

## Water Quality Modelling for the Southland Region

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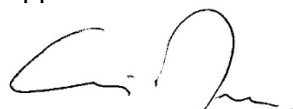
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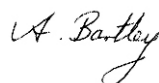
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## Executive summary

This report describes the catchment model used to predict median concentrations of TN (total nitrogen), TP (total phosphorus) and *E. coli* at monitored sites in the Southland region and the loads of these contaminants to estuaries in this region. The model is part of a broader study of the implications of on-farm mitigation measures on water quality in the region.

Various farm-level scenarios/tools were run. The 16 'uniform TN and TP discharge cap' scenarios/tool numbers can be clustered into five tool sets (A–E) based on their economic and environmental impact. The caps become progressively more stringent, with those in Tool Set A being the least stringent and those in Tool Set E being the most stringent. Tool Set F examined non-uniform nutrient caps and 'grandparenting'. Tool Set G focused on farm practices rather than nutrient caps. Grandparenting refers to a type of policy that bases limits on current practice. This is distinct from uniform caps, which apply a blanket limit across the region. It is also distinct from non-uniform caps, which apply limits based on the farm physical characteristics such as LUC (Land Use Capability) and soil drainage, but apply to all farms regardless of past activities.

Farmers can achieve compliance with the nutrient limits or caps in two ways. They can adopt on-farm mitigation practices, modelled as three bundles of increasingly effective and cumulative mitigation practices (M1–M3). Alternatively, they can shift their land use to another agricultural industry with a smaller environmental footprint. Land use change is between dairy, sheep/beef and forestry.

Both 'without DCD' and 'with DCD' scenarios are modelled, where DCD refers to a chemical nitrification inhibitor. The assessment for different future scenarios (i.e., all except Baseline2012) is based on modelled conditions in 2037 (at the end of the simulation period).

The catchment model used was spreadsheet-based and a simplified adaptation of the SPARROW model which is used in CLUES. Mean annual loads of TN, TP and *E. coli* for each stream reach in the region were calculated using

- farm areas
- farm enterprises (e.g., dairy, sheep/beef)
- mean annual TN and TP yields from farm enterprises
- percentage reductions in *E. coli* losses
- LCDB3 land cover and areas of non-pasture land uses
- TN, TP and *E. coli* yields from non-pasture land, and
- point source loads of TN, TP and *E. coli*.

The model was calibrated to the measured loads at those monitored sites where flow was recorded, and a reliable estimate of mean annual load could be determined. For TN calibration, 37% of the monitored sites were suitable; for TP calibration, 30% of the monitored sites were suitable; and for *E. coli*, 15% of the monitored sites were suitable.

For the seven future scenario sets listed above, median 2037 concentrations at the monitored sites were calculated by multiplying the observed median 2012 concentrations by the ratio of 2037 total load to 2012 total load.

Although the distribution of concentrations across the measurement stations does not necessarily reflect the distribution across all reaches in the region, it still gives an indication across a range of stream sites of interest.

Little is currently known about the age of the groundwater in the Southland region. If there are significant groundwater lags in the region, then our model results are likely to underestimate stream concentrations and estuary loads in 2012 and 2037.

The results show that predicted TN and TP concentrations increased from the current situation to Baseline2037, reflecting increased conversions to dairying. TN and TP yields were higher for dairy than for sheep/beef farms, so that the increase in dairy land area from Baseline2012 (17%) to Baseline2037 (28%) leads to increased TN and TP concentrations and loads. The lowest TN and TP concentrations were for Tool Set E, (the 'uniform discharge cap' tool set with the most stringent nutrient caps, meaning that all dairy farms either converted to sheep/beef or forestry), which approximately halved the concentrations for a given percentile.

Unlike TN and TP, predicted *E. coli* concentrations and loads were lower for Baseline2037 than for Baseline2012. This is because the area of agricultural land that was dairy or sheep/beef for Baseline2037 was lower than for Baseline2012 – 92% and 97% respectively, i.e., forestry area increased by 5% between Baseline2012 and Baseline2037. Furthermore, although the percentage dairy farmland was higher for Baseline2037 (28%) than Baseline2012 (17%), the *E. coli* yield from all agricultural land was the same (0.07 peta number km<sup>-2</sup> y<sup>-1</sup>).

The catchment-wide effect of mitigating dairy *E. coli* loads was minor, because non-dairy pasture produces a large proportion of the total *E. coli* loading. Also mitigations were based on reducing TN and TP rather than on *E. coli* specifically. More targeted mitigation for *E. coli* would be more effective in reducing *E. coli* loads. Tool Set G (the tool set which focuses on farm practices rather than nutrient caps) did result in significant reductions, however, because in that tool, mitigations were applied to both dairy and non-dairy areas.

The response of estuary TN loading to the various tools was variable. For some estuaries, there was little, if any, response, because they were in undeveloped catchments where there is no pasture and therefore no agriculture. For other estuaries there was an approximate halving of TN load between scenarios. The results for TP were much less pronounced than for TN. This can partly be explained by the contribution of TP derived from background erosion, and furthermore the contrast between dairy and sheep/beef losses is greater for TN than for TP.

Introduction of DCD had a small effect on the TN concentrations and loads, but very little effect on TP and *E. coli* concentrations and loads.

# 1 Introduction

As part of a broader study of the implications of on-farm mitigation measures on water quality values in the Southland region (see Figure 1-1), the Ministry for the Environment (MfE) requires a model to assess the water quality implications of farm contaminant losses as predicted by NZIER's<sup>1</sup> Multi-Agent Simulation (MAS) farm model for various scenarios in the Southland region. The contaminants of interest are total nitrogen (TN), total phosphorus (TP) and the faecal indicator bacteria *E. coli*. The scenarios/tools are given in Table 1-1 and Table 1-2.

For 'without DCD'<sup>2</sup> (Table 1-1), the 16 'uniform TN and TP discharge cap' scenarios/tool numbers can be clustered into five tool sets (A–E) based on their economic and environmental impact. The caps become progressively more stringent, with those in Tool Set A being the least stringent and those in Tool Set E being the most stringent. The MAS modelling also examined non-uniform nutrient caps and 'grandparenting' (Tool Set F). Tool Set G focuses on farm practices rather than nutrient caps. Grandparenting refers to a type of policy that bases limits on current practice. This is distinct from uniform caps, which apply a blanket limit across the region. It is also distinct from non-uniform caps, which apply limits based on the farm physical characteristics such as LUC (Land Use Capability) and soil drainage, but apply to all farms regardless of past activities (Kaye-Blake et al. 2013).

Farmers can achieve compliance with the nutrient limits or caps in two ways. They can adopt on-farm mitigation practices, modelled as three bundles of increasingly effective and cumulative mitigation practices (M1–M3). Alternatively, they can shift their land use to another agricultural industry with a smaller environmental footprint (Kaye-Blake et al. 2013). Land use change is between dairy, sheep/beef and forestry.

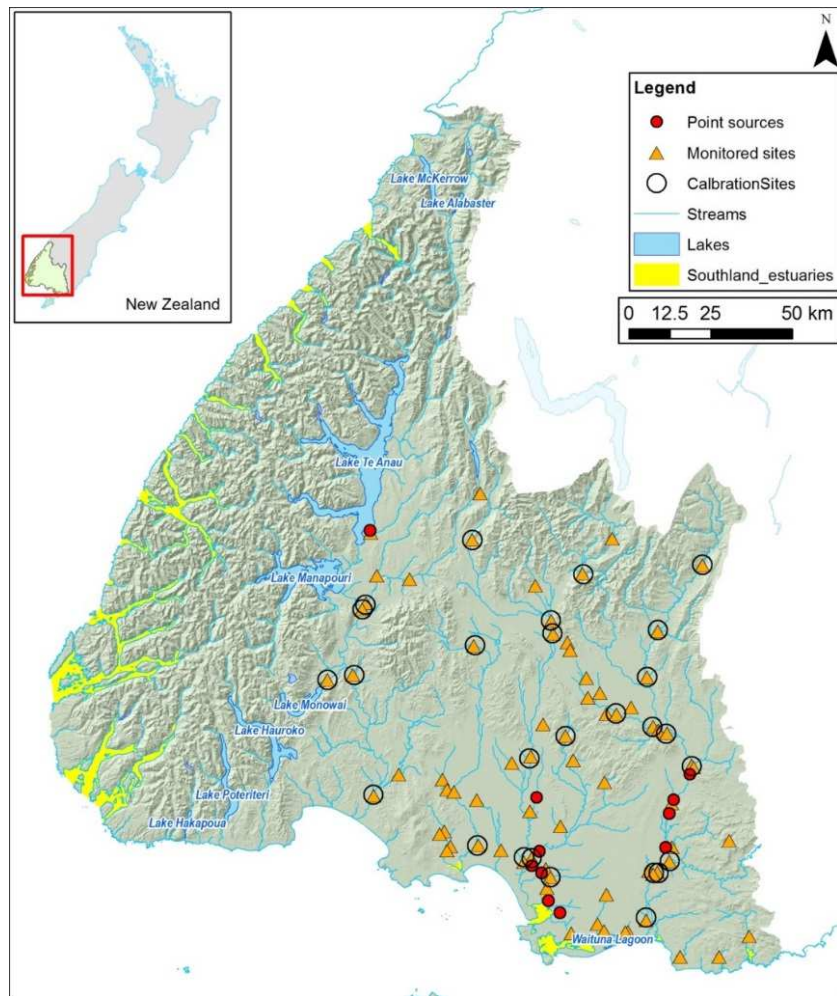
For 'with DCD' (Table 1-2), the interaction between mitigations and nutrients caps changes, so that scenarios/tools do not group in quite the same way. Therefore the results are presented just by scenario/tool number.

The assessment for different future scenarios (i.e., all except Baseline2012) is based on modelled conditions in 2037 (at the end of the simulation period).

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<sup>1</sup> New Zealand Institute of Economic Research.

<sup>2</sup> DCD is a chemical nitrification inhibitor.



**Figure 1-1: Southland region showing streams of order  $\geq 4$ , estuaries, lakes, point sources, monitored and calibration sites.**



**Table 1-1: Farm-level scenarios/tools without DCD.** Taken from Kaye-Blake et al. (2013) and results of MAS model runs. Agriculture here is dairy, sheep/beef or forestry; and constitutes about one third of the total land area in the Southland region.

Farm-level Tool Set	Scenarios/ tool numbers	TN cap kg ha <sup>-1</sup> y <sup>-1</sup>	TP cap kg ha <sup>-1</sup> y <sup>-1</sup>	Type of 'tool'	Dairy practices	Comment
Baseline2012		No cap, but typically TN loss is 29-49, 8-18 and 2 for dairy, sheep/beef and forestry respectively.	No cap, but typically TP loss is 0.8-2.1, 0.1-0.5 and 0.1 for dairy, sheep/beef, and forestry respectively.	Not applicable	No change	The current situation. Dairy farmland constitutes 17% of the total agricultural area, with sheep/beef and forestry comprising about 80% and 3% of the remainder.
Baseline2037						The situation in 2037 if the current dairy practices and policy settings continue. Dairy farmland constitutes 28% of the total agricultural area, with sheep/beef and forestry comprising 64% and 8% of the remainder.
A <sup>a</sup>	1	60	2.0	Uniform discharge caps	No change	No change in land use from Baseline2037 or dairy practices.
	2	60	1.5			
B	3	60	1.0	Uniform discharge caps	64% of dairy farmland adopts mitigation bundle M2 <sup>b</sup> .	No change in land use from Baseline2037, but some change in dairy practices.
	5	45	2.0			
	6	45	1.5			
C	7	45	1.0	Uniform discharge caps	All farms adopt mitigation bundle M2.	Some land use change from Baseline2037 – dairy farmland decreases to 20% of the total agricultural area, sheep/beef increases to 73%, and forestry remains about the same (7%). Change in dairy practices to middle mitigation option.
	4	60	0.5			
D	8	45	0.5	Uniform discharge caps	All farms adopt mitigation bundle M3 <sup>c</sup> .	Land use change as for Tool Set C. Change in dairy practices to highest mitigation option.
	9	30	2.0			
	10	30	1.5			
E	11	30	1.0	Uniform discharge caps	Dairying unable to comply with discharge caps.	Change in land use away from dairy. Sheep/beef and forestry constitute 88% and 12% of the total agricultural area respectively. 15% of sheep/beef farmland adopt the middle mitigation option.
	12	30	0.5			
	13	15	2.0			
	14	15	1.5			
	15	15	1.0			
	16	15	0.5			

Farm-level Tool Set	Scenarios/ tool numbers	TN cap kg ha <sup>-1</sup> y <sup>-1</sup>	TP cap kg ha <sup>-1</sup> y <sup>-1</sup>	Type of 'tool'	Dairy practices	Comment
	17				All farms adopt mitigation bundle M2.	
F	18			Non-uniform discharge caps – based on soil drainage	55% of dairy farmland adopts mitigation bundle M2, with the remaining 45% adopting M3.	No change in land use from Baseline2037.
	19			Grandparenting	All farms adopt mitigation bundle M3.	No change in land use from Baseline2012.
G	20			Mandated farm practices	All farms adopt mitigation bundle M3.	No change in land use from Baseline2037. All sheep/beef farms also adopt mitigation bundle M3.

<sup>a</sup> Results from the MAS model for Tool Set A were the same as those for Baseline2037, so this tool set not included in the report.

<sup>b</sup> Mitigation bundle M2 reduces TN and TP leaching by 5.3 and 0.7 kg ha<sup>-1</sup> y<sup>-1</sup> respectively; and *E. coli* is reduced by 69% for dairy and 58% for sheep/beef. See Kaye-Blake et al. (2013) for the details of on-farm implementation of M2.

<sup>c</sup> Mitigation bundle M3 reduces TN and TP leaching by 13 and 0.6 kg ha<sup>-1</sup> y<sup>-1</sup> respectively; and *E. coli* is reduced by 69% for dairy and 58% for sheep/beef. See Kaye-Blake et al. (2013) for the details of on-farm implementation of M3.

**Table 1-2: Farm-level scenarios/tools with DCD<sup>e</sup>.** Taken from Kaye-Blake et al. (2013) and results of MAS model runs. Also see Table 1-1. As for 'without DCD', the MAS model results for Scenarios 1 and 2 were the same as for Baseline 2037, so not included in this table. The MAS model results for Scenarios 13, 14, 15 and 16 with DCD were the same as those for without DCD, so not included in this table.

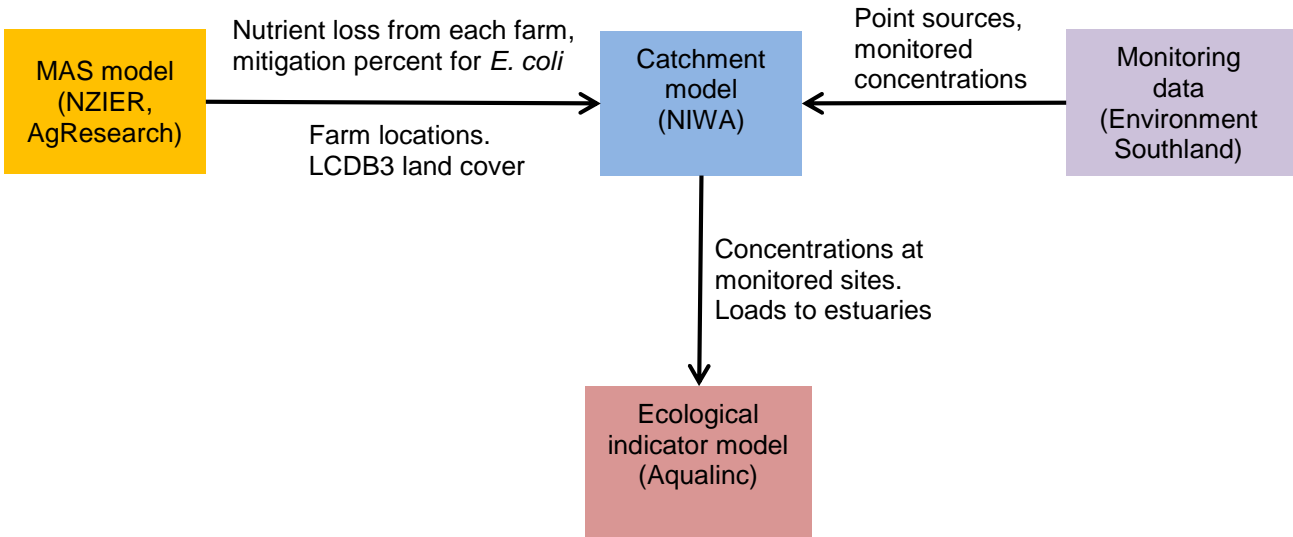
Scenarios/tool numbers	Dairy practices	Comment
3, 5, 6, 7	54% of dairy farmland adopts mitigation bundle M2, with a further 10% adopting M1 <sup>f</sup> .	No change in land use from Baseline2037 (i.e., dairy, sheep/beef and forestry constitute 28%, 64% and 8% respectively of the total agricultural area), but some change in dairy practices.
4, 8	75% of dairy farmland adopts mitigation bundle M2, with the remaining 25% adopting M1.	Some land use change from Baseline2037 – dairy farmland decreases to 20% of the total agricultural area, sheep/beef increases to 73%, and forestry remains about the same (7%).
9, 10, 11	55% of dairy farmland adopts mitigation bundle M3, with the remaining 45% adopting M2.	No change in land use from Baseline2037, but some change in dairy practices.
12	All dairy farms adopt mitigation bundle M2.	Land use change as for Scenarios 4 and 8.
17	84% of dairy farmland adopts mitigation bundle M2, with the remaining 16% adopting M1.	No change in land use from Baseline2037.
18		
19	All farms adopt mitigation bundle M3.	No change in land use from Baseline2012.
20	All farms adopt mitigation bundle M3.	No change in land use from Baseline2037. All sheep/beef farms also adopt mitigation bundle M3.

<sup>e</sup> DCD adds between 2.6 and 7.2 kg N ha<sup>-1</sup> of mitigation to the M2 and M3 bundles, and adds more mitigation to well-drained soils than to poorly-drained soils.

<sup>f</sup> Mitigation bundle M1 reduces TN and TP leaching by 4.3 and 0.6 kg ha<sup>-1</sup> y<sup>-1</sup> respectively; and *E. coli* is reduced by 69% for dairy and 0% for sheep/beef. See Kaye-Blake et al. (2013) for the details of on-farm implementation of M1.

This report describes the catchment model used to obtain median concentrations of TN, TP and *E. coli* at the monitored sites in the region and the loads of these contaminants to the estuaries in the region (Figure 1-1). These loads and concentrations will be used by Aqualinc (Snelder and Fraser 2013) to determine environmental outcomes in relation to numeric state objectives for stream water quality and estuarine eutrophication.

Figure 1-2 shows how the components of the broader study relating to water quality fit together. This report addresses just the catchment modelling component but is dependent upon inputs from the MAS model and existing monitoring data.



**Figure 1-2: Overview of the interrelation between components of the broader water quality assessment process.**

## 2 Method

### 2.1 Description of the catchment model for calculating loads

The catchment model used in this study was spreadsheet-based and is a simplified adaptation of the SPARROW (Spatially Referenced Regressions On Watershed) model (Smith et al. 1997). This model, originating from the U.S. Geological Survey, has been used in New Zealand for the Waikato River Basin (Alexander et al. 2002) and for the country as a whole (Elliott et al. 2005) to predict mean annual loads of TN and TP in streams. It is also the catchment model used in CLUES (Elliott et al. 2008), and *E. coli* modelling capabilities (prediction of mean annual load) have been added to the SPARROW model in CLUES.

Only a brief overview of the SPARROW model used here will be given, and the reader is referred to the papers in the above paragraph for more details. A schematic of the model is shown in Figure 2-1. Within each reach's sub-catchment, there are a number of sources (e.g., point source, diffuse source from cattle or sheep). The load of contaminant generated for a particular source type (*source load*) is the product of the amount of source (area of land cover, load from point sources, or pasture losses from a separate model) times a source coefficient (yield for diffuse sources, a dimensionless source coefficient for point sources<sup>3</sup> and pasture). This source load is then modified by a *land-to-water delivery term*, which is an exponential function of a number of delivery variables (such as rainfall or land drainage class) and delivery coefficients. An additional source term for TP associated with mass erosion of sediment was also added (Elliott et al. 2008). These modified sources are then summed for a given sub-catchment to give the total load entering the associated stream reach. *In-stream losses* are modelled by a first-order decay term, and the load is then accumulated and attenuated during movement down the reach or stream network. A separate *attenuation factor for reservoirs* (e.g., lakes), is also calculated (Elliott et al. 2005). The result of the calculations is the modelled mean annual load for each stream reach.

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<sup>3</sup> We only consider point sources that discharge directly into waterways, i.e., point sources that discharge to land are not accounted for.

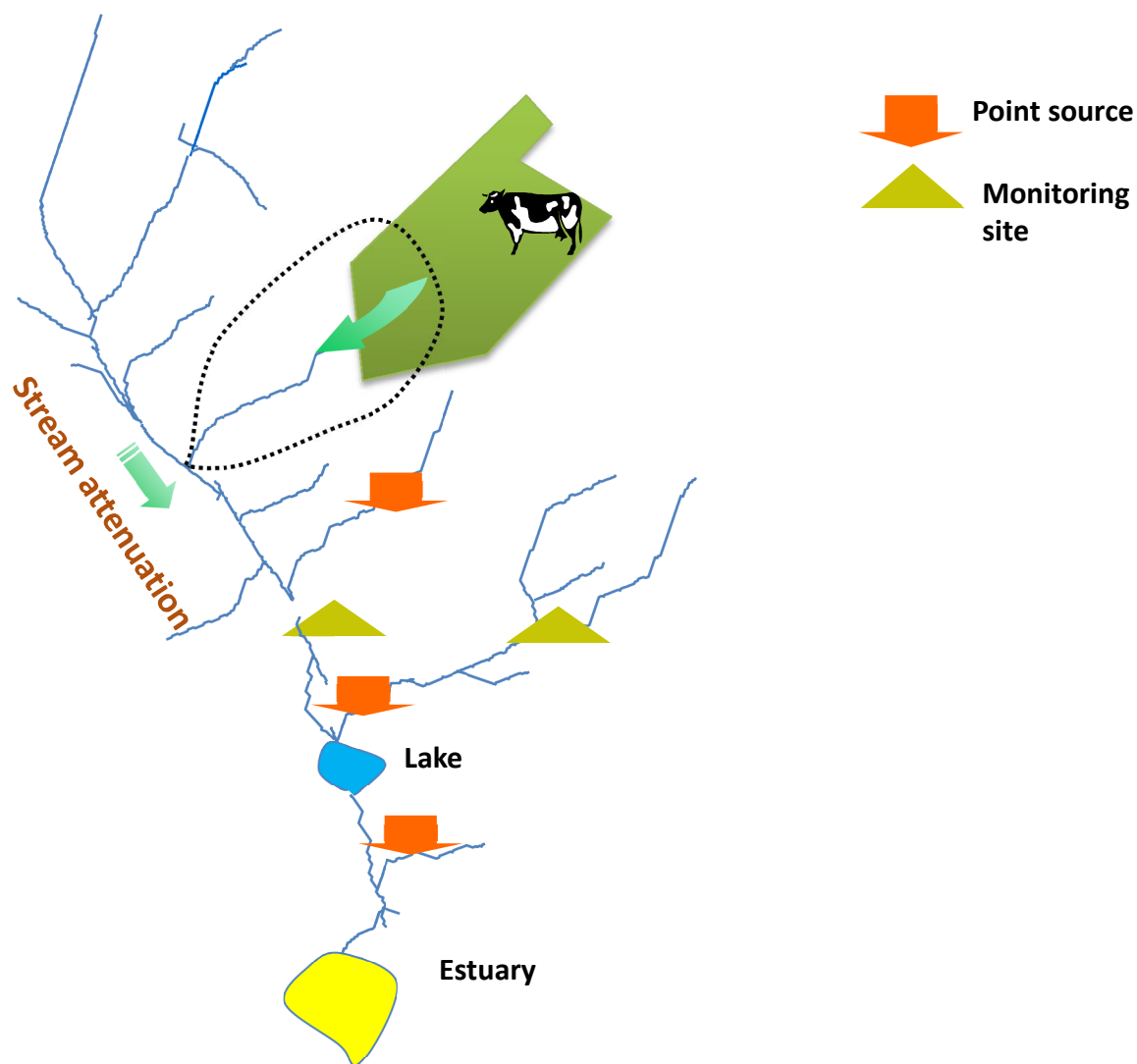


Figure 2-1: Schematic of SPARROW sources and transport.

## 2.2 Source loads

### 2.2.1 Farms

Output from NZIER's MAS model consists of estimates of current and forecast mean annual TN<sup>4</sup> and TP loads from farms, percentage reduction in *E. coli* load, farm areas and agricultural enterprise type (dairy, sheep/beef or forestry) for each of the 3290 farms in the region<sup>5</sup> based on the modelling assumptions, which are detailed in Kaye-Blake et al. (2013). The loads from forestry were estimated from yields included in SPARROW (see Section 2.2.3). *E. coli* annual loads from farms were not provided by the MAS model, but were calculated as part of the catchment modelling.

The LCBD3 data from AgResearch has 33 land cover categories. The two 'grass cover' categories – high producing exotic grassland and low producing grassland – were assumed

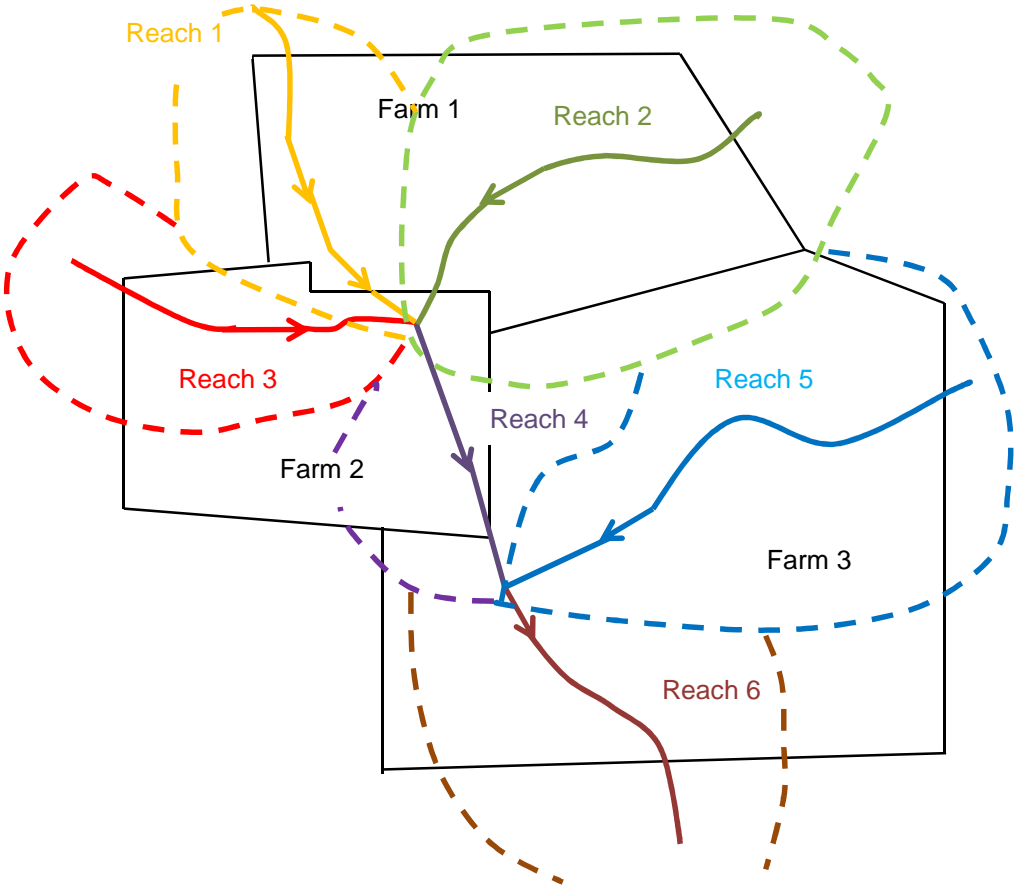
<sup>4</sup> MAS model gave results for TN without-wintering off, TN wintering off, and TN total (= without-wintering off + wintering off) loads. We used TN total for our simulations.

<sup>5</sup> Only farms with area > 20 ha are considered (Josef Beutrais and Chris Schilling, AgResearch and NZIER respectively, *pers. comm.*).

to be the areas of pasture grazed by dairy cattle or sheep/beef stock on the farms (Josef Beautrais, AgResearch, *pers. comm.*). Modelled TN and TP losses from these two pasture categories were specified for each scenario using information supplied by NZIER, while *E.coli* losses were estimated by fitting the SPARROW model to monitoring data using the information on *E.coli* load reduction supplied by NZIER.

NZIER’s MAS model also estimated the effect that DCD (a chemical nitrification inhibitor) has on contaminant discharges, specifically TN. DCD adds between 2.6 and 7.2 kg N/ha of mitigation to the M2 and M3 bundles, and adds more mitigation to well-drained soils than to poorly-drained soils (Kaye-Blake et al. 2013).

A farm may lie in more than one sub-catchment, so methods to allocate the farm loads to sub-catchments were applied.



**Figure 2-2: Diagram showing the relation between farms and sub-catchments.**

The area of each farm in each REC (River Ecosystem Classification) was used to allocate the load from each farm to the relevant stream reach, on an area-proportional basis. Then the loads for each sub-catchment were determined by summing the contributions from the various farms in the sub-catchment, to give the TN, TP and *E. coli* loads entering each reach, from farms. For example in Figure 2-2, Reach 2’s sub-catchment consists of parts of Farms 1, 2 and 3. This means that the estimated annual loads of TN, TP and *E. coli* from any dairy

or sheep/beef farming in the region are now available on a reach-by-reach basis. Of the 62,711 reaches in the region, 24,041 of them are within farm boundaries.

## 2.2.2 Point sources

Data on 11 point sources were obtained from Environment Southland. These point sources do not include those that discharge to land, some of which may eventually enter waterways. Table 2-1 describes the data used in our model and Figure 1-1 shows the locations of the point sources.

**Table 2-1: Mean annual point source loads of TN, TP and *E. coli*.**

Name	Type	TN load t y <sup>-1</sup>	TP load t y <sup>-1</sup>	<i>E. coli</i> load number y <sup>-1</sup>
Fonterra <sup>a</sup>	Dairy factory (Edendale)	3.0	0.2	
Winton	Sewage/Wastewater Treatment Plant	4.4	1.1	6.43 x 10 <sup>12</sup>
Gore	Sewage/Wastewater Treatment Plant	11.0	2.7	4.16 x 10 <sup>14</sup>
ICC WWTP Clifton	Sewage/Wastewater Treatment Plant	231.1	34.7	1.88 x 10 <sup>14</sup>
SDC Te Anau STP	Sewage/Wastewater Treatment Plant	4.3	2.4	
Alliance: Makarewa	Meat Works	67.0	8.1	6.82 x 10 <sup>12</sup>
Alliance: Lorneville	Meat Works	448.1	48.8	4.38 x 10 <sup>13</sup>
Alliance: Mataura	Meat Works	164.7 <sup>b</sup>	14.8	1.01 x 10 <sup>16</sup>
Prime Range Meats	Meat Works	6.1	0.1	
Ballance: Awarua	Fertiliser Plant	6.1 <sup>c</sup>	0.1 <sup>d</sup>	
Mataura (Dongwha)	Medium Density Fibreboard (MDF) Factory	11.0	4.4	6.78 x 10 <sup>11</sup>

<sup>a</sup> Only stormwater is discharged to the waterway (wastewater goes to land). <sup>b</sup> Just TKN. <sup>c</sup> Just NH<sub>4</sub>-N + NH<sub>3</sub>-N.

<sup>d</sup> Just DRP.

## 2.2.3 Non-farm land uses

Estimates of the losses from non-farm uses were determined from the areas of different land uses (LCDB3).

The conversion of the remaining 31 land cover areas (diffuse sources) to loads was achieved by ascribing a yield (t km<sup>-2</sup> y<sup>-1</sup>) to each of them.

For TN and TP, the yield for 'urban' land cover was taken from Williamson (1991) – 0.8 and 0.08 t km<sup>-2</sup> y<sup>-1</sup> respectively. For lakes and other similar waterways, the yield was 0.109 and 0.003 t km<sup>-2</sup> y<sup>-1</sup> respectively (Piet Verburg, NIWA, *pers. comm.*). The yields for the other non-



pasture land covers were either based on expert knowledge, previous SPARROW modelling, or estimated in the calibration process. There was considerable lumping of land-use classes to reduce the number of calibration parameters. The effect of rainfall and drainage on land cover losses was determined from previous modelling (Elliott et al. 2008).

## 2.3 Model calibration

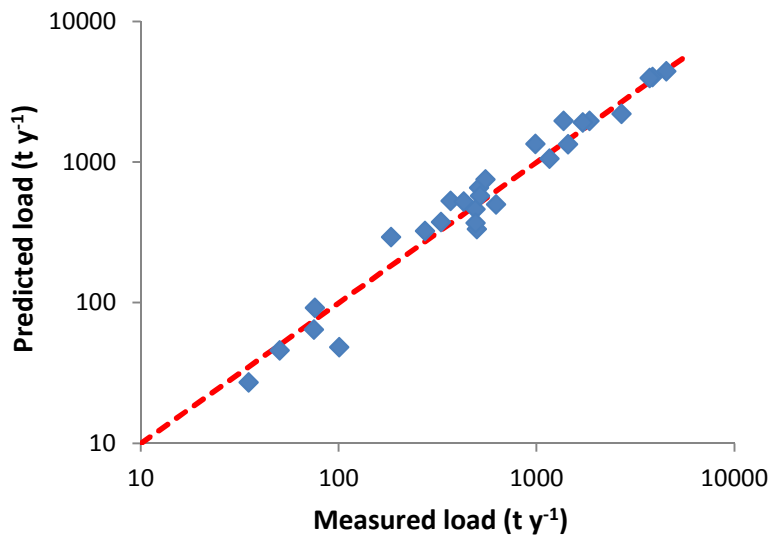
Measured loads of TN, TP and *E. coli* were calculated for monitoring station data using rating curve methods. Methods for load calculation are discussed in Diffuse Sources and NIWA (2012). The loads are mean annual averages calculated for the period 2001–2011. In these methods, non-linear relationships were developed between concentration (from monthly sampling) and flow, and these were then applied to continuous flow records to derive a synthetic time-series of concentration. The mean annual load was then determined by summing the product of the flow and concentration. This method requires a flow record, so the load could not be calculated for all of the monitoring stations. The uncertainty in measured load was also calculated, and sites with high uncertainty<sup>6</sup>, or where a large proportion (> 50%) occurs in high flows beyond the range of the measured data, were removed from the calibration dataset, leaving 27 sites for TN, 22 for TP and 11 for *E. coli*. High flows can carry a large proportion of the load, especially for TP and *E. coli*, whereas monthly sampling only captures high flows by chance. The rating curve methods take account of high flows to some degree because they include the full range of flows in the flow record. The exclusion of sites as discussed above also moderates for some of the error associated with high flows. Still, uncertainty in ‘measured’ loads remains (from a variety of error sources), which limits the accuracy of calibration and associated predictions.

### TN

The measured (or observed) loads from 27 of the 73 monitored sites (refer to Figure 1-1) were used to adjust five key model coefficients in order to obtain the best fit of the predicted to the measured loads, based on minimisation of the sum of squares of differences between logs of measured and simulated loads (rmse). The five coefficients of the TN model estimated in this manner were: two yield coefficients (‘trees’ and other non-pasture), the delivery coefficients for rainfall and drainage, and the in-stream decay coefficient. As there are a limited number of sites, only a few parameters could be modified, and these were kept within reasonable ranges. Jack-knifing methods were used for cross-validation. The resulting best fit is shown in Figure 2-3.

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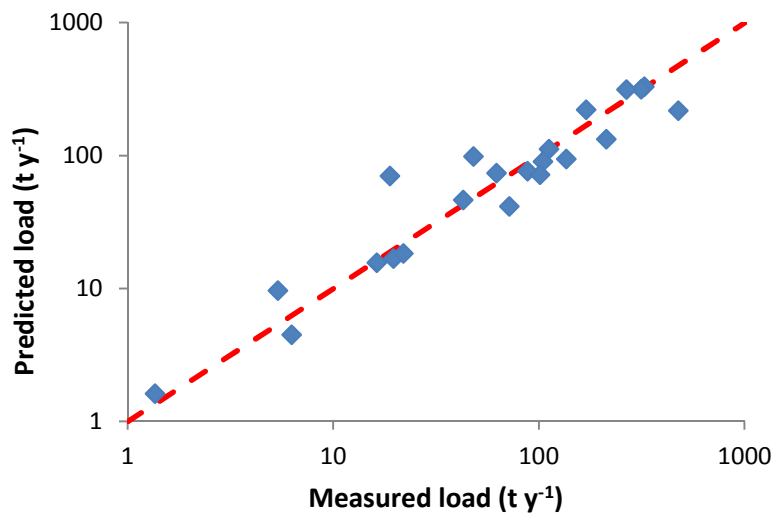
<sup>6</sup> ‘High uncertainty’ meant that the natural logarithm of the standard deviation of the mean annual load exceeded 1 for *E. Coli*, 0.5 for TP, and 0.4 for TN.



**Figure 2-3: Measured vs predicted TN loads for 27 monitoring sites in the Southland region.** Dotted red line is 1-1 line.

### TP

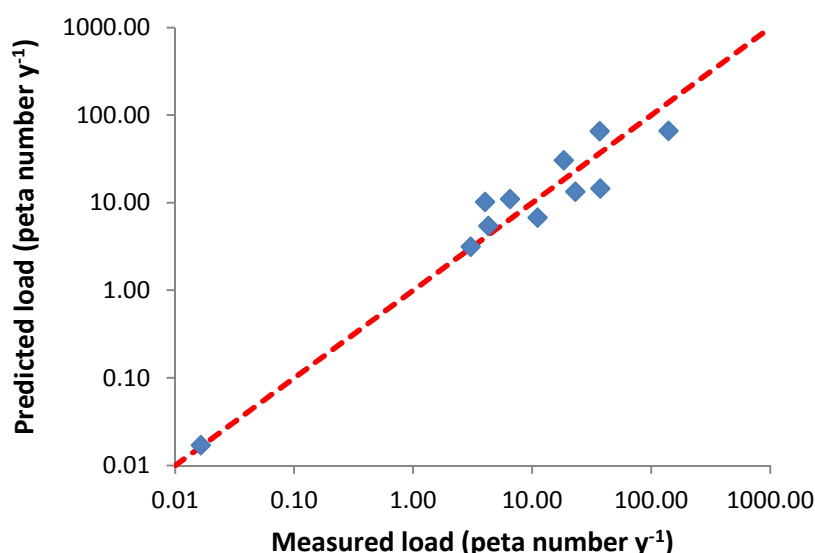
For TP, measured loads from 22 of the 73 monitored sites were used. For the TP model, seven coefficients were estimated by fitting to measured stream loads – the yield coefficients for trees and other non-pasture, the rainfall and drainage delivery coefficients, the P load from mass-eroded sediment, the in-stream decay coefficient, and the apparent settling velocity in lakes. The best fit is given in Figure 2-4.



**Figure 2-4: Measured vs predicted TP loads for 22 monitoring sites in the Southland region.** Dotted red line is 1-1 line.

## *E. coli*

Only 11 of 73 monitored sites were suitable for calibration purposes for *E. coli*. Considering the small amount of data, we just calibrated the *E. coli* yields for dairy, sheep/beef, and all other land covers. Figure 2-5 illustrates the resulting best fit. The yields for the pastoral land uses were set equal, consistent with the national *E. coli* model in CLUES (Graham McBride, NIWA, *pers. comm.*). McDowell and Wilcock (2008) estimated that *E. coli* losses from sheep/beef are generally comparable to those from dairying, although this is based on very limited data. Comparison of *E. coli* concentrations in relation to land use from Environment Southland data showed little difference between pastoral land use classes (analysis not shown here). Due to the small amount of data, difficulty of measuring loads, the coarse nature of the *E. coli* model, and the inherent variability of microbial populations, the predictions of the *E. coli* model involve considerable uncertainty. This is moderated to some degree by using measured concentrations in conjunction with relative changes in loadings to derive future concentrations.



**Figure 2-5: Measured vs predicted *E. coli* loads for 11 monitoring sites in the Southland region.** Dotted red line is 1-1 line. Peta =  $1 \times 10^{15}$ .

## 2.4 Calculation of concentrations and estuary loadings

Concentrations are required for Aqualinc's stream effects assessment, but the load model described above only provides estimates of mean annual load, so methods were developed to calculate median concentrations from loads. The essence of this method is that the factor change in loads between tool sets/scenarios was used to adjust the measured median long-term concentration. This process is described as follows:

Let the measured (or observed) median concentration at a monitored site be  $C_m$ , the Baseline2012 load at that site be  $L_b$ , and the scenario/tool set load at that site be  $L_s$ . Then the load factor =  $L_s/L_b$ , and the scenario/tool set median concentration at the monitored site,  $C_s$ , is equal to the load factor times  $C_m$ , that is:

$$C_s = \frac{L_s}{L_b} C_m$$

In other words, if the load increases by 10% then we expect the concentration to increase by 10%.

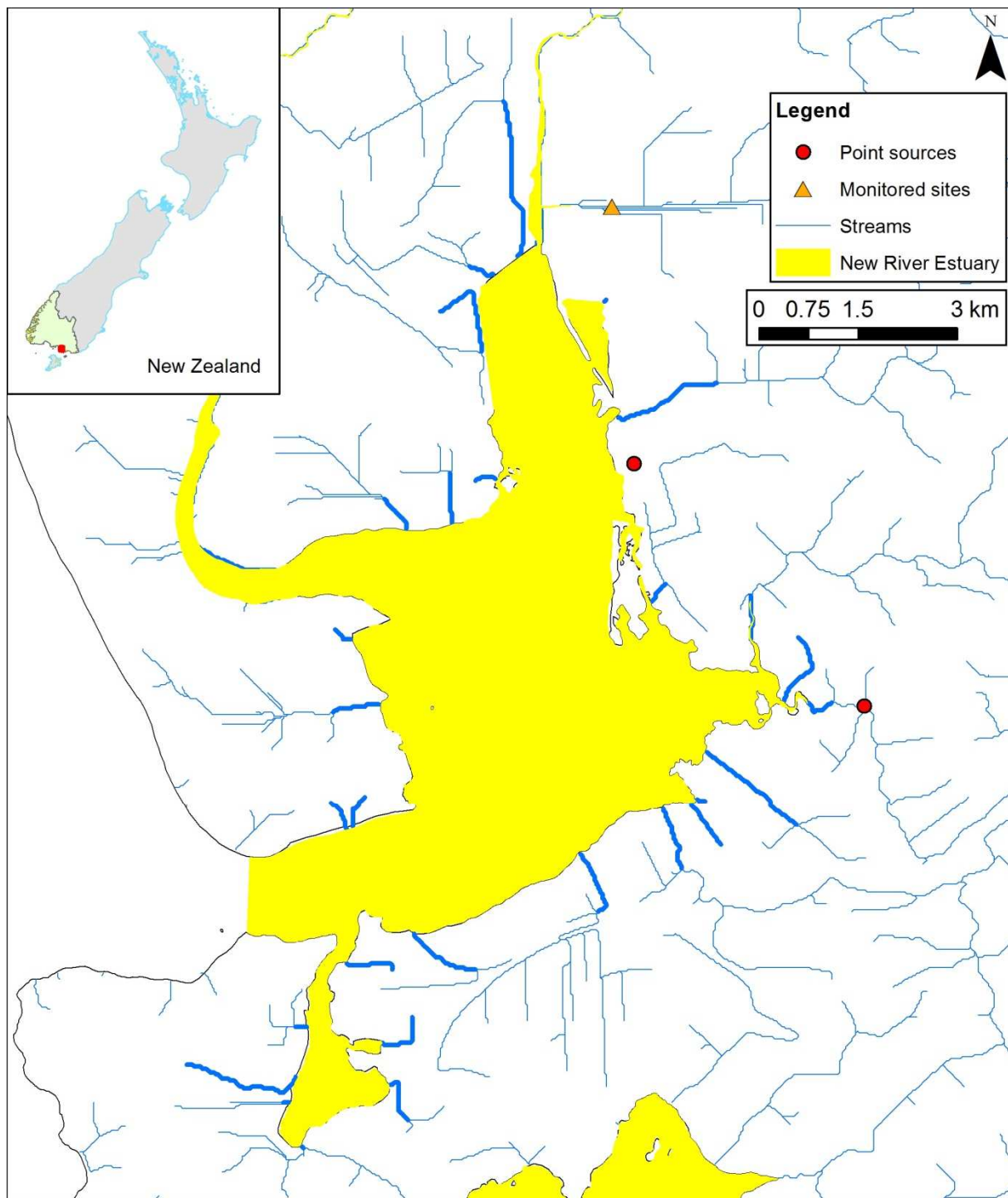
This method involves an assumption of linearity between load and concentration at a site, which is reasonable for a first approximation. This assumption has not been validated with experimental data because it would require long-term observations covering a period of substantial change. Indeed, it is possible to envisage situations where the relationship may break down, such as under large climate shifts, timing of loading, large land-use change, or transitioning of limiting nutrient threshold. Nevertheless, this is a reasonable assumption, and significantly more detailed modelling and measurement would be required to improve upon it.

The concentrations in this study were extracted from data provided by Environment Southland, generally based on monthly sampling over the period 1975 to 2012.

Note that the median concentrations at only the 73 monitored sites can be predicted in this manner, because only these sites have measured data. This approach could be extended to other sites using separate empirical models for concentration, but this would have involved introduction of further error and increased uncertainty. Considering that the Environment Southland dataset is fairly extensive, and the desirability of using measured concentrations, we decided to use just the 73 sites.

## **2.5 Estuary loads**

There are 28 estuaries in the Southland region (refer to Figure 1-1), and the reaches discharging into each of them were found. Figure 2-6 illustrates this for the New River Estuary near Invercargill.



**Figure 2-6: The New River Estuary.** The darker blue streams or reaches are those discharging into the estuary.

## 3 Results

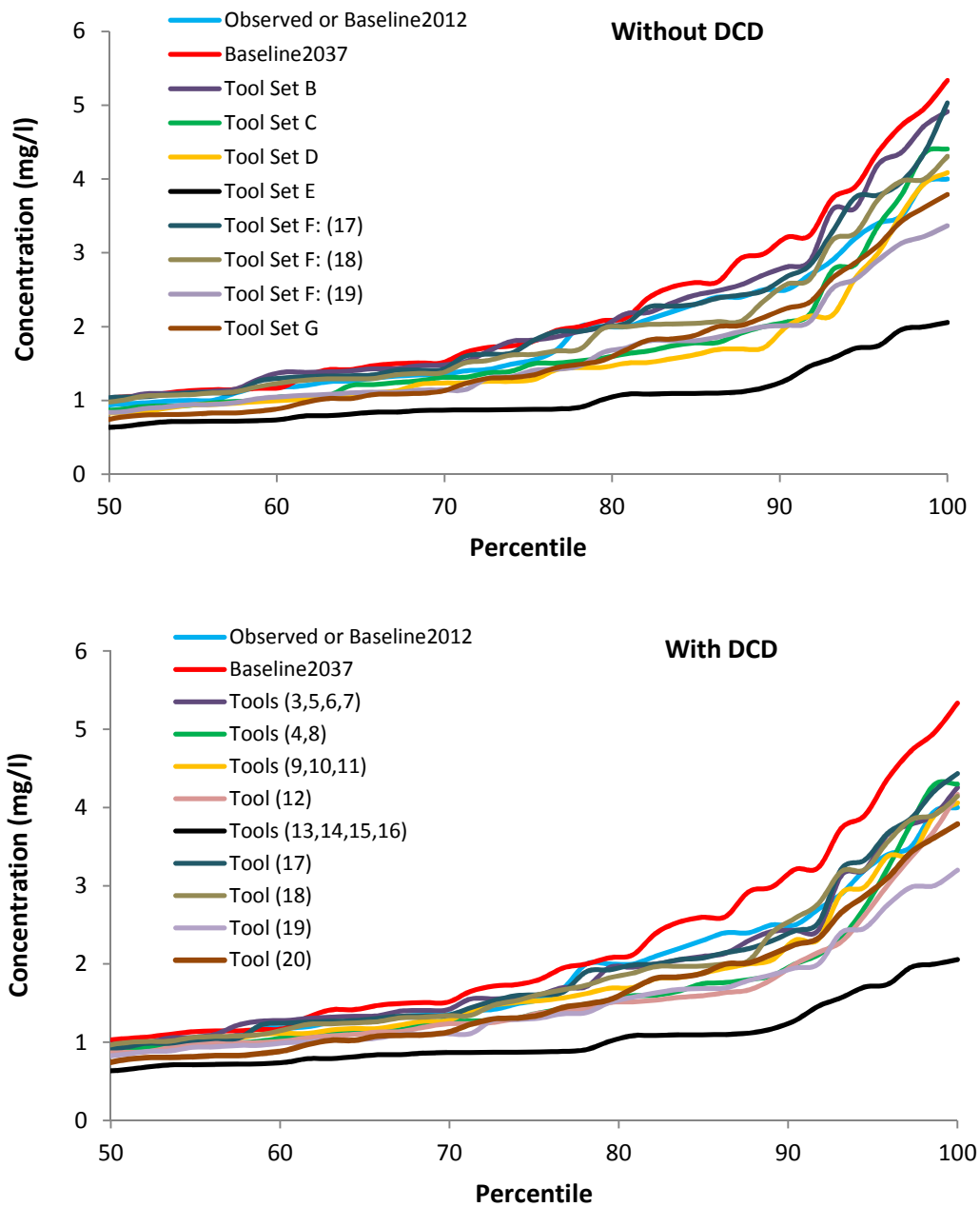
### 3.1 Stream concentrations

The modelled probability distribution of median concentration for TN, TP and *E. coli* are given in Figure 3-1 to Figure 3-3 for the 73 monitored sites (refer to Figure 1-1)<sup>7</sup>. Included are the measured concentrations and predicted concentrations for the various scenarios/tool sets. The figures show the percentage of sites with median concentrations less than the value on the vertical axis. For example, for Baseline 2037, 80% of the sites have a median TN concentration less than 2.0 mg/L.

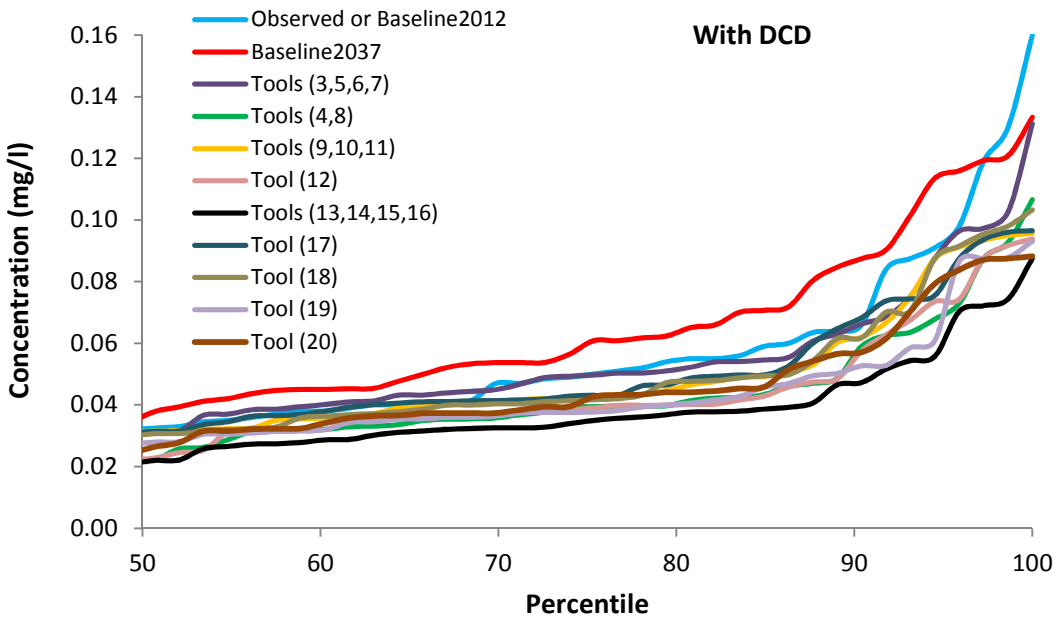
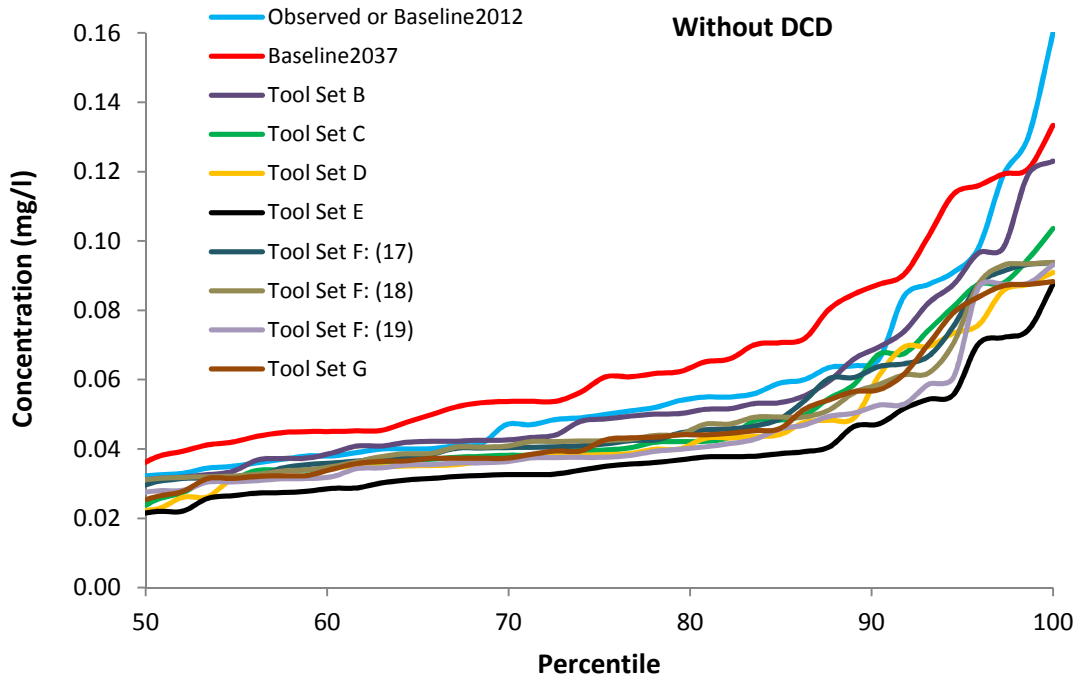
The figures summarise the distribution across sites, rather than the more variable increases or decreases on a site-by-site basis. This way of summarising the results is for convenience and clarity, and does not influence subsequent stages of assessment of effects. Figure 3-4 shows four example sites for TN demonstrating various cases (e.g., decreasing and increasing) under various scenarios/tool sets.

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<sup>7</sup> For clarity and because the results are all similar up to 50<sup>th</sup> percentile, only the 50–100<sup>th</sup> percentile results are shown in these figures. For the entire results, see Appendix A-1.

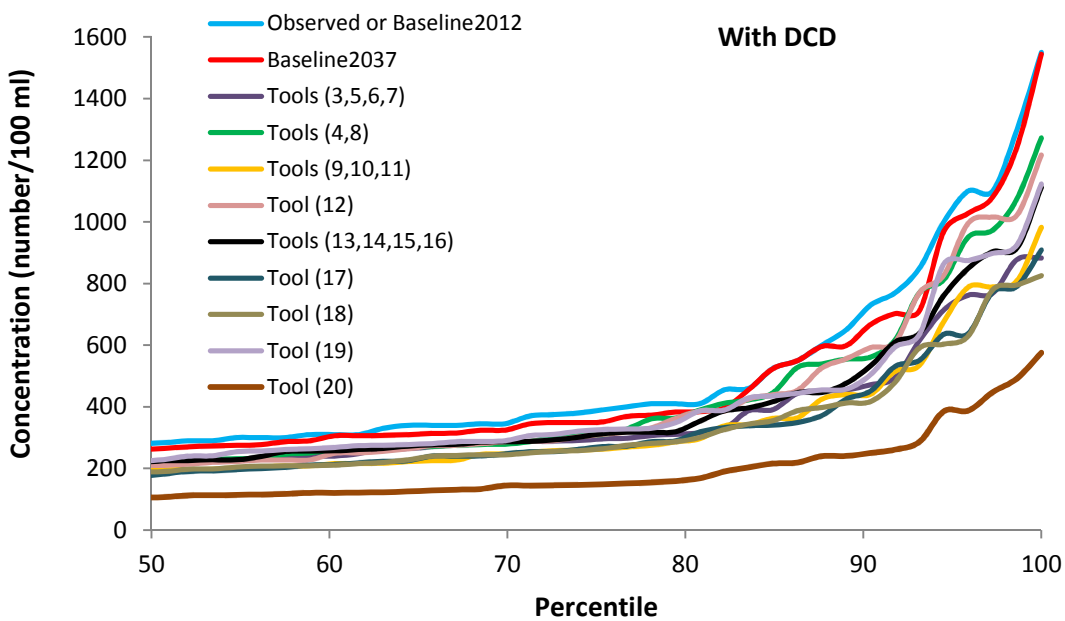
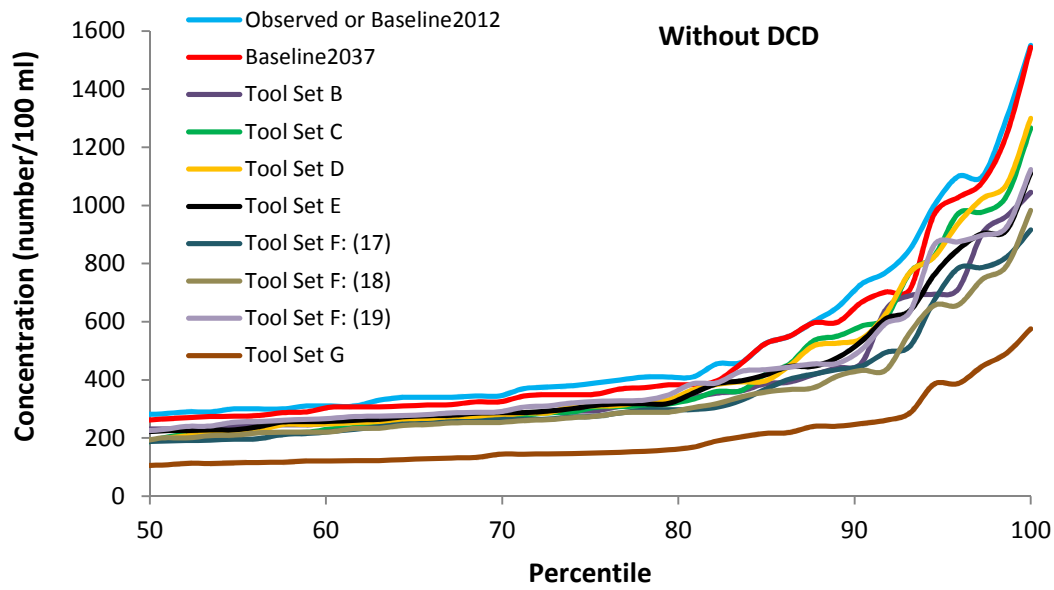


**Figure 3-1: Distribution of median TN concentrations across the monitored sites for various scenarios/tool sets.**



**Figure 3-2: Distribution of median TP concentrations across the monitored sites for various scenarios/tool sets.**





**Figure 3-3: Distribution of median *E. coli* concentrations across the monitored sites for various scenarios/tool sets.**

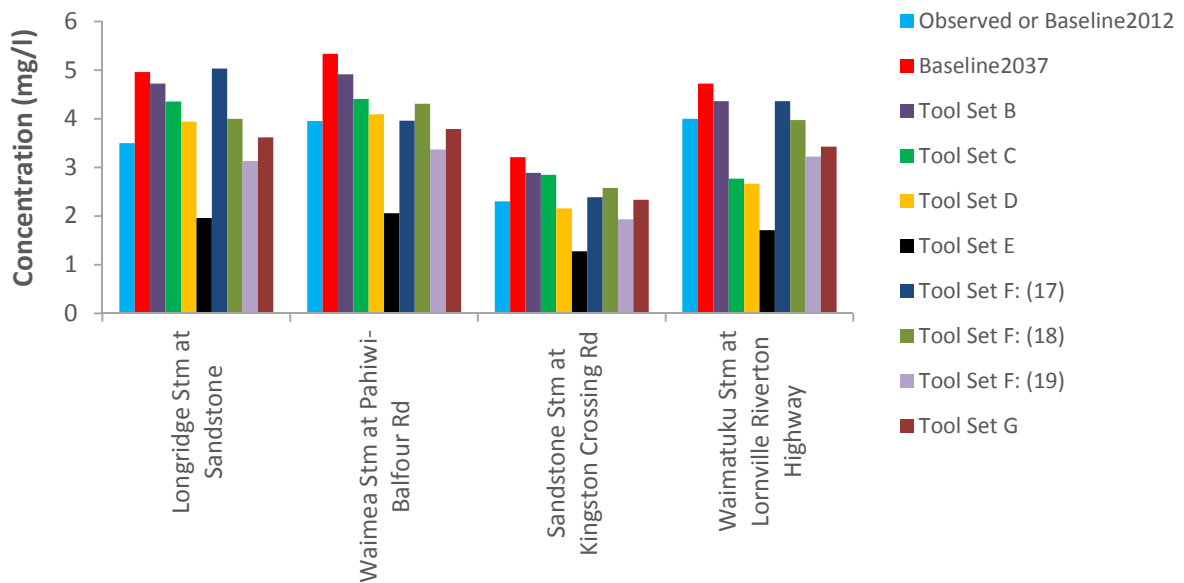


Figure 3-4: Median TN concentrations (without DCD) across four monitored sites for various scenarios/tool sets.

### 3.2 Estuary loads

Figure 3-5 to Figure 3-13 show the TN, TP and *E. coli* loads for the various scenarios/tool sets for the 28 estuaries in the region (refer to Figure 1-1)<sup>8</sup>.

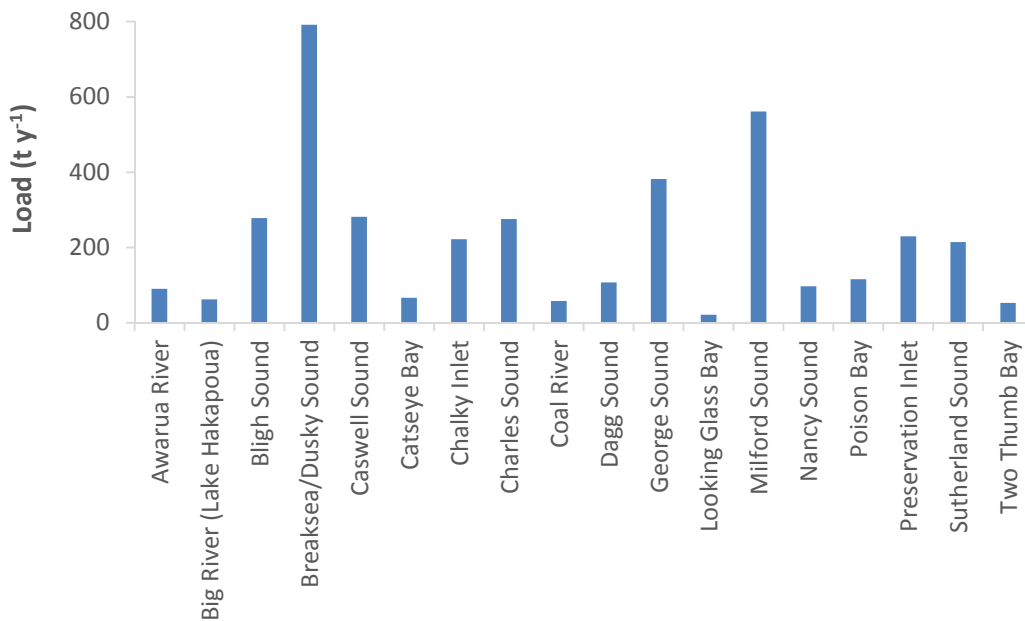


Figure 3-5: TN loads for 18 estuaries which have the same load regardless of scenario/tool set and DCD.

<sup>8</sup> Due to the wide range of load values, for clarity, the loads for each contaminant are split into three figures: 18 estuaries where the load is the same regardless of scenario/tool set and DCD, 5 estuaries where the load < X, and 5 estuaries where the load > X.

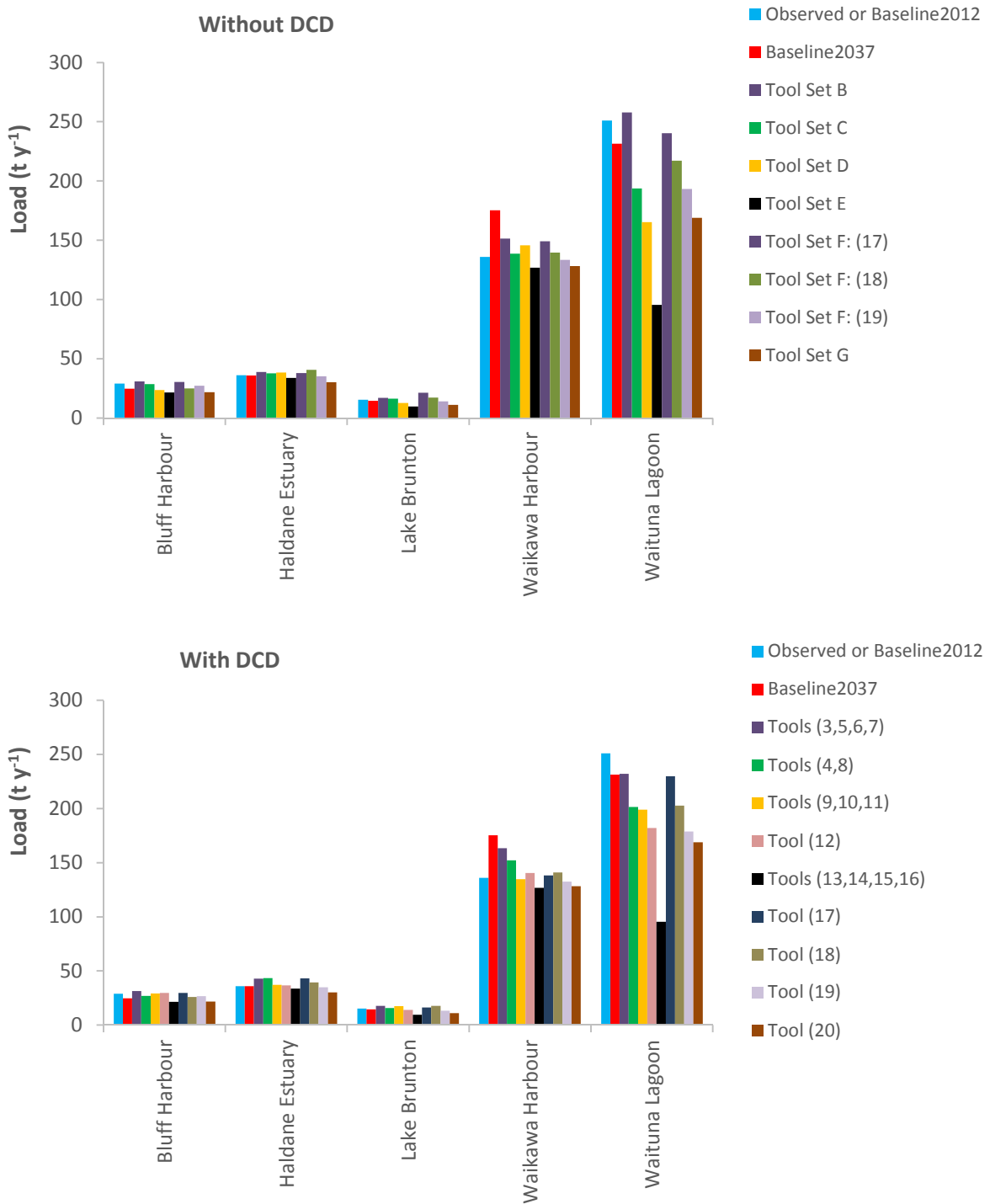
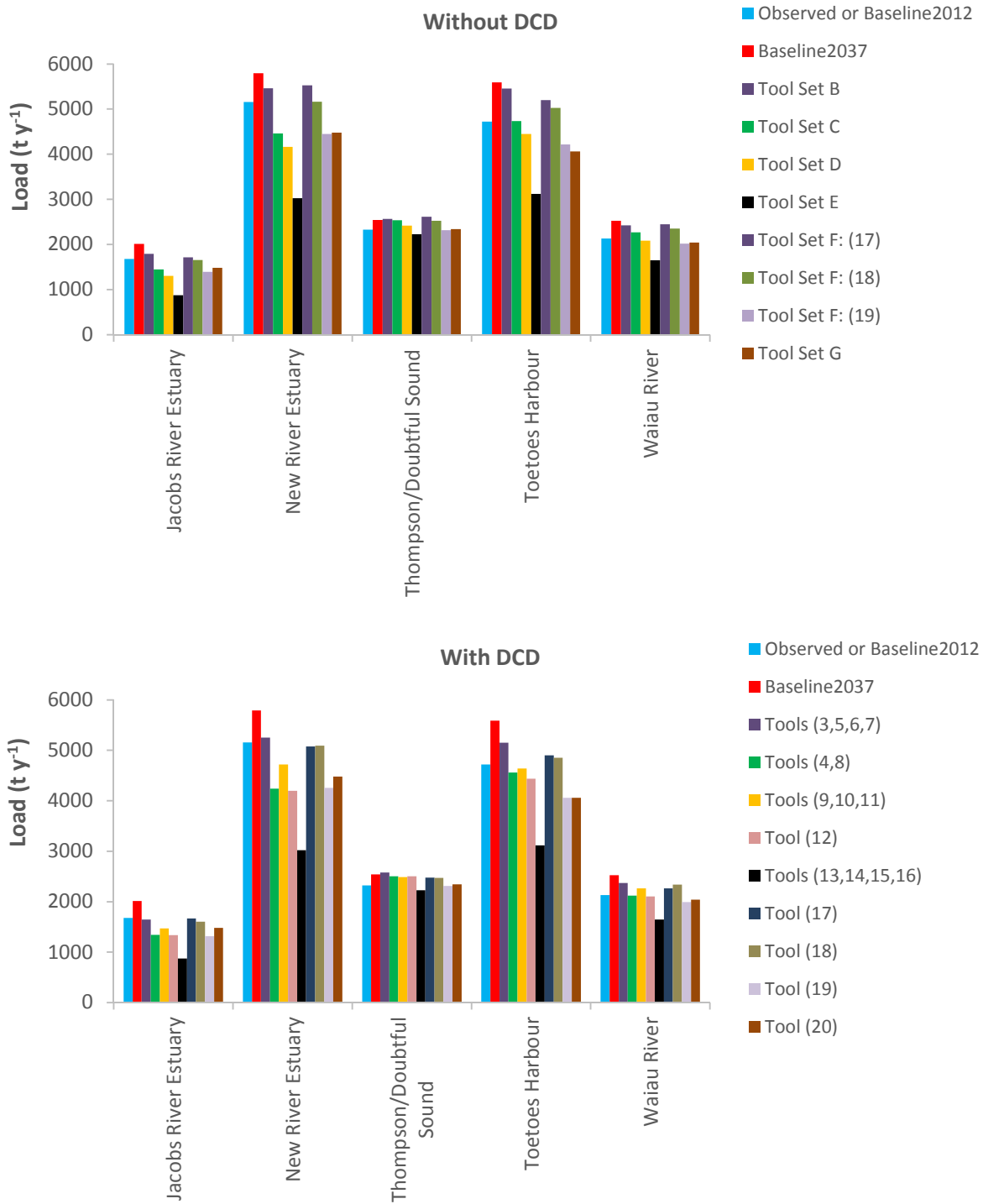
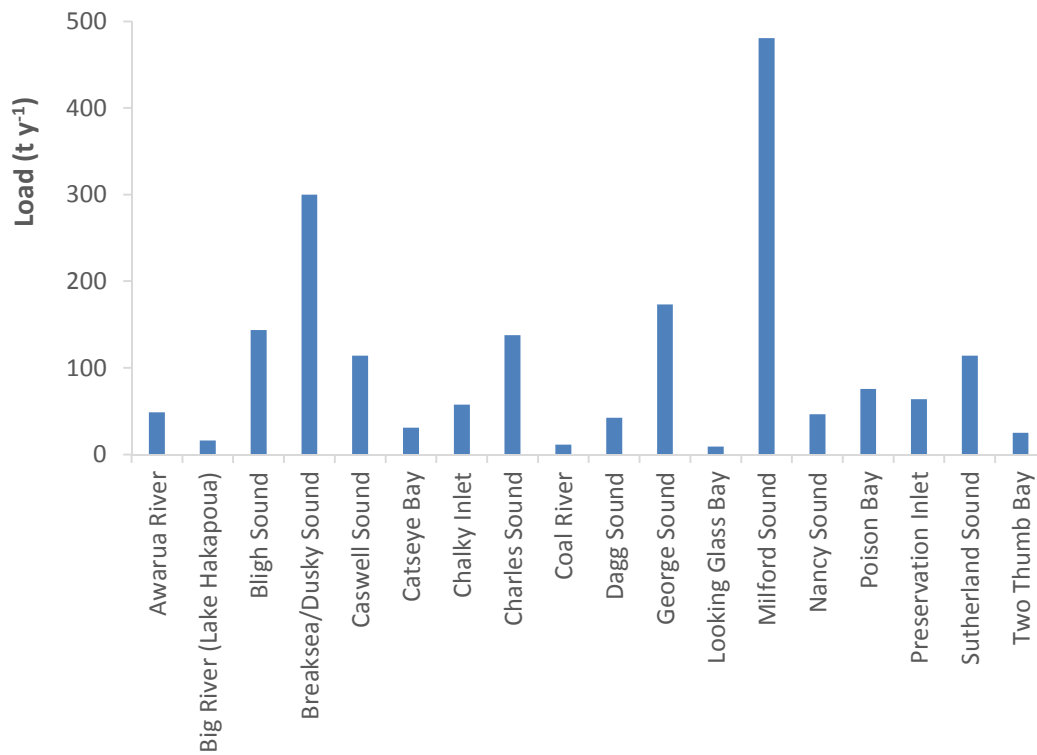


Figure 3-6: TN loads for five estuaries for various scenarios/tool sets that have loads < 300 t y<sup>-1</sup>.



**Figure 3-7: TN loads for five estuaries for various scenarios/tool sets that have loads > 300 t y<sup>-1</sup>.**



**Figure 3-8: TP loads for 18 estuaries which have the same load regardless of scenario/tool set and DCD.**

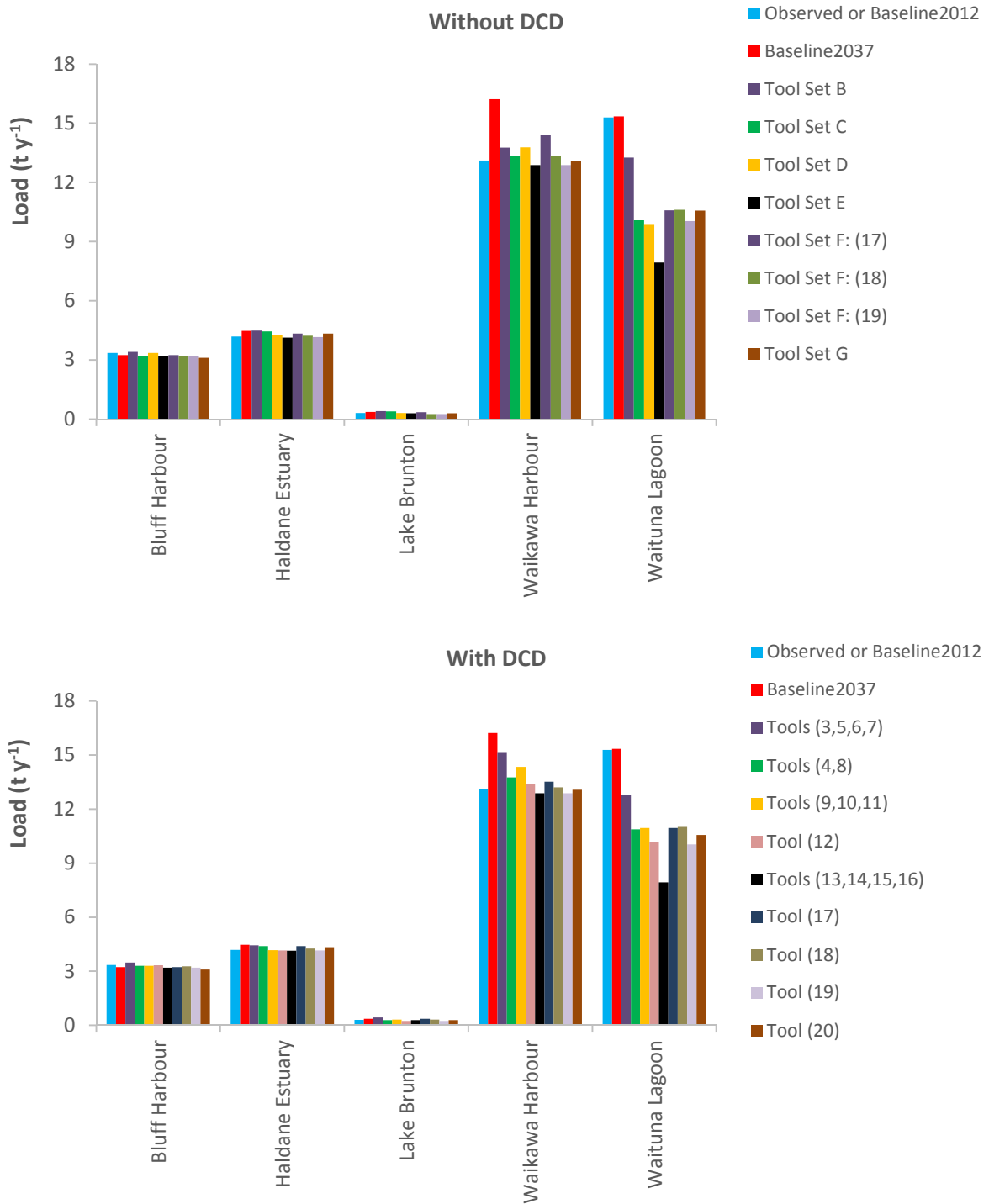


Figure 3-9: TP loads for five estuaries for various scenarios/tool sets that have loads < 18 t y<sup>-1</sup>.

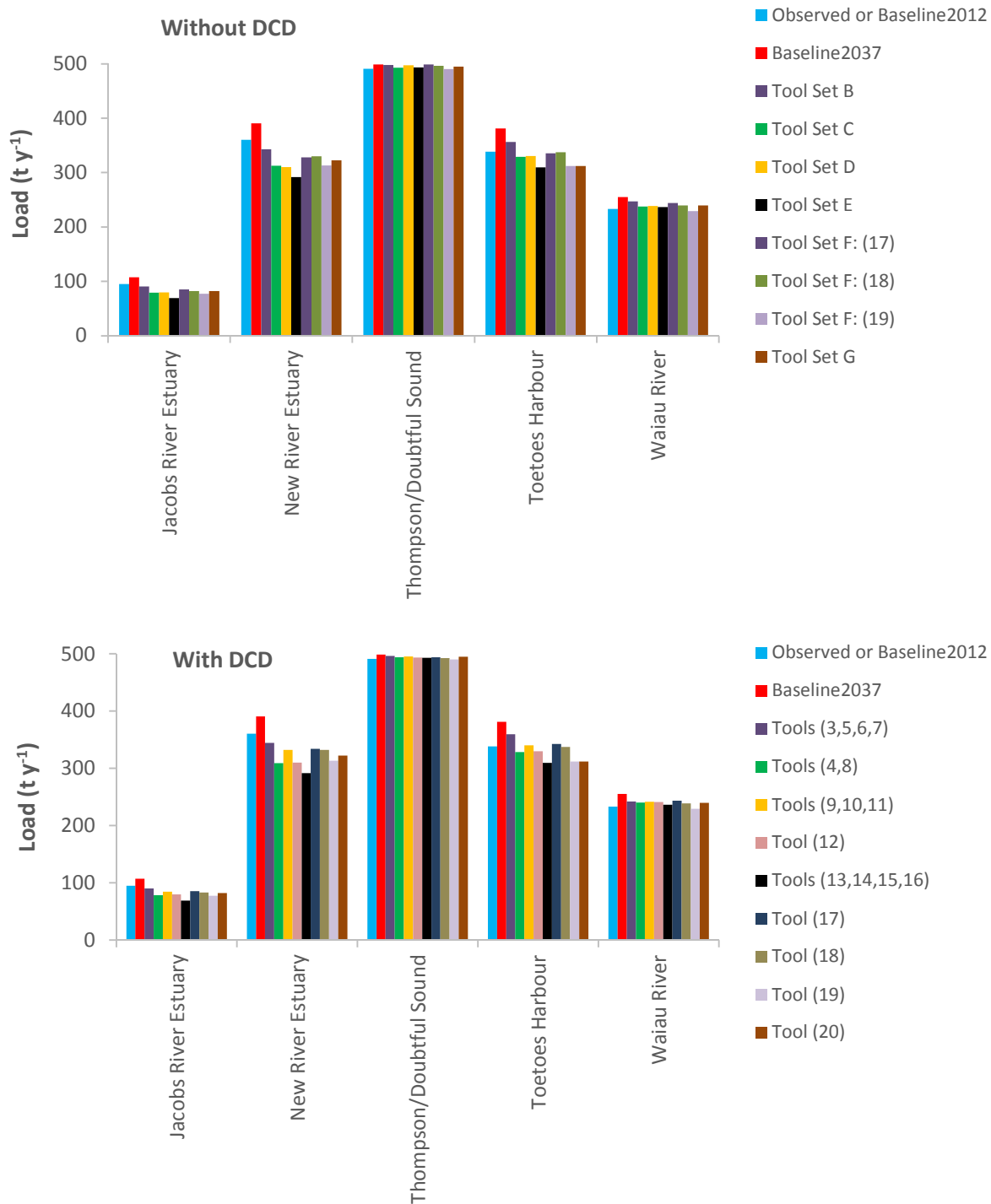
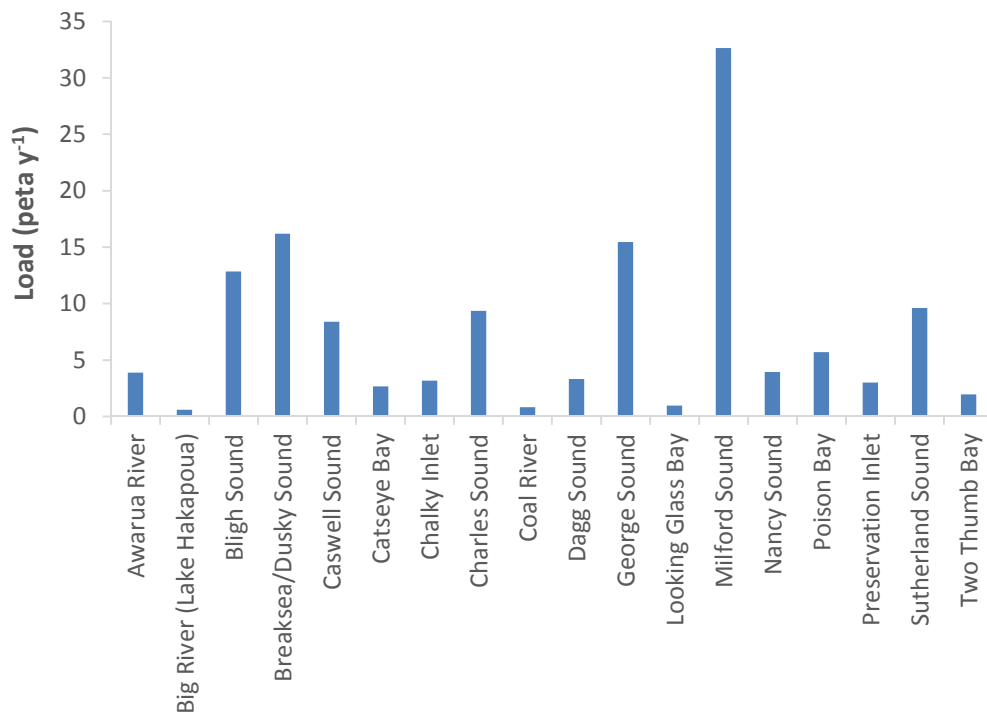
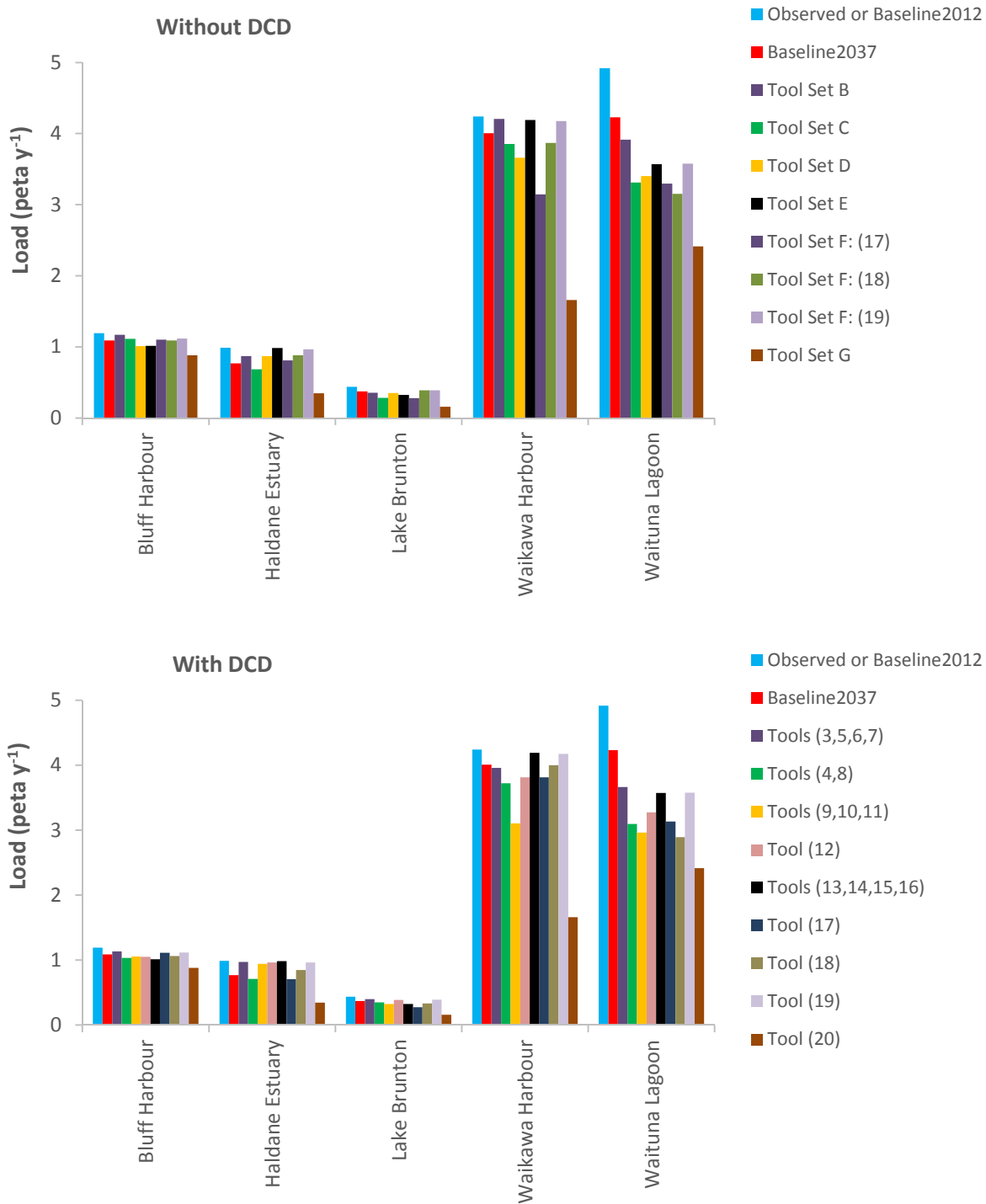


Figure 3-10: TP loads for five estuaries for various scenarios/tool sets that have loads > 18 t y<sup>-1</sup>.

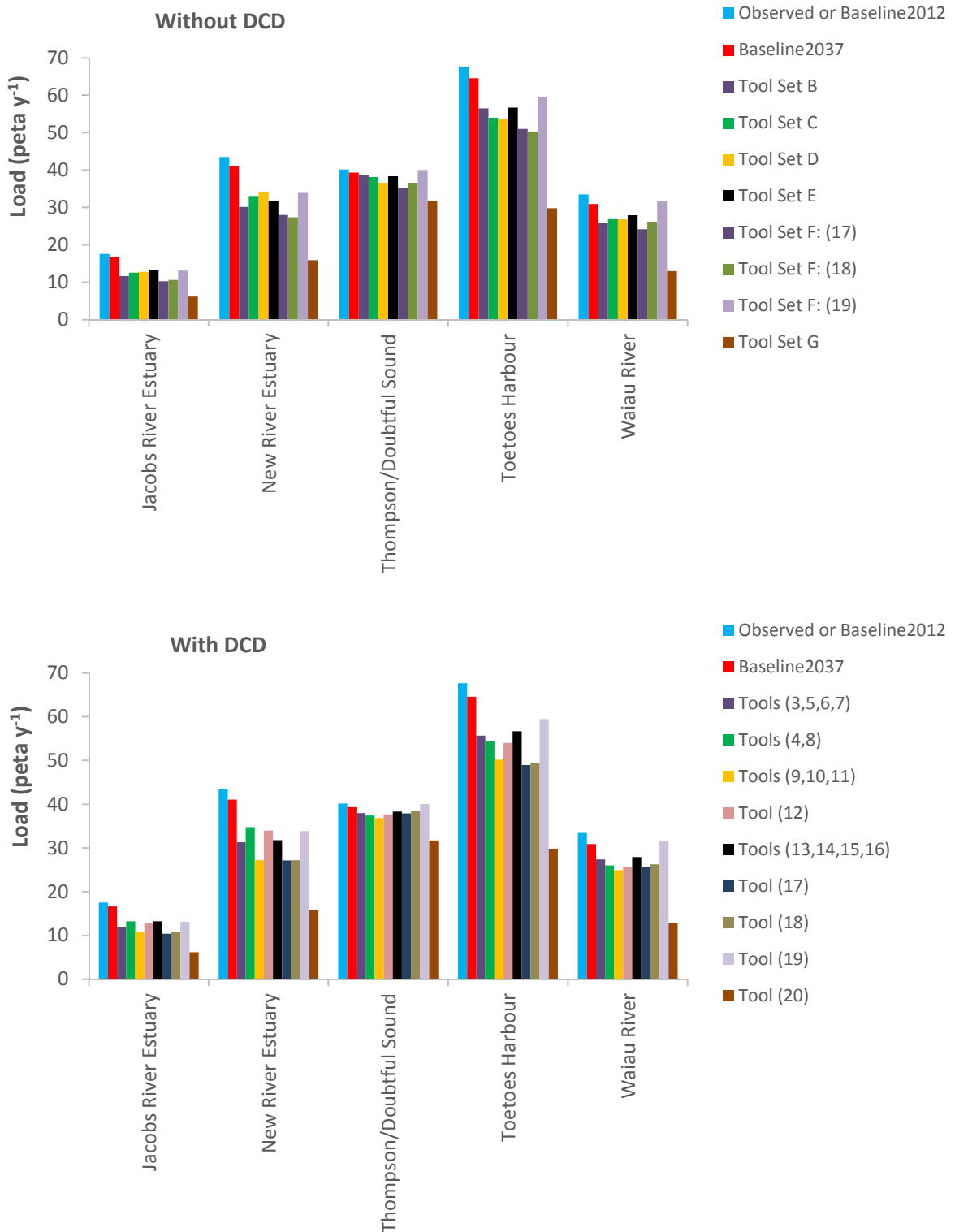


**Figure 3-11: *E. coli* loads for 18 estuaries which have the same load regardless of scenario/tool set and DCD. Peta = 1 x 10<sup>15</sup>.**





**Figure 3-12: *E. coli* loads for five estuaries for various scenarios/tool sets that have loads < 5 peta  $y^{-1}$ . Peta =  $1 \times 10^{15}$ .**



**Figure 3-13: *E. coli* loads for five estuaries for various scenarios/tool sets that have loads > 5 peta  $y^{-1}$ . Peta =  $1 \times 10^{15}$ .**

## 4 Discussion and conclusions

The calibration results for the model used in this study were generally satisfactory. The model is able to represent the variations in loading across the different sites, and the main effects of different land uses based on the data used for calibration. However, there is some error in the model load predictions (with an approximate standard error of 30% for TN, 57% for TP and 83% for *E. coli*). The predicted concentrations will be more accurate than the loads, because the concentrations are based on measurements and they are adjusted by the relative change in load, which has less error than the absolute values. The ecological assessment for estuaries will be based on TN loading, so the uncertainty associated with the loadings reported here need to be considered when evaluating the results for the estuarine impact assessment.

Calibration to local data helped improve the model predictions. For example, the un-calibrated TN model consistently under-predicted the load, which was addressed in the calibration by changing the attenuation coefficient.

The distribution of concentrations across the measurement stations does not necessarily reflect the distribution across all reaches in the region. For example, there are no monitoring stations in Fiordland. This could be improved by estimating the current concentrations from separate empirical models or from methods in Oehler and Elliott (2011), but this would introduce significant additional error in concentration prediction. Nevertheless, using the measurement stations gives an indication across a range of stream sites of interest.

Little is yet known about the age of the groundwater in the Southland region although data collection and modelling are currently being done and the results from this work are expected soon (Clint Rissmann, Environment Southland, *pers. comm.*). The SPARROW model assumes groundwater lags are zero (i.e., that stream concentrations reflect current land use) and adjusts key coefficients (e.g., TN and TP yields from non-pasture land and stream attenuation coefficients) to match current observations. If there are significant groundwater lags in the region, then the SPARROW model results are likely to under-predict stream concentrations and estuary loads in 2037. Similar under-prediction for the 2012 results is likely also, because any significant groundwater lags mean that the effects of the recent growth in dairying will not yet be fully shown in the stream concentrations and estuary loads.

Median TN and TP concentrations predicted under various scenarios/tool sets appear reasonable. Concentrations generally increased from the current situation (Baseline2012) to Baseline2037, reflecting increased conversions to dairying. The lowest concentrations were for Tool Set E (the 'uniform discharge cap' tool set with the most stringent nutrient caps, meaning that all dairy farms either converted to sheep/beef or forestry), which approximately halved the concentrations for a given percentile.

For *E. coli* there was not much sensitivity to the scenarios/tool sets, which reflects the equal loading given in the model to dairy and non-dairy pasture (so that land use change between pasture classes has no effect). The effect of mitigations on dairy land was fairly minor, because non-dairy pasture produces a large proportion of the loading. Tool Set G (the tool set which focuses on farm practices rather than nutrient caps) did result in significant reductions, however, because in that tool, mitigations were applied to both dairy and non-dairy areas.

Unlike TN and TP, predicted *E. coli* concentrations and loads were lower for Baseline2037 than for Baseline2012 (current observed). This is because the area of agricultural land that was dairy or sheep/beef for Baseline2037 was lower than for Baseline2012 – 92% and 97% respectively, i.e., forestry area increased by 5% between Baseline2012 and Baseline2037. Furthermore, although the percentage dairy farmland was higher for Baseline2037 (28%) than Baseline2012 (17%), the *E. coli* yield from all agricultural land was the same (0.07 peta number km<sup>-2</sup> y<sup>-1</sup>). The dairy yields of TN and TP are far greater than those for sheep/beef, so that the increase in dairy land area for Baseline 2037 leads to greater TN and TP concentrations and loads when compared to the observed.

The response of estuary TN loading to the various scenarios/tool sets was variable. For the majority (18 out of 28) estuaries, there was little, if any, response, because they were in undeveloped catchments. For example, the load to the estuary of the Awarua River in Fiordland did not change, because the catchment contains no pasture and is in a National Park. For other estuaries (e.g., Waituna Lagoon, Jacobs River Estuary, New River Estuary and Toetoes Harbour) there was an approximate halving of TN load between Tool Set E and some of the other scenarios.

The predicted decreases for TP were much less pronounced than for TN. For example, the TP load to Toetoes Harbour decreased by 19% from Baseline2037 to Tool Set E compared with 44% for TN. This can partly be explained by the contribution of TP derived from background erosion, and furthermore the contrast between dairy and sheep/beef losses is greater for TN than for TP.

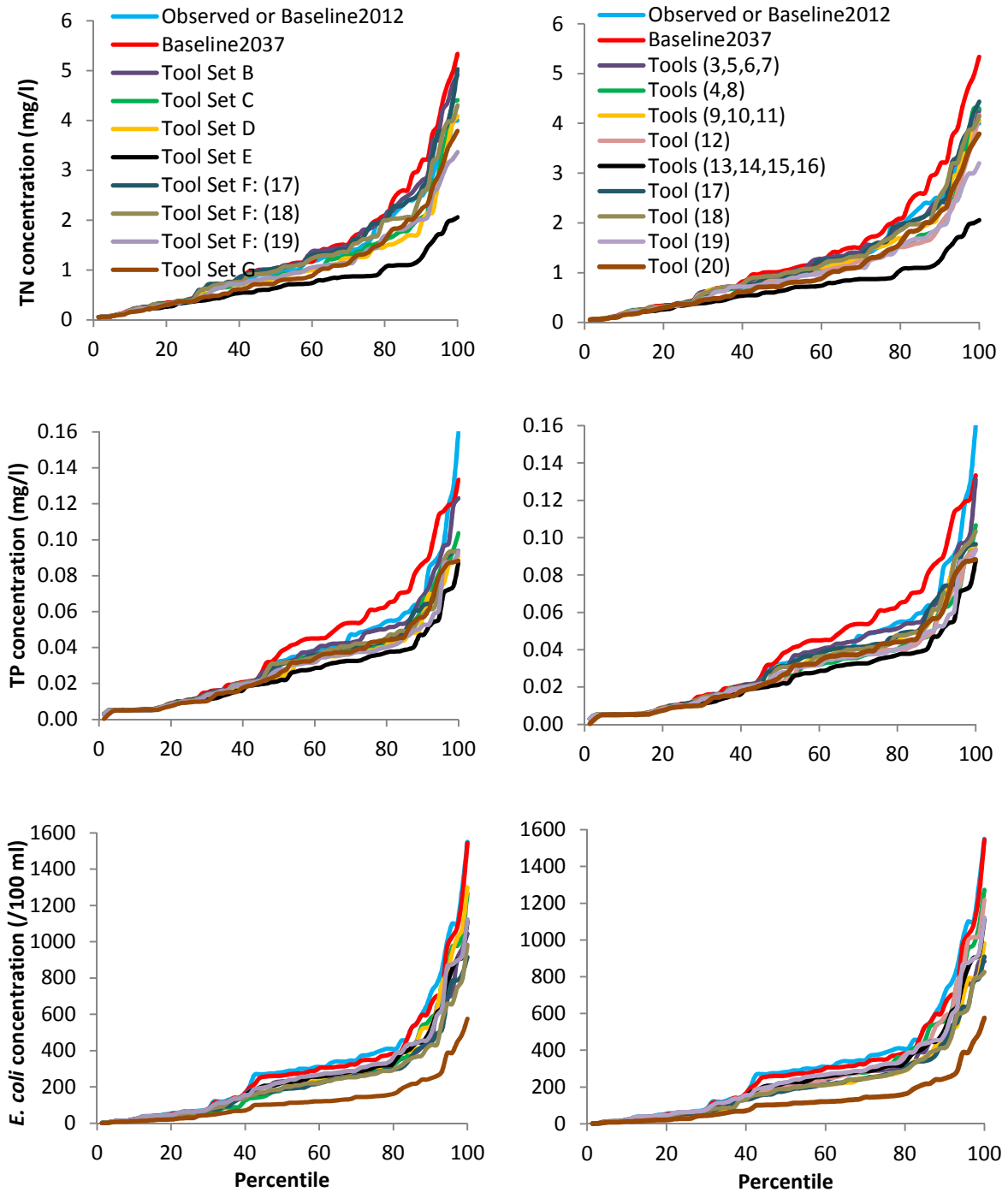
Introduction of DCD had a small effect on the TN concentrations and loads, but very little effect on TP and *E. coli* concentrations and loads.

These results will be interpreted in more depth in subsequent analysis steps reported by Aqualinc (Snelder and Fraser 2013).

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## Appendix A



**Figure A-1: Distribution of median TN, TP and E. coli concentrations across the monitored sites for various scenarios/tools. Left column is without DCD, right column is with DCD.**