have this for load estimation)
Flow monitored:	-
Likely attenuation:	Low Moderate
Load to come:	Yes?
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	13. Tahunaatara
Catchment Group:	Upper Waikato: above Wakamaru
Comments:	Surface flow is dominated by baseflow, and groundwater outflow from the catchment is likely. The water table is typically in the Tauranga Group. Water tables are typically deeper than 3 m. Aquifers in this catchment drains from the Mamaku Plateau, including Horohoro. Many small valleys are dry above the Waikato River. A single surface water age exists for site 0934_001 (34 yr), which suggests moderately long lag times. TN concentrations have increased gradually and to a minor degree since 2000. Recent increases in dairy and intensive sheep and beef are probably not yet reflected in TN concentrations. Both depths mainly oxic with some reducing zones in shallow depths in upper catchment. Attenuation is likely to be low.
Groundwater outflow:	Only 10%, ignore
Flow monitored:	Yes
Likely attenuation:	Low
Load to come:	Yes
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	14. Mangaharakeke
Catchment Group:	Upper Waikato: above Wakamaru
Comments:	Surface flow is dominated by baseflow, and groundwater outflow from the catchment is likely. The water table is typically in the Ohakuri Formation. Water tables are typically deeper than 3 m. This catchment drains from the southern end of the Mamaku Plateau. Many small valleys are dry in the catchment. A single surface water age value of 32 years exists for site 0359_001. The available data and hydrogeology suggests a moderately long lag time. Land use is predominantly forestry, with minor recent (2000-2010) history of land use conversions, and considerable forest harvesting since 2012. The ages suggest a moderately long lag time. There has been a significant increase of TN concentrations after 2000, increasing by a factor of 2-3, suggesting a rapid response component. The resonse suggesting that water quality may be reflecting activities in the developed part of the catchment near the outlet. Medium depth is largely oxic with some reducing zones near outlet; shallow has much more reducing zones. Attenuation will depend on groundwater flow paths and is likely to be low to moderate.
Groundwater outflow:	Y, but only 1 gauging. Neglect
Flow monitored:	-
Likely attenuation:	Low Moderate
Load to come:	Maybe

Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	15. Waikato at Waipapa
Catchment Group:	Upper Waikato: above Karapiro
Comments:	Surface flow inputs from the catchment are dominated by baseflow, and groundwater outflow from the catchment is unlikely. The water table is typically in the Whakamaru Group. Water tables are typically deeper than 3 m. Many small streams flow to the Waikato River and its lakes. Generally, stream valleys are dry to the east of the river. A single groundwater age value exists for well 68_107 (220 yr), and a surface water age for site 0388_001 (13 yr) which is influenced by Taupo outflow. Lag times of catchment inflows are likely to be moderately short. There has been a land use change from S&B to irrigated dairy in previous decade. Medium depth is nearly all oxic with a little reducing zones along river margin; shallow depth is mostly reducing zones. Attenuation will depend on groundwater flow path and is likely to be moderate, (dependent on flow paths, proximity of key sources to reducing zones).
Groundwater outflow:	-
Flow monitored:	Yes
Likely attenuation:	Moderate
Load to come:	Yes?
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	16. Mangakino
Catchment Group:	Upper Waikato: above Karapiro
Comments:	Surface flow is dominated by baseflow, and groundwater outflow from the catchment is likely. The water table is typically in the Whakamaru Group. Water tables are typically deeper than 3 m. High rainfall in the west means that quick flow is more important in this catchment than other Upper Waikato areas. Two groundwater age data exist: (177 yrs at 72_377 & 24yrs at 72_331), but spring and stream ages are unknown. Limited dating data and hydrogeology setting suggest moderately long lag times, with relatively quick fracture flow a likely influence. Land use is subject to current, ongoing dairy conversions and intensification of lower catchment; TN has increased gradually since 2000 showing a response to dairy conversions in the late 1990's, and to a large degree reflect the mix of landuse in the catchment. This response is inconsistent with expected long lag time in groundwater, suggesting a rapid response component may be followed by a longer response. Medium groundwater depth is all oxic; the shallow depth has much more reducing zones. A composite short and long response is likely, with al large component of short response in developed parts of the catchment. Overall attenuation is likely to be low.
Groundwater outflow:	Y, 40%, but only 5 gaugings, and geological setting not necessarily supporting bypass
Flow monitored:	Yes
Likely attenuation:	Low
Load to come:	Maybe
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	17. Mangamingi
Catchment Group:	Upper Waikato: above Karapiro
Comments:	Surface flow is dominated by baseflow, and groundwater outflow from the catchment is likely. The water table is typically in the Whakamaru Group. Water tables are typically deeper than 3 m. Spring-fed streams cross the catchment but generally the stream beds are dry. A single groundwater age value exists for well 67_445 (9 yr), as well as a surface water age of 10 yr at site 0407_001. Lag time is inferred to be moderately young and water quality monitoring suggests there is already a significant impact of intensification. TN concentrations are about 3.5 mg/m3, which is higher than might be expected given that the catchment includes 27% forestry. This suggests a point source (the sub-catchment drains an old mill treatment soakage, is downstream of Tokoroa waste discharge, and TP has decreased markedly since 2005, suggesting management of a point source). The catchment may receive some groundwater from the Whakauru subcatchment. Medium groundwater depth is all oxic; Shallow depth has a small component of reducing zones in the upper catchment. Attenuation is expected to be low.
Groundwater outflow:	Y, 61 %, 49 gaugings

Flow monitored:	-
Likely attenuation:	Low
Load to come:	No
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	18. Whakauru
Catchment Group:	Upper Waikato: above Karapiro
Comments:	Surface flow is dominated by baseflow, and groundwater outflow from the catchment is likely. The water table is typically in the Whakamaru Group. Water tables are typically deeper than 3 m. Spring-fed streams cross the catchment but generally the stream beds are dry. Two groundwater age values exist (wells: 72_3648 (45 yr), 72_3582 (>245 yr)). Lag time is likely to be moderately long given available information, hydrogeology setting and neighbouring sub-catchment inference. However, the downstream site (Mangamingi) surface age is only 10 years. Considerable baseflow appears to bypass the catchment. Surface water concentrations are trending up, reflecting conversion of forest to dairy post 2006 (nearly doubling the amount of pasture), suggesting that there is a short component to the catchment response. The large groundwater ages and the fairly low concentrations given the land use suggest that there will also be some catchment response to come. Further development has occurred post 2012. Medium depth is all oxic; Shallow is about 50% reducing zones which is located in the upper half of catchment. There is likely to be a compound short/long response in this catchment, attenuation is likely to be low, and significant catchment response to come.
Groundwater outflow:	Y, 70%, 59 gaugings
Flow monitored:	-
Likely attenuation:	Low
Load to come:	Yes
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	19. Pokaiwhenua
Catchment Group:	Upper Waikato: above Karapiro
Comments:	Surface flow is dominated by baseflow, and groundwater outflow from the catchment is likely. The water table is typically in the Whakamaru Group. Water tables are typically deeper than 3 m. Spring-fed streams drain the Mamaku Plateau across the catchment. There is a surface water age of 31 years MRT and groundwater age is highly variable 17-255+ years. Lag is indicated to be moderately long. Baseflow dominated, large storage capacities. Little seasonality evident. Drains Mamaku plateau north of Tokoroa, through area being converted from forest; Hart conversions, dairying along old Taupo Road. TN concentrations increasing post 2000 from a moderately high base concentration, reflecting an increase in pasture area by about 50%. Anticipate increased concentration rise due to some of the long response times and recent conversion. Good groundwater information from Fonterra Lichfield. Oxidised medium groundwater, reduced shallow groundwater (speculative). Low denitrification potential in medium groundwater but possible denitrifiction in shallow groundwater, but this is to be confirmed. Overall low-medium attenuation, a fast response component, but with some load to come.
Groundwater outflow:	Y, 53%, continuous record
Flow monitored:	Yes
Likely attenuation:	Low Moderate
Load to come:	Yes
Flow comparison (Woods et al., 2006):	Woods flow considerably larger than measured. Is woods flow over-estimated due to pine effect

Sub-Catchment:	20. Little Waipa
Catchment Group:	Upper Waikato: above Karapiro

Comments:	Surface flow is dominated by baseflow, and groundwater outflow from the catchment is likely. The water table is typically in the Whakamaru Group. Water tables are typically deeper than 3 m. Groundwater outflow from the catchment may flow to the Waikato River as springs were observed at river level before the construction of hydro-electric power dams Surface water age ~51 years, inflows from fractured flows incised in gullies in ignimbritic materials. The Huihuitaha Spring (336_2) and Hodderville Farm Spring have ages of 60 and 35 years respectively, similar to the surface water age. These indicate relatively long lags .Stream discharge is baseflow dominated, with 1/3 of catchment outflow bypassing catchment as groundwater. Potential for reducing materials at lower elevation, reducing zones at catchment outflow adjacent to Waikato River. Gradual increase in TN from 2000, but no response yet to some of the most recent dairy conversion. Anticipate a trend to increased TN as deeper groundwater is increasingly impacted following some forestry conversions to dairy over preceding 15 years period. Incised nature of channel limits potential for denitrification. Upper catchment appears oxidised. Substantial load to come anticipated. Overall there is likely to be a compound short and long phase response, with some groundwater likely to miss attenuation, and a component of future increases in concentration response to past catchment changes likely to come. Low to moderate attenuation likely.
Groundwater outflow:	Maybe 20%. Neglect, only 6 gaugings
Flow monitored:	-
Likely attenuation:	Low Moderate
Load to come:	Yes
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	21. Waikato at Karapiro
Catchment Group:	Upper Waikato: above Karapiro
Comments:	Surface flow inputs from the catchment are dominated by baseflow, and groundwater outflow from the subcatchment is unlikely. The water table is typically in the Pakaumanu Group. Water tables are typically deeper than 3 m. Many small streams flow to the Waikato River its lakes. However, generally, stream valleys are dry above lake level to the east of the river. There are 4 groundwater ages (wells: 72_7776 at >250 years, 72_4178 at >245 years, 70_76 at 31 years and 67_478 at 24 years) also 2 spring ages (72_5621 at 87years and 72_5620 at 103yrs) but no other known stream age data. Available information and the hydrogeologic setting suggest the lag is likely to be moderate overall. Medium depth is mostly oxic with reducing zones at the downstream end of the catchment and along the middle section; Shallow groundwater is ~80% oxic with some reducing zones in upper end of catchment. There has been some dairy conversion from other pasture in the last decade, and this may not have been fully expressed in the loads from the catchment due to long lag components in conjunction with oxic groundwater. Attenuation is likely to be low but will depend on groundwater flow paths. Overall moderate age and low to moderate attenuation is anticipated.
Groundwater outflow:	-
Flow monitored:	-
Likely attenuation:	Low Moderate
Load to come:	Yes. Minor?
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	22. Karapiro
Catchment Group:	Lower Middle Waikato: above Taupiri
Comments:	Surface flow is dominated by baseflow, and groundwater outflow from the catchment is likely. The water table is typically in the Pakaumanu Group. Water tables are typically deeper than 3 m. Valleys are generally dry as ignimbrite is prominent. There is one groundwater age only for this sub-catchment. Well 70_526 has an MRT of 2 years. Hydrogeology infers that lag times can be moderately long. On the other hand, the geology indicates slightly cemented and some welded ignimbritic material, and the catchment drains the Te Miro hills - these factors indicate lag times will tending to be moderately short. Land use is generally stable, with a trend from sheep and beef to deer. Stable water quality is evident. Groundwater is approximately 90% oxic for both depths and attenuation is likely to be low to moderate.
Groundwater outflow:	Y, 67% based on 15 gaugings only
Flow monitored:	-
Likely attenuation:	Low Moderate
Load to come:	No

Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	23. Waikato at Narrows
Catchment Group:	Lower Middle Waikato: above Taupiri
Comments:	Surface flow is dominated by baseflow, and groundwater outflow from the catchment is likely. The water table is typically in the Tauranga Group. Water tables are typically deeper than 3 m. Tauranga Group sediments include Hinuera Formation where infiltration is relatively rapid and drained peats, where infiltration is slow. Two groundwater age values exist (wells: 70_56 at 7 years and 70_22 at 5 years). Available information and hydrogeology setting suggests the lag is likely to be moderately short. The medium depth is nearly all reducing zones; the shallow depth is about 50:50, with the reducing zones concentrated in the west. Increasing stream concentrations from 2000 reflect land use change in the upstream catchment. Attenuation is likely to be moderate overall. These conditions are likely to be similar to those in Mangaone sub-catchment.
Groundwater outflow:	Analysis following workshop suggests no groundwater
Flow monitored:	Yes
Likely attenuation:	Moderate
Load to come:	No
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	24. Mangawhero
Catchment Group:	Lower Middle Waikato: above Taupiri
Comments:	Baseflow and quick flow are both important to surface flow, and groundwater outflow from the catchment is likely. The water table is typically in the Tauranga Group. Water tables are typically deeper than 3 m. Tauranga Group sediments include Hinuera Formation where infiltration is relatively rapid and drained peats, where infiltration is slow. A single surface water age of 12 yr was measured at site 1131_160. The hydrogeologic setting suggests moderately short lag. The catchment is similar to Mangaone, with short lags, moderate attenuation. Significant flow directly to Waikato River is likely. There are considerable areas of poorly-drained soils, which likely have artificial drainage. Medium depth is mainly reducing zones; Shallow groundwater is oxic in the lower half of catchment with reducing zones is upper half. TN concentrations are high and stable, consistent with stable intensive land-use and short lags. Attenuation will depend on groundwater flow paths and is likely to be moderate.
Groundwater outflow:	Y, 43% based on 38 gaugings. Hydrolgoical assessment suggests significant direct flow to the Waikato, so retain
Flow monitored:	-
Likely attenuation:	Moderate
Load to come:	No
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	25. Waikato at Bridge St Br
Catchment Group:	Lower Middle Waikato: above Taupiri
Comments:	Baseflow and quick flow are both important to surface flow drainage, and groundwater outflow from the catchment is unlikely. The water table is typically in the Tauranga Group. Water tables are typically deeper than 3 m. Tauranga Group sediments include Hinuera Formation where infiltration is relatively rapid and drained peats, where infiltration is slow. No water age information exists for this sub-catchment. The hydrogeology setting suggests the lag is likely to be moderately short. The water quality record includes entire Waikato upstream of this inflow, with TN concentrations increasing markedly since 2000, reflecting intensification in the cumulative catchment. Medium depth groundwater has nearly all reducing zones; Shallow has mostly reducing zones. Attenuation is likely to be moderate (high denitrification conter-balanced by short flow paths in artificial drainage and urban areas).
Groundwater outflow:	-
Flow monitored:	Yes
Likely attenuation:	Moderate
Load to come:	No

Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	26. Mangaonua
Catchment Group:	Lower Middle Waikato: above Taupiri
Comments:	Surface flow is dominated by baseflow, and groundwater outflow from the catchment is likely. The water table is typically in the Tauranga Group. Water tables are typically deeper than 3 m. Tauranga Group sediments include Hinuera Formation where infiltration is relatively rapid.There is 1 groundwater age at well 70_47 of 1 yr and a surface water age 12 years at site 421_10. The lag time is likely to be similarly moderatey short given predominance of shallow flux and water quality evidence. The boggy soils and resulting short flow paths are likely to cause lag time to be similarly moderately short, given predominance of shallow flux. TN concentrations are stable and around 2 mg/L, reflecting the fairly stable intensive land use Medium depth groundwater is oxic in the upper catchment with reducing zones in lower catchment; Estimates of source in relation to measured load suggest little attenuation, at odds with the estimate of dentrifying conditions. Shallow groundwater is similar but has less reducing zones in lower catchment. Attenuation will depend on groundwater flow paths and is likely to be moderate.
Groundwater outflow:	Y, 55% based on 30 gaugings, However, flow in inferred from continuous site is considerably larger, suggesting that mean rated flow is under-estimate. So neglect
Flow monitored:	Yes
Likely attenuation:	Moderate
Load to come:	No
Flow comparison (Woods et al., 2006):	Woods flow less than measured by factor of 2, suggesting imported flow

Sub-Catchment:	27. Mangakotukutuku
Catchment Group:	Lower Middle Waikato: above Taupiri
Comments:	Baseflow and quick flow are both important to surface flow, and groundwater outflow from the catchment is likely. The water table is typically in the Tauranga Group. Water tables are typically deeper than 3 m. Tauranga Group sediments include Hinuera Formation where infiltration is relatively rapid and drained peats, where infiltration is slow. No water age information exists for this sub-catchment. This sub-catchment, which includes part of Hamilton, drains peaty swamps which is likely to have artificial drainage. TN concentrations are high, reflecting the dairy land-use, and they are stable reflecting the long history of intensive land use. The hydrogeology setting suggests the groundwater may be moderately young with a tendency to short lag times due to artificial drainage. Both medium and shallow are largely reducing zones. Attenuation is likely to be moderate, the potential for denitrification in peats being counterbalanced by artificial drainage.
Groundwater outflow:	Y, 50%. Only 15 gaugings, neglect.
Flow monitored:	-
Likely attenuation:	Moderate
Load to come:	No
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	28. Mangaone
Catchment Group:	Lower Middle Waikato: above Taupiri
Comments:	Baseflow and quick flow are both important to surface flow, and groundwater outflow from the catchment is likely. The water table is typically in the Tauranga Group. Water tables are typically deeper than 3 m. Tauranga Group sediments include Hinuera Formation where infiltration is relatively rapid. There is a surface water age for site 417_7 of 15 years and a groundwater age of 9 years at well 70_453. Lag time is likely to be moderately short given predominance of shallow flux and water quality evidence. Drained, iron-rich sands underlie the sub-catchment, and the sharp reduction in TN from 1995 to 2000 was probably related to management of point discharges to land. TN concentrations have been fairly stable since then. Medium depth is mainly reducing zones; shallow is a reasonably even mixture between reducing and oxic. Attenuation will depend on groundwater flow paths and is likely to be moderate.
Groundwater outflow:	Only about 10%, so neglect
Flow monitored:	-
Likely attenuation:	Moderate

Load to come:	No
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	29. Waikato at Horotiu Br
Catchment Group:	Lower Middle Waikato: above Taupiri
Comments:	Surface flow is dominated by baseflow, and groundwater outflow from the catchment is likely. The water table is typically in the Tauranga Group. Water tables are typically deeper than 3 m. Tauranga Group sediments include Hinuera Formation where infiltration is relatively rapid. No water age information exists for this sub-catchment. The hydrogeology setting suggests the lag is likely to be moderately short. 70% of the catchment is urban which is excluded from the attenuation model. Attenuation is probably similar to Waikato at Bridge St (moderate overall).
Groundwater outflow:	Analysis following workshop suggests no groundwater
Flow monitored:	Yes
Likely attenuation:	Moderate
Load to come:	No
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	30. Waitawhiriwhiri
Catchment Group:	Lower Middle Waikato: above Taupiri
Comments:	Baseflow and quick flow are both important to surface flow, and groundwater outflow from the catchment is likely. The water table is typically in the Tauranga Group. Water tables are typically deeper than 3 m. Tauranga Group sediments include Hinuera Formation where infiltration is relatively rapid and drained peats, where infiltration is slow. No water age information exists for this sub-catchment. The hydrogeology setting suggests the lag is likely to be moderately short. Increasing urbanisation is occurring in this catchment, along with associated stormwater/tradewaste control (lake Rotoroa/Hamilton catchment). Both depths are reducing zones but have about 50% of the catchment as urban (excluded from the reducing zone assessment model). Attenuation is likely to be moderate to high.
Groundwater outflow:	Y, but based on only 5 gaugings so ignore
Flow monitored:	-
Likely attenuation:	Moderate H
Load to come:	No
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	31. Kirikiriroa
Catchment Group:	Lower Middle Waikato: above Taupiri
Comments:	Surface flow is dominated by baseflow, and groundwater outflow from the catchment is likely. The water table is typically in the Tauranga Group. Water tables are typically deeper than 3 m. Tauranga Group sediments include Hinuera Formation where infiltration is relatively rapid. No water age information exists for this sub-catchment. The hydrogeology setting suggests a moderately short lag, confirmed by the water quality data which demonstrates a marked and rapid decrease in concentrations, which is likely to be a response to intervention in leachate discharge from closed HCC landfill in 1998 and also expansion of Hamilton. Mainly reducing zones for medium depth; less reducing zones at shallow depth. Attenuation likely to be moderate.
Groundwater outflow:	Y, but based on 16 gaugings and with urban influence, so ignore
Flow monitored:	-
Likely attenuation:	Moderate
Load to come:	No
Flow comparison (Woods et al., 2006):	-
Sub-Catchment:	32. Waikato at Huntly-Tainui Br
Catchment Group:	Lower Middle Waikato: above Taupiri

Comments:	Baseflow and quick flow are both important to surface flow, and groundwater outflow from the catchment is likely. The water table is typically in the Tauranga Group. Water tables are typically deeper than 3 m. Tauranga Group sediments include Hinuera Formation where infiltration is relatively rapid and drained peats, where infiltration is slow. No water age information currently exist for this sub-catchment. The hydrogeology setting suggests the lag is likely to be moderately short. Medium depth is mostly reducing zones; Shallow is more oxic. Attenuation probably depends on groundwater flow paths and is likely to be moderate.
Groundwater outflow:	Analysis following workshop suggests no groundwater
Flow monitored:	Yes
Likely attenuation:	Moderate
Load to come:	No
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	33. Komakorau
Catchment Group:	Lower Middle Waikato: above Taupiri
Comments:	Surface flow is dominated by baseflow, and groundwater outflow from the catchment is unlikely. The water table is typically in the Tauranga Group. Water tables are typically deeper than 3 m. Tauranga Group sediments large areas of drained peats, where infiltration is slow. Dairy land use established for a considerable time, with high TN concentrations and little trend. No water age information exists for this sub-catchment. The hydrogeology setting suggests the lag will be moderately short, with increased tendency to short lag times due to artificial drainage of the tight, boggy Hamilton basin soils. High reducing zones for both medium and shallow depth, but less at downstream end of catchment. Concentrations are high and stable reflecting a long histrory of intensive land use. There has been some conversion to dairy over the last decade, but this not reflected in the concentrations. Attenuation likely to be moderate (high attenuation for deep flow paths but significant drainage will bypass denitrification zones).
Groundwater outflow:	-
Flow monitored:	-
Likely attenuation:	Moderate
Load to come:	No
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	34. Mangawara
Catchment Group:	Lower Middle Waikato: above Taupiri
Comments:	Baseflow and quick flow are both important to surface flow, and groundwater outflow from the catchment is unlikely. The water table is typically in the Tauranga Group. Water tables are typically deeper than 3 m. Tauranga Group sediments include large areas of silt and drained peats where infiltration is relatively slow. There is a surface water age of 14 years and a groundwater age at well 69_365 of 2 yrs. The hydrogeology setting suggests moderately short lag. The catchment has peat bog, is artificially drained, with short transition time. Land and TN concentrations are is stable by variable, with TN concentrations approaching 2 g/m3 reflecting the intensive land use. Both depths are 50-60% reducing zones, and in both depths, the reducing zones is focused in lower catchment. Attenuation is likely to be moderate (potential for denitrification balanced by likely high degree of artificial drainage).
Groundwater outflow:	-
Flow monitored:	-
Likely attenuation:	Moderate
Load to come:	No
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	35. Waikato at Rangiriri
Catchment Group:	Lower Middle Waikato: above Mercer

Comments:	Surface flow is dominated by baseflow, and groundwater outflow from the catchment is likely. The water table is typically in the Tauranga Group. Water tables are typically deeper than 3 m. Tauranga Group sediments include silt and sands; infiltration is relatively slow. There is a surface water age at site 1131_117 (main stem) of 10 years MRT but no other known water age information for this sub-catchment. The hydrogeology setting suggests the lag is likely to be moderately short. There is potential for a tendency to short lag times due to substantial artificial drainage. Medium depth is about 50:50 with most of the reducing zones is the lower part of catchment; the shallow depth is a bit more OX. Cumulative upstream land use has increasing dairy area, with slightly increasing TN concentrations. Attenuation is likely to be moderate to low depending on the groundwater flow paths.
Groundwater outflow:	Analysis following workshop suggests no groundwater
Flow monitored:	Yes
Likely attenuation:	Low Moderate
Load to come:	No
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	36. Awaroa (Rotowaro) at Harris/Te Ohaki Br
Catchment Group:	Lower Middle Waikato: above Mercer
Comments:	Surface flow is dominated by baseflow, and groundwater outflow from the catchment is unlikely. The water table is typically in the Tauranga Group. Water tables are typically deeper than 3 m. Stream beds are dry in their upper reaches. This site has no TN monitoring data yet. No water age information exists for this sub-catchment. Relatively deeper flux contribution probably limited by tighter tertiary formations hence predominant lag likely to be short to moderate. Lake Waahi is located in the catchment. Reducing zones likely to occur in approximately 20% of area. Attenuation likely to be low to moderate.
Groundwater outflow:	-
Flow monitored:	-
Likely attenuation:	Moderate
Load to come:	No
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	37. Awaroa (Rotowaro) at Sansons Br
Catchment Group:	Lower Middle Waikato: above Mercer
Comments:	Baseflow and quick flow are both important to surface flow,, and groundwater outflow from the catchment is unlikely. The water table is typically in the Te Kuiti Group. Water tables are typically deeper than 3 m. Stream beds are commonly dry. No water age information exists for this sub-catchment. Relatively minor flux through Tertiary formations is likely to result in short lags. TN concentrations increasing steadily since 2000 despite fairly stable land use with 52% pasture dominated by hill pasture, which could reflect land use intensification. Minor reducing zones for medium depth; more reducing zones in shallow depths at downstream end of catchment, but impact will depend on extent of groundwater flow through these zones before entering stream and will be influenced by drainage. Attenuation likely to be low to moderate. Background land use intensification should be evident in concentration data.
Groundwater outflow:	-
Flow monitored:	-
Likely attenuation:	Low Moderate
Load to come:	No
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	38. Waikato at Mercer Br
Catchment Group:	Lower Middle Waikato: above Mercer

Comments:	Baseflow and quick flow are both important to surface flow, and groundwater outflow from the catchment is unlikely. The water table is typically in the Tauranga Group. Water tables are typically in the range 0.5 to 3 m. Low-lying areas in the catchment have heavy soils; stream valleys are dry in their upper reaches. Four groundwater age values exist (wells: 61_93 sampled again at 8 years, 61_702 at 20 or 35yrs; 61_230 at 4 or 50 years; and 61_221 at 11 or 22 or 40 years). These data and hydrogeology suggests that the lag is likely to be moderately short. Both depths have a mixture of OX and reducing zones with the medium depth having less reducing zones. The reducing zones for the shallow depth is concentrated in the east of the catchment. Attenuation is likely to be moderate to low. Cumulative upstream land use has increasing dairy area, with slightly increasing TN concentrations. Overall, moderately short lag time is anticipated, with moderate to low attenuation, tending to higher attenuation along downstream reaches.
Groundwater outflow:	-
Flow monitored:	Yes
Likely attenuation:	Low Moderate
Load to come:	No
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	39. Whangape
Catchment Group:	Lower Middle Waikato: above Mercer
Comments:	Surface flow is dominated by baseflow, and groundwater outflow from the catchment is unlikely. The catchment contains Lake Whangape. The water table is typically in the Tauranga Group. Water tables are typically deeper than 3 m. Stream beds are dry in their upper reaches. Valleys draining to Whangape are typically formed from silts and drained peats. No water age information exists for this sub-catchment. The hydrogeology setting suggests the lag is likely to be moderately short, dominated by shallow flux. Dairy conversions have occurred recently in the catchment in the last decade, with a fairly stable land use before that; Marked increase in P may indicate lake collapse. N has also increased, which may reflect intensification and dairy conversion or lake collapse. Medium groundwater depth is mainly oxic with some reducing zones located at outlet of catchment; shallow depth has slightly more oxic fraction with some reducing zones located near outlet. Attenuation (excluding the lake) will depend on groundwater flowpaths but is likely to be low to moderate.
Groundwater outflow:	-
Flow monitored:	-
Likely attenuation:	Low Moderate
Load to come:	No
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	40. Whangamarino at Island Block Rd
Catchment Group:	Lower Middle Waikato: above Mercer
Comments:	Surface flow is dominated by quick flow, and groundwater outflow from the catchment is unlikely. The water table is typically in the Tauranga Group. Water tables are typically very shallow, i.e. less than 0.5 m. Swamps dominate the area. Age is currently unknown. There is a high proportion of groundwater inflow from adjacent catchment, and no groundwater outflow. Dominated by surface quickflow through wetlands. Medium denitrification potential exists, but limited flow through groundwater occurs, therefore surface TN increasing. Overall summary of attenuation - low to moderate attenuation, influenced by drainage.
Groundwater outflow:	Possibly, but within uncertainty bounds
Flow monitored:	-
Likely attenuation:	Low Moderate
Load to come:	No
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	41. Whangamarino at Jefferies Rd Br
Catchment Group:	Lower Middle Waikato: above Mercer

Comments:	Surface flow is dominated by baseflow, and groundwater outflow from the catchment is likely. The water table is typically in the Tauranga Group. Water tables are typically deeper than 3 m. Low-lying areas in the catchment have heavy soils. There is a surface water age of 10 years for site 1293_9 indicating the lag is relatively short. Very little surface outflow occurs, with most outflow in groundwater which is likely to bypass the catchment outlet. Longer lag times across system likely. Redox conditions - medium depth oxidised, shallow mixed, more reduced. Moderate denitrification expected due to underlying materials, but this is offset by the likely high degree of subsuface drainage on the heavy soils. Land use has been stable over the long term, although with some recent increase in the proportion of dairy, and TN concentrations are high or decreasing slightly. Overall moderate attenuation is likely.
Groundwater outflow:	Possibly a large proportoin. But limited gaugings that might be biased, so neglect
Flow monitored:	-
Likely attenuation:	Moderate
Load to come:	No
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	42. Waerenga
Catchment Group:	Lower Middle Waikato: above Mercer
Comments:	Baseflow and quickflow are both important, and groundwater outflow from the catchment is likely. The water table is typically in the Basement. Water tables are typically deeper than 3 m. Most streams are dry; basement rocks and fine sediments in the valleys make for quick runoff. No age data are available for this catchment. This is a small basement catchment, with a small discharge, likely to be mixed oxic-reducing groundwater. Surface likely to be relatively well drained, relatively young water. TN concentrations increasing despite stable land use, which is dominated by hill pasture but also includes significant intensive sheep and beef and dairy. Attenuation likely to be moderate.
Groundwater outflow:	Y, 67%, based on 19 gaugings. Could review this
Flow monitored:	-
Likely attenuation:	Moderate
Load to come:	No
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	43. Matahuru
Catchment Group:	Lower Middle Waikato: above Mercer
Comments:	Baseflow and quick flow are both important to surface flow, and groundwater outflow from the catchment is unlikely. The water table is typically in the Tauranga Group. Water tables are typically deeper than 3 m. Most streams are dry but basement rocks and fine sediments in the valleys make for quick runoff. One groundwater age data available in adjacent catchment (2 yr). Vadose zone estimate 24 years. This is a short flashy stream, underlain by peat. TN concentration at outlet is stable and land use is stable, dominated by intensive pasture. Water quality likely to be in approximate equilibrium with inputs. Low to moderate attenuation likely. Surface water ages coming for several similar catchments, one groundwater result is coming.
Groundwater outflow:	-
Flow monitored:	Yes
Likely attenuation:	Low Moderate
Load to come:	No
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	44. Waikare
Catchment Group:	Lower Middle Waikato: above Mercer

Comments:	Surface flow is dominated by baseflow, and groundwater outflow from the catchment is unlikely. The water table is typically in the Tauranga Group. Water tables are typically very shallow, i.e. less than 0.5 m. Swamps are common around Lake Waikare, which the catchment drains to. Stream beds are dry in the middle-upper reaches. There is a surface water age at site 326_10 of 5 years MRT but no other known water age information for this sub-catchment. Likely predominance of relatively shallow flux and available information indicates the lag is short. Short, rapid flow from east catchment, with limited attenuation; stronger attenuation expected along western side. There is nutrient input from point source - Te Kauwhata WWTP. Both medium and shallow depths have mixture of OX and reducing zones, with shallow having more reducing zones suggesting moderate to high attenuation (apart from attenuation in the lake itself), but there is also significant artificial drainage that is likely to bypass reducing zones. Landuse is about 52% intensive sheep and beef and dairy, fairly stable, and there is no water quality monitoring. Overall expect moderate attenuation and little lag.
Groundwater outflow:	-
Flow monitored:	-
Likely attenuation:	Moderate
Load to come:	No
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	45. Opuatia
Catchment Group:	Lower Middle Waikato: above Port Waikato
Comments:	Surface flow is dominated by baseflow, and groundwater outflow from the catchment is likely. The water table is typically in the Kerikeri Volcanic Group. Water tables are typically deeper than 3 m. Conny - greywacke? No water age information exists for this sub-catchment. The hydrogeologic setting suggests the lag is likely to be moderately short. Te Kuiti series and volcanics dominate; predominantly forestry land use. Fairly stable TN concentrations and landuse, with perhaps a slight increase reflecting intensification. High sediment yield. Both depths mostly oxic. Attenuation likely to be low with short lags.
Groundwater outflow:	Y, but based on only 6 gaugings, so neglect at this stage
Flow monitored:	-
Likely attenuation:	Low
Load to come:	No
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	46. Mangatangi
Catchment Group:	Lower Middle Waikato: above Mercer
Comments:	Baseflow and quick flow are both important to surface flow, and groundwater outflow from the catchment is likely. The water table is typically in the Tauranga Group. Water tables are typically deeper than 3 m. Basement and Tauranga Group sediments that include silts mean that runoff is generally rapid; stream valleys are dry in their upper reaches. There is a surface water age of 6 years MRT but no known groundwater water age information for this sub-catchment. Available information and the the hydrogeologic setting indicates the lag is short.Upper catchment cut off by RC boundary, with half the catchment in the Hunua Ranges. Water quality data indicates flashy catchment, consistent with moderately short lag. Land use is 57% pasture, mostly intensive, with stable or slightly reducing TN concentrations. The concentrations are fairly low considering the land use, but could be diluted by flows from the Hunuas. Moderate attenuation, short flow paths. Medium depth is mostly oxic; Shallow depth is mixture of oxic and reducing. Attenuation is likely to be moderate.
Groundwater outflow:	Full flow record suggests 20%, within uncertainty bounds
Flow monitored:	Yes
Likely attenuation:	Moderate
Load to come:	No
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	47. Waikato at Tuakau Br
Catchment Group:	Lower Middle Waikato: above Port Waikato

Comments:	Baseflow and quick flow are both important to surface flow, and groundwater outflow from the catchment is likely. The water table is typically in the Kerikeri Volcanic Group. Water tables are typically in the range 0.5 to 3 m. Low-lying areas in the catchment have heavy soils. Three groundwater age values exist (wells: 61_644 at 154 yr, 61_644 >165 years and 61_143 at 9 yr). The hydrogeology suggests that the lag is likely to be moderately short. Medium depth is nearly all oxic; Shallow depth is about 50:50. TN concentration is stable or increasing slightly, reflecting the slight increase in dairy and intensification in the cumulative upstream catchment. Attenuation will depend on groundwater flow paths but is likely to be low to moderate.
Groundwater outflow:	Analysis following workshop suggests no groundwater
Flow monitored:	Yes
Likely attenuation:	Low Moderate
Load to come:	No
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	48. Ohaeroa
Catchment Group:	Lower Middle Waikato: above Port Waikato
Comments:	Baseflow and quick flow are both important to surface flow, and groundwater outflow from the catchment is likely. The water table is typically in the Kerikeri Volcanic Group. Water tables are typically deeper than 3 m. Probably relatively large recharge and high water tables in volcanic aquifer; stream beds are typically dry. A single groundwater age result exists for well 61_280 (14 yr) and another due for well 61_245. The hydrogeologic setting suggests the lag is likely to be moderately short. Volcanic fields underlie the catchment. Shallow mainly OX; Medium has some reducing zones towards outlet. Water quality reflects dairying, intensification of S&B, and market gardening. TN concentrations have been increasing over the last two decades, although they may have levelled off recently. Attenuation likely to be low to moderate depending on the groundwater flow paths, with short lag times.
Groundwater outflow:	Y, about 50%, but uncertain. Maybe less. CLUES estimate of flow is smaller, so bypass less, more like 30%
Flow monitored:	-
Likely attenuation:	Low Moderate
Load to come:	No
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	49. Mangatawhiri
Catchment Group:	Lower Middle Waikato: above Port Waikato
Comments:	Surface flow is dominated by quick flow, and groundwater outflow from the catchment is unlikely. The water table is typically in the Basement. Water tables are typically deeper than 3 m. Basement rocks make for quick runoff. No water age information currently exists for this sub-catchment. The hydrogeology setting suggests moderately short lag. (Note upper catchment cut off by RC boundary). Land use is predominantly forestry with some dairying. Both depths are mostly oxic. TN concentrations are low although variable, and may be trending down slightly. Attenuation is likely to be low and time lags short.
Groundwater outflow:	-
Flow monitored:	Yes
Likely attenuation:	Low
Load to come:	No
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	50. Waikato at Port Waikato
Catchment Group:	Lower Middle Waikato: above Port Waikato

Comments: Surface flow is dominated by baseflow, and groundwater outflow from the catchment is likely. The water table is typically in the Tauranga Group. Water tables are typically in the range 0.5 to 3 m. The area of the Waikato River valley is very low-lying and drainage systems provide baseflow in the Waikato River valley; other stream valleys are typically dry. Ten groundwater age estimates exist, ranging from 11 to >110 years with a median of 76 years (72_631, 72 yr; 72_631, >100 yr; 72_5623, 88 yr; 72_3140, 110 yr; 61_876, 14 yr; 61_59, 11 or 45 yr; 61_1441, >76 yr; 61_1316, 11 yr; 61_126, 5 yr; 61_117, > 76 yr). There is a surface water age at site 739_4 of 15 years MRT. Despite the deeper Kaawa aquifer groundwater resource, the lag is likely to be moderately short due to relatively high flux through shallow formation e.g. volcanics. The medium depth is a mixture of reducing zones and oxic with most of the reducing zones on the north side of the river. There is not water qualtiy monitoring at this site. The shallow depth has a similar pattern but with more reducing zones throughout the catchment. Attenuation is likely to be moderate.

Groundwater outflow: Analysis following workshop suggests no groundwater

Flow monitored: -

Likely attenuation: Moderate

Load to come: No

Flow comparison (Woods et al., 2006): -

Sub-Catchment: 51. Whakapipi

Catchment Group: Lower Middle Waikato: above Port Waikato

Comments: Baseflow and quick flow are both important to surface flow, and groundwater outflow from the catchment is unlikely. The water table is typically in the Kerikeri Volcanic Group. Water tables are typically deeper than 3 m. Relatively large recharge and high water tables in the volcanic aquifer. There is a stream age for site 1282_8 of 16 years MRT and there are 4 groundwater ages (wells: 70_781 at >80 years, 61_54 at 7.5 or 23 or 52 years, 61_27, at 80 years and 61_113, at 4 years). Available information and hydrogeology setting suggests the lag is likely to be moderately short. Peat layers occur through the catchment. Medium depth is all oxic; Shallow depth has some reducing zones (~30%). Stream TN concentrations are high, approaching 4 g/m3, and are probably influenced by market gardening. Concentrations have increased by approximately 20% over the last two decades, but may be tapering off as very intensive land use is replaced by urban and lifestyle blocks in the vicinity of Pukekohe. Attenuation is likely to be low to moderate.

Groundwater outflow: -

Flow monitored: Yes

Likely attenuation: Low Moderate

Load to come: No

Flow comparison (Woods et al., 2006): -

Sub-Catchment: 52. Awaroa (Waiuku)

Catchment Group: Lower Middle Waikato: above Port Waikato

Comments: Surface flow is dominated by baseflow, and groundwater outflow from the catchment is likely. The water table is typically in the Awhitu Group. Water tables are typically deeper than 3 m. Stream valleys typically dry Three groundwater age data exist for this sub-catchment: 72_58, 165 (>151) yr; 61_208, 9 yr; 61_135, 40 or 19 yr. Potential for short to moderate lags given some possible deeper flux involving Kaawa Formation and deeper volcanics. Shallow flow paths likely to be perched on iron. Reducing zones likely to be mainly in lower part of catchment for both medium and shallow depths. If groundwater enters stream at bottom of catchment then attenuation will be high; if groundwater enters stream upstream of this zone, then attenuation could be moderate (or even low). TN concentration trending up gradually reflecting gradual intensification, although there has also been introduction of urban/lifestyle block areas in the last decade; land was originally developed in the 1860s, has therefore been under pasture for long time. Attenuation and lags are likely to moderate, but are uncertain.

Groundwater outflow: Y, but uncertain and based on only 3 ratings, so neglect

Flow monitored: -

Likely attenuation: Moderate

Load to come: ?

Flow comparison (Woods et al., 2006): -

Sub-Catchment:	100. Waipa at Mangaokewa Rd
Catchment Group:	Waipa: above Otorohanga
Comments:	Surface flow is dominated by baseflow, and groundwater outflow from the catchment is likely. The water table is typically in the Pakaumanu Group. Water tables are typically deeper than 3 m. Valleys are generally dry as ignimbrite is prominent. No water age information exists for this sub-catchment. The hydrogeology setting suggests that the lag is likely to be moderately short. Well incised streams exist. Land use change has involved recent conversion of S&B to dairy. The medium depth is all OX; the shallow depth is all reducing zones. Attenuation will depend on groundwater flow paths but is likely to be low to moderate.
Groundwater outflow:	Baseflow assessment based on only 1 rating, so best to ignore
Flow monitored:	-
Likely attenuation:	Low Moderate
Load to come:	No
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	101. Waipa at Otewa
Catchment Group:	Waipa: above Otorohanga
Comments:	Baseflow and quick flow are both important to surface flow, and groundwater outflow from the catchment is unlikely. The water table is typically in the Pakaumanu Group. Water tables are typically deeper than 3 m. Significant flow gains in the lower reaches, elsewhere flows are low. There is a groundwater age of 190 years at well 72_5009, but ages from adjacent streams suggest short age. Streams are well-incised in old lithologies (Greywacke and old ignimbrite). Equal proportions of quick and baseflow exist. Hydrology indicates immediate surface runoff, followed by groundwater response. Headwaters are covered in native forest (DoC reserve), while in lower catchment, a small proportion of sheep and beef has been converted to dairy. Medium depth groundwater oxidised, shallow indicates some reducing conditions may exist, but these may not intercept groundwater. TN concentrations generally stable but variable. Overall, moderate to short lag, low to moderate attenuation, little load to come.
Groundwater outflow:	-
Flow monitored:	Yes
Likely attenuation:	Low Moderate
Load to come:	No
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	102. Mangaokewa
Catchment Group:	Waipa: above Otorohanga
Comments:	Baseflow and quick flow are both important to surface flow, and groundwater outflow from the catchment is unlikely. The water table is typically in the Pakaumanu Group. Water tables are typically deeper than 3 m. Quick flow dominates in upper catchment as basement rocks are prominent. There is a surface water age of 8 years for site 414_6. The hydrogeology setting indicates that the lag time is likely to be moderately short (dominated by ignimbrites), with fracture flow influence and significant quickflow component. Medium depth is mainly oxic; Shallow groundwater has some reducing zones in upper catchment. TN concentrations stable and less than 1 g/m3, reflecting generally stable land use and predominantly hill and forest land use. Attenuation is likely to be low.
Groundwater outflow:	-
Flow monitored:	Yes
Likely attenuation:	Low
Load to come:	No
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	103. Mangarapa
Catchment Group:	Waipa: above Otorohanga

Comments:	Baseflow and quick flow are both important to surface flow, and groundwater outflow from the catchment is likely. The water table is typically in the Tauranga Group. Water tables are typically deeper than 3 m. Wells are typically located in Tauranga Group sediments at the bottom of the catchment. No water age information currently exists for this sub-catchment. The hydrogeology setting - hard hill, relatively short lag, limestone dominated, likely to have some quickflow, suggests moderately short lag. It is likely to be similar to Waitomo Stream at Tumutumu Road or Mangapu; Both depths are oxic in most of the catchment; some reducing zones in lower catchment towards outlet for shallow depths. Geomorphology indicates incised river valleys so attenuation likely to be low (groundwater doesn't enter stream just at bottom of catchment). Water quality is not monitored at this site. Low - moderate attenuation (lower gradient than previous)
Groundwater outflow:	Y
Flow monitored:	-
Likely attenuation:	Low Moderate
Load to come:	No
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	104. Mangapu
Catchment Group:	Waipa: above Otorohanga
Comments:	Baseflow and quick flow are both important to surface flow, and groundwater outflow from the catchment is likely. The water table is typically in the Holocene sediments. Water tables are typically deeper than 3 m. Shallow wells in valleys are typical. There is 1 groundwater age at well 71_26 of 60 yr and a surface water age of 7 years for site 443_3. The available information and hydrogeologic setting suggests a short lag. Previously a lake existed in the catchment, which is characterised by tertiary plastic soils with artificial drainage: short pathways and low attenuation is likely. Concentrations are stable, reflecting the historical mix of land use. Both depths are oxic in most of the catchment; some reducing zones in lower catchment towards outlet. The geomorphology indicates incised river valleys, so attenuation is likely to be low (groundwater doesn't enter stream just at downstream of catchment, where reducing zones occur).
Groundwater outflow:	NIWA flow analysis suggests unlikely
Flow monitored:	Yes
Likely attenuation:	Low
Load to come:	No
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	105. Mangarama
Catchment Group:	Waipa: above Otorohanga
Comments:	Surface flow is dominated by baseflow, and groundwater outflow from the catchment is likely. The water table is typically in the Mahoenui Group. Water tables are typically deeper than 3 m. Catchment is generally dry. No water age information currently exists for this sub-catchment. The hydrogeology setting - hard hill, relatively short lag, limestone dominated, likely to have some quickflow, suggests moderately short lag. It is likely to be similar to Waitomo Stream at Tumutumu Road or Mangapu; Medium depth is Ox in most of the catchment; Shallow has some reducing zones in lower catchment towards outlet. The geomorphology indicates incised river valleys, so attenuation is likely to be low (groundwater doesn't enter stream just at downstream of catchment, where reducing zones occur). Water quality is not monitored at this site. Low attenuation anticipated.
Groundwater outflow:	Only one gauging.
Flow monitored:	-
Likely attenuation:	Low
Load to come:	No
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	106. Waipa at Otorohanga
Catchment Group:	Waipa: above Otorohanga

Comments:	Baseflow and quick flow are both important to surface flow, and groundwater outflow from the catchment is unlikely. The water table is typically in the Tauranga Group. Water tables are typically deeper than 3 m. Wells are typically located in relatively permeable Tauranga Group sediments at the bottom of the catchment. There is a surface water age for site 1191_12 of 2 years. This and the hydrogeologic setting indicates a short lag. Medium depth is about 50:50 reducing zones:oxic with reducing zones mostly in lower part of catchment; 50:50 medium, drained sediments exist, tending to be wet in lower half of catchment shallow depth has more oxic but reducing zones is at catchment outlet. TN concentrations in the river are fairly stable, reflecting fairly stable land use in the catchment in conjunction with fairly short lags. Attenuation of sources in the subcatchment is likely to be moderate.
Groundwater outflow:	-
Flow monitored:	-
Likely attenuation:	Moderate
Load to come:	No
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	107. Waipa at Pirongia-Ngutunui Rd Br
Catchment Group:	Waipa: above Pirongia
Comments:	Baseflow and quick flow are both important to surface flow, and groundwater outflow from the catchment is unlikely. The water table is typically in the Tauranga Group. Water tables are typically deeper than 3 m. Volcanogenic sediments, silts and drained peats dominate in the lower reaches.There is a surface water age for site 1191_10 of 6 years. This and the hydrogeologic setting indicate a short lag. Well established dairy land use in the subcatchment. Both depths have more oxic than reducing zones, and these conditions are reasonably distributed through the catchment. TN trend is only minor, despite intensification in parts of the catchment, which has been counteracted to some degree by retirement of some pasture areas. Attenuation will depend on groundwater flow paths but is likely to be low to moderate.
Groundwater outflow:	-
Flow monitored:	Yes
Likely attenuation:	Low Moderate
Load to come:	No
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	108. Waitomo at Tumutumu Rd
Catchment Group:	Waipa: above Otorohanga
Comments:	Baseflow and quick flow are both important to surface flow, and groundwater outflow from the catchment is likely. The water table is typically in the Mahoenui Group. Water tables are typically deeper than 3 m. Karst conditions are common. No water age information exists for this sub-catchment. The hydrogeology setting suggests the lag is likely to be moderately short. The catchment is predominantly forest. Medium depth is all oxic; Shallow depth has some reducing zones (perhaps 25%). Measured TN load in comparison with estimated suggests little attenuation. Attenuation is likely to be moderate to low.
Groundwater outflow:	Y? 20%. Ignore, within bounds of error
Flow monitored:	Yes
Likely attenuation:	Low Moderate
Load to come:	No
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	109. Waitomo at SH31 Otorohanga
Catchment Group:	Waipa: above Otorohanga

Comments:	Surface flow is dominated by baseflow, and groundwater outflow from the catchment is likely. The water table is typically in the Mahoenui Group. Water tables are typically deeper than 3 m. Waitomo caves and karst conditions are common.here is a surface water age of 4 years at site 1253_5 indicating a short lag time. Hydrology indicates zero quickflow, baseflow dominated. Groundwater bypass from the catchment is unlikely. Stable TN concentrations are expected to reflect current sources. Redox conditions mixed, largely inferred from limited data. Overall summary of attenuation - expect low to moderate attenuation with little load to come.
Groundwater outflow:	Y? Baseflow analysis suggests 80% bypass, but this is uncertain as few measured flows and upstream site had little bypass based on continuous record
Flow monitored:	-
Likely attenuation:	Low Moderate
Load to come:	No
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	110. Moakurarua
Catchment Group:	Waipa: above Pirongia
Comments:	Surface flow is dominated by baseflow, and groundwater outflow from the catchment is likely. The water table is typically in the Alexandra Group volcanics (??). Water tables are typically deeper than 3 m. There is only one groundwater age of 11 years for well 72_5433 in this sub-catchment. The hydrogeologic setting suggests the lag is likely to be short. The catchment is greywacke/volcanic cone dominated; quickflow dominated; clay-rich soils. Similar to Kaniwhaniwha. Both depths mostly oxic. Water quality is not measured at this site. Fairly stable land use over the last two decades. Low attenuation likely, possibly more along river channels.
Groundwater outflow:	Y, but based on only 5 gaugings
Flow monitored:	-
Likely attenuation:	Low
Load to come:	No
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	111. Puniu at Bartons Corner Rd Br
Catchment Group:	Waipa: above Pirongia
Comments:	Baseflow and quick flow are both important to surface flow, and groundwater outflow from the catchment is unlikely. The water table is typically in the Tauranga Group. Water tables are typically deeper than 3 m. Volcanogenic sediments and silts dominate in the middle and lower reaches. There are 4 groundwater ages (72_5619 of >56 years, 72_5186 >150 years,72_5034 > 250 and 72_7021 at 120 years) and a surface water age for site 818_2 of 16 years. Long history of dairy - water quality reflects denitrification and dilution of surface water from groundwater off upland areas. Moderate age for shallow flow paths with some older deep flow paths. Recent conversion to dairy and intensive sheep and beef not yet reflected in TN concentration trend (only a minor increase in concentration). Moderate attenuation in lower catchment, low in upper catchment; boggy Tauranga materials adjacent to stream. Low to moderate attenuation; slightly more denitrification because of boggy conditions relative to upstream catchment. Both depths mostly oxic with some reducing zones at shallow depths along valley floor. Depending on groundwater flow paths attenuation is likely to be low to moderate.
Groundwater outflow:	-
Flow monitored:	Yes
Likely attenuation:	Moderate
Load to come:	Yes
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	112. Puniu at Wharepapa
Catchment Group:	Waipa: above Pirongia

Comments:	Baseflow and quick flow are both important to surface flow, and groundwater outflow from the catchment is likely. The water table is typically in the Pakaumanu Group. Water tables are typically deeper than 3 m. Valleys are generally dry as ignimbrite is prominent. No TN concentration data for this sub-catchment. No water age information exists for this sub-catchment. The hydrogeologic setting suggests the lag is likely to be moderately short. Recent conversions to dairy mean that there may be some load to come. Medium depth is all oxidised; Shallow depth has 50% reducing zones located in upper catchment. Attenuation is likely to be low to moderate.
Groundwater outflow:	Y. Baseflow analysis suggests 50%. Based on 14 ratings
Flow monitored:	-
Likely attenuation:	Low Moderate
Load to come:	No
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	113. Mangatutu
Catchment Group:	Waipa: above Pirongia
Comments:	Baseflow and quick flow are both important to surface flow, and groundwater outflow from the catchment is unlikely. The water table is typically in the Pakaumanu Group. Water tables are typically deeper than 3 m. Valleys are generally dry as ignimbrite is prominent. No water age information currently exists for this sub-catchment. The hydrogeology setting suggests moderately short lag. Dairy conversions from other pasture and intensive sheep and beef are occurring in the catchment, but the concentration of TN has remained fairly stable or is increasing only slowly, suggesting that there may be some increase in the future. Medium depth is mostly oxic with some reducing zones near bottom of catchment; Shallow depth has some reducing zones along valley bottom near stream. Depending on GW flow paths attenuation is likely to be moderate to low.
Groundwater outflow:	-
Flow monitored:	Yes
Likely attenuation:	Low Moderate
Load to come:	No
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	114. Mangapiko
Catchment Group:	Waipa: above Waikato confluence
Comments:	Baseflow and quick flow are both important to surface flow, and groundwater outflow from the catchment is likely. The water table is typically in the Tauranga Group. Water tables are typically deeper than 3 m. Tauranga Group sediments include Hinuera Formation where infiltration is relatively rapid and drained peats, where infiltration is slow. There is 1 groundwater age at well 70_47 of 1 yr and a surface water age 12 years at site 421_10. The lag time is likely to be similarly moderatey short given predominance of shallow flux and water quality evidence. The catchment drains peat land west of Maungatautari and is subject to extensive dairying, short lag times; the downward trend in TN is associated with increased management of Te Awamutu WWTP and dairy factory. The current water quality is similar to other rural streams in catchments dominated by dairy. Medium depth is Ox in upper catchment and reducing zones in lower catchment; the Shallow depth is similar but has slightly less reducing zones in lower catchment. Attenuation will depend on groundwater flow paths and is likely to be moderate.
Groundwater outflow:	Y
Flow monitored:	-
Likely attenuation:	Moderate
Load to come:	No
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	115. Mangaohoi
Catchment Group:	Waipa: above Waikato confluence

Comments:	Surface flow is dominated by baseflow, and groundwater outflow from the catchment is unlikely. The water table is typically in the Maungatautari Formation. Water tables are typically deeper than 3 m. Steep gradients on Maungatauteri mean rapid runoff, however baseflow is a significant component of surface water outflow. No water age information exists for this sub-catchment. The hydrogeology setting indicates that the lag time is likely to be moderately short. Land use in this steep volcanic catchment is mainly forest, with low nutrient inputs. Medium and Shallow depths are all oxic. Land use is predominantly native forest, and concentrations of TN have reduced considerably, possibly a result of de-intensification in the vicinity of the Maungatuatiri reserve. Attenuation should be low.
Groundwater outflow:	-
Flow monitored:	-
Likely attenuation:	Low
Load to come:	No
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	116. Waipa at SH23 Br Whatawhata
Catchment Group:	Waipa: above Waikato confluence
Comments:	Baseflow and quick flow are both important to surface flow, and groundwater outflow from the catchment is unlikely. The water table is typically in the Tauranga Group. Water tables are typically deeper than 3 m. Tauranga Group sediments include Hinuera Formation where infiltration is relatively rapid and drained peats, where infiltration is slow. There are 4 groundwater ages (wells: 70_74 at 1 year, 70_1134 at 0.3 years, 61_143 at 9 years, 70_632 at 235 years and 72_4014 at 225 years) but no known stream age data. The available information and hydrogeologic setting suggests the lag is likely to be moderately short. Boggy soils occur in this subcatchment. Medium depth has more reducing zones than oxic; Shallow has more oxic than reducing zones. TN concentrations in the Waipa river are fairly stable and reflect the mix of land use in the upstream catchment, despite the increase in dairy and intensive sheep and beef pasture. Attenuation within the subcatchment will depend on groundwater flow paths but is likely to be low to moderate, tending to moderate, and time lags are likely to be short.
Groundwater outflow:	-
Flow monitored:	Yes
Likely attenuation:	Moderate
Load to come:	No
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	117. Mangauika
Catchment Group:	Waipa: above Waikato confluence
Comments:	Baseflow and quick flow are both important to surface flow, and groundwater outflow from the catchment is unlikely. The water table is typically in the Alexandra Group volcanics. Water tables are typically deeper than 3 m. Steep gradients on Pirongia mean rapid runoff, however baseflow is a significant component of surface water outflow. There is a groundwater age of > 250 years at well72_5103 and a surface water age for site 477_10 of 7 years. The catchment is steep and the volcanic catchment is predominantly forested, with anticipated short lag. The surface water age and the hydrogeologic setting suggests the lag is likely to be short. TN has increase substantially from a low baseline, reflecting recent dairy conversions in the minor non-forested parts of the catchment. Both depths look oxic (some of the map is steep mountain so is omitted). Attenuation is likely to be low.
Groundwater outflow:	-
Flow monitored:	-
Likely attenuation:	Low
Load to come:	No
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	118. Kaniwhaniwha
Catchment Group:	Waipa: above Waikato confluence

Comments:	Baseflow and quick flow are both important to surface flow, and groundwater outflow from the catchment is likely. The water table is typically in the Tauranga Group. Water tables are typically deeper than 3 m. Steep gradients on Pirongia mean rapid runoff, however baseflow is a significant component of surface water outflow. Wells are typically located in Tauranga Group sediments at the bottom of the catchment. There is a stream age for site 222_16 of 9.5 years. The lag is indicated to be short consistent with expected rapid runnoff from Pirongia with some Tauranga Group buffering. Oxic in upper catchment for both shallow and medium depths; some reducing zones for both depths in lower catchment. The lower half of the catchment is intensifying; water quality and age characteristics likely to be determined by clean upper catchment water mixing with material leaching from intensifying lower catchment. TN concentrations have little trend and are variable despite some intensification; this may be due to retirement of some pasture areas. Attenuation likely to be moderate
Groundwater outflow:	Only 20%, within measurment uncertainty.
Flow monitored:	-
Likely attenuation:	Moderate
Load to come:	No
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	119. Waipa at Waingaro Rd Br
Catchment Group:	Waipa: above Waikato confluence
Comments:	Baseflow and quick flow are both important to surface flow, and groundwater outflow from the catchment is unlikely. The water table is typically in the Tauranga Group. Water tables are typically deeper than 3 m. Tauranga Group sediments include sands where infiltration is moderate and drained peats to the east, where infiltration is slow. No water age information exists for this sub-catchment. The hydrogeology setting suggests the lag is likely to be moderately short. Boggy soils occur in this subcatchment. No water quality is collected at this site, but the Whatawhata site is not very far upstream. Both depths have about 50:50 oxic and reducing zones. Attenuation will depend on groundwater flow paths but is likely to be low to moderate, tending to moderate.
Groundwater outflow:	-
Flow monitored:	-
Likely attenuation:	Moderate
Load to come:	No
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	120. Ohote
Catchment Group:	Waipa: above Waikato confluence
Comments:	Surface flow is dominated by baseflow, and groundwater outflow from the catchment is likely. The water table is typically in the Tauranga Group. Water tables are typically deeper than 3 m. Tauranga Group sediments include volcanogenic sands where infiltration is moderate and drained peats, where infiltration is slow. No water age information exists for this sub-catchment.There are 2 groundwater ages for this sub-catchment with both wells 72_6408 at 62_96 having ages of >250 years. The hydrogeologic setting suggests the lag is likely to be moderately short. Tendency to short lag times due to artificial drainage, but deeper pathways have long lag times. TN has reduced steadily and by roughly 20% from 1995, along with TP, but is still around 1.3 g/m3. This may reflect long-term decreases in dairying and expansion of Hamilton peri-urban areas into the catchment, and improved management of the Rotokauri catchment. Both depths have slightly more reducing zones than oxic. Attenuation is likely to be moderate to high.
Groundwater outflow:	Y, but few measurements, so ignore
Flow monitored:	-
Likely attenuation:	Moderate H
Load to come:	No
Flow comparison (Woods et al., 2006):	-

Sub-Catchment:	121. Firewood
Catchment Group:	Waipa: above Waikato confluence

Comments:	Surface flow is dominated by baseflow, and groundwater outflow from the catchment is likely. The water table is typically in the Basement (Murihiku terrane). Water tables are typically deeper than 3 m. Drainage is rapid as topographic gradients are high. No water age information exists for this sub-catchment. Lags are likely to be shorter than moderate given relatively little Tauranga Group (TG) sediments and rapid runoff from Hakarimata Range. Mainly Oxic for medium depth; some reducing zones in shallow around downstream end of catchment. Attenuation likely to be low to moderate, determined whether groundwater goes through reducing zones before entering stream. Water quality is not monitored at this site. As for Awaroa, attenuation is likely to be low to moderate.
Groundwater outflow:	Y, but few measurements, so ignore
Flow monitored:	-
Likely attenuation:	Low Moderate
Load to come:	No
Flow comparison (Woods et al., 2006):	-