A Framework for Managing Non-Point Source and Point Source Nutrient Contributions to Water Quality

Technical Report to Support Policy Development

horizons
regional council

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EXECUTIVE SUMMARY

Managing point source and non-point diffuse nutrient contamination of freshwaters is one of the major challenges facing freshwater resource managers, both in New Zealand and internationally. Horizons Regional Council has proposed water quality standards and land use rules via the One Plan to tackle water quality issues resulting from point and non-point sources.

As background to the nutrient management issue, this report outlines the current state and trend of nutrient enrichment in the Region's rivers, and identifies areas with significant nutrient issues. Additional information on current Horizons research into variation in nutrient limitation status is also included.

This report provides an analysis framework to assist water resource decision-makers in understanding the complex and varied nutrient and flow relationships in catchments subject to enrichment from point and non-point sources. The key aim of the report is to inform decision-making around water management, from a technical perspective. Additionally, this report captures the current research knowledge surrounding nutrient management in relation to intensive land uses and river environments, and documents the process Horizons has undertaken to understand these relationships regionally.

Examples within this report are based on data from two study catchments with significant nutrient loads: the upper Manawatu above the Hopelands monitoring site, and the Mangatainoka. Analysis was undertaken to assess the relationships between Soluble Inorganic Nitrogen (SIN), Dissolved Reactive Phosphorus (DRP) and river flow in these study catchments.

Results showed that nutrient and flow relationships vary depending on the nutrient of interest, the environmental variables and the human impacts that influence river flow regimes, total nutrient loads, and nutrient transport from the landscape to surface water at the catchment scale. The following steps are described for the analysis of river catchments for the purposes of managing water quality with respect to nitrogen and/or phosphorus:

1. Determine the Standard load limit for the catchment based on flow record and concentration-based water quality standards;
2. Determine the average annual Measured load and compare to the Standard load limit;
3. Describe the significant PS nutrient inputs and estimate the PS loads;
4. Calculate the relative inputs of PS and NPS using Measured loads and PS load estimates;
5. Estimate the potential for NPS load improvements and describe the combined BMP for PS and NPS loads;
6. Calculate the projected NPS target loads from Rule 13-1 of the Proposed One Plan, based on Land Use Capability (LUC) class; and
7. Recommend an approach for PS management, given the NPS loads under various nutrient management scenarios.

The ideal soluble nitrogen (SIN) and dissolved phosphorus (DRP) loads were exceeded when compared with the current state in the upper Manawatu and the Mangatainoka catchments. Results have shown that the majority of this annual nutrient load comes from NPS inputs, and occurs largely during higher flows. At times, taking a pragmatic approach was necessary to develop the technical framework outlines above, due to limitations of the data or limitations of what could realistically be achieved, in terms of nutrient reduction.

As a result of the work undertaken for this report, several changes to the State of the Environment (SOE) monitoring programme have been implemented; these are documented and included in this report in the context of the report's findings, and further recommendations for research are included.

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1. Introduction and Scope

1.1 Introduction

Managing point source and non-point diffuse nutrient contamination of freshwaters is one of the major challenges facing freshwater resource managers, both in New Zealand and internationally. Management frameworks for freshwater nutrient enrichment are the subject of considerable scientific research, policy development and public debate.

Under the Resource Management Act (1991) (RMA), Horizons Regional Council has a responsibility to promote the sustainable management of natural and physical resources, requiring the integration and balancing of environmental, social, cultural and economic considerations. Two of the specific roles given to Regional Councils by the RMA are: the control of land use for the purposes of maintaining and enhancing water quality, and the control of discharges onto land or into water. As mechanisms to achieve sustainable management, Horizons is required to develop objectives, policies, rules and other methods in Regional Policy Statements and Regional Plans.

'Catchment specific' nutrient standards for all surface waters in the Manawatu-Wanganui Region are defined in Schedule D of the Proposed One Plan (Horizons' second generation combined Regional Plan and Policy Statement). Many of the water quality standards, particularly those relating to nutrient enrichment, apply only at specific flows (ie. less than three times the median flow), others apply at all flows.

National water quality trends have identified improvements over time in the levels of gross organic pollution as the result of better treatment of point source discharges to water. However, nutrient enrichment/pollution, particularly from diffuse sources, has increased in many of the country's rivers and streams (Scarsbrook, 2006).

Horizons has closely examined the state and trend of water quality throughout the Manawatu-Wanganui Region, with a particular focus on nutrient contamination (Horizons, 2005; Scarsbrook, 2006; Gibbard *et al.,* 2006; Roygard *et al.,* 2006; Ledein *et al.,* 2007; McArthur & Clark, 2007; Ausseil & Clark, 2007b). The combined outputs of this body of research have identified several rivers with significant increasing trends in nutrient enrichment (Gibbard *et al.,* 2006) and poor current water quality state (Horizons, 2005). The level of knowledge gained from this research has enabled the water quality management framework developed for the Proposed One Plan to target problem catchments such as the upper Manawatu and Mangatainoka, amongst other river and lake catchments (Parfitt *et al.,* 2007; Clothier *et al.,* 2007).

Understanding the regional context of nutrient enrichment issues and then determining objectives, policies and rules to manage water quality issues under the Proposed One Plan (POP) are important steps in catchment-based management to avoid adverse consequences on ecosystem health. However, there are still issues that need resolving on how nutrient management can be practically and pragmatically applied in the Horizons Region.

1.2 Aims

The aims of this project are to answer the following key questions:

- How is a concentration-based nutrient standard translated into a nutrient standard load limit?
- How is a standard load limit target managed in relation to river flow?
- How can non-point source inputs from developed land be managed to meet nutrient load targets?
- Are there flows at which the river's capacity to assimilate nutrient pollution from point sources is unsustainable?
- How can wastewater discharges be managed on a day to day basis to meet flow and nutrient load standards?
- How should Horizons manage point source nutrient loads in catchments where the non-point source contributions already exceed nutrient target loads?
- How should Horizons allocate nutrient loads from several point source discharges in addition to non-point source contributions and still remain within target nutrient loads?

It is the intention of this document to answer these questions by presenting an analysis framework to inform the water resource management debate from a technical perspective.

1.3 Scope

This report reviews some of the approaches to managing nutrient enrichment in freshwaters; documents the methods used to calculate target nutrient loads that meet concentration-based water quality standards; and defines methods to measure in-river nutrient loads from point and non-point sources. The loading calculation methods quantify target and measured nutrient loads for different flow categories (deciles) and timescales (annual and daily loads). Where relevant to the development of these methods, this report also documents improvements made to the monitoring of water quality in the Region's waterways.

Whilst the development of robust methods to manage the desired and current state of nutrient enrichment is the primary scope of this report, determining the potential effect of land use or point source discharge change on water quality is integral to the future viability of the framework. This report examines the potential effects on water quality of the implementation of nutrient management solutions, such as those recommended by the *Farm Strategies for Contaminant Management* project and Rule 13.1 of the Proposed One Plan for two case study catchments: the upper Manawatu and the Mangatainoka.

These catchments were selected for the case studies because significant nutrient enrichment problems have been identified from a combination of point and non-point source inputs in these catchments (Horizons, 2005; Roygard *et al.,* 2006; Ledein *et al.,* 2007; McArthur & Clark, 2007). Detailed information on the study catchments can be found within the Appendices.

1.4 Context

Prior to the notification of the Proposed One Plan (POP), the only catchment with water quality standards in the Region was the Manawatu catchment. Nutrient standards in the Manawatu Catchment Water Quality Regional Plan (1999) (MCWQRP) were limited to dissolved reactive phosphorus (DRP) at flows equal to or below half median and ammoniacal nitrogen (ammonia) at all flows, depending on water temperature.

Nitrogen and phosphorus standards (in addition to a range of other water quality standards) were defined as part of the development of the POP, following recommendations from an expert panel on the management of nutrients to control periphyton growth. The panel strongly identified the need to control both nitrogen and phosphorus at all flows below flood flows to reduce the risk of nuisance periphyton growth, and advised moving away from relying on reducing inputs of a 'limiting nutrient' only (Wilcock *et al.,* 2007).

The development of the POP has focussed on four big issues for the Region:

1. Water Quality;
2. Water Quantity;
3. Sustainable Hill Country Land Use; and
4. Indigenous Biodiversity.

This report is one of several prepared to provide technical support to the Proposed One Plan policy development for water quality management in the Region (Figure 1), and is the culmination of several interlinked investigations and considerable expert advice undertaken by Horizons in recent years.

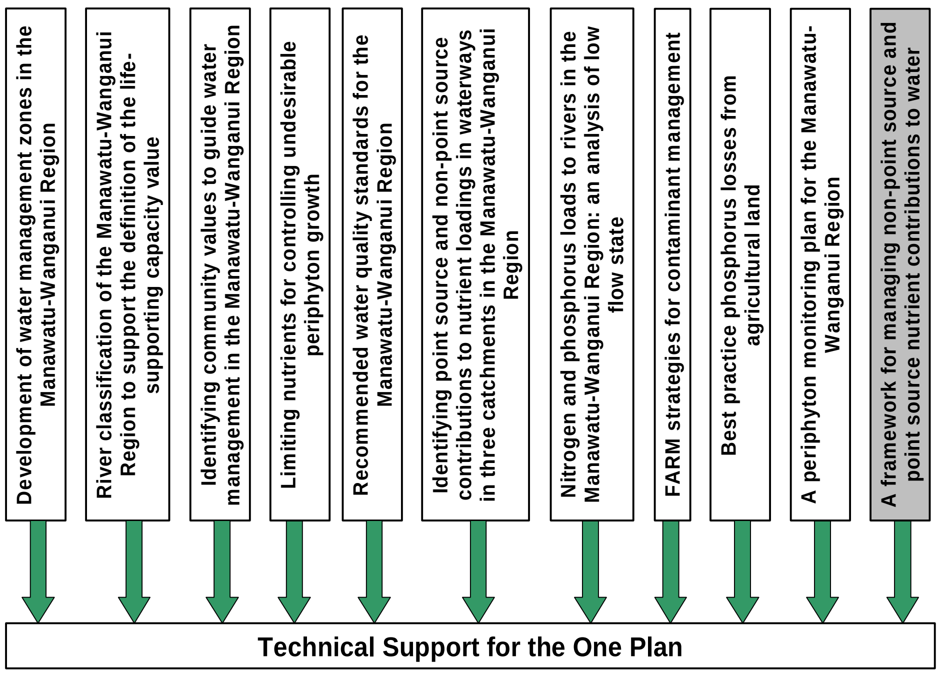

Figure 1: Planning context of the Water Management Zones project in relation to the technical reports supporting the One Plan process.

a) The key water quality issue identified within the Proposed One Plan is Issue 6-1: "The water quality of most rivers and lakes in the Region has declined to the point that ecological values are compromised and contact recreation (such as swimming) is considered unsafe."

The key principle of the technical work supporting the policy development to address this issue was the integration of water management using a framework which:

1. Established physical management units, known as water management zones and sub-zones (McArthur *et al.,* 2007);
2. Identified water body values for each unit (zone) (Ausseil & Clark, 2007a);
3. Derived water quality standards to protect the values (Ausseil & Clark, 2007b); and
4. Formulated a monitoring framework to assess policy effectiveness monitoring.

The values and standards developed for each water management zone and sub-zone are individually tailored to account for the values associated with the waterbody in question and the water quality standards required to support those values. Objective (6-1) of the Plan states that "Surface waterbodies are managed in a manner which sustains their life-supporting capacity and recognises and provides for the values set out in Schedule D."

Because the water quality standards are related to the individual values of each water management zone, and the objectives require the values to be provided for, the Plan objectives are also specific to each water management zone. Objective (6-2) sets out to ensure that water quality is managed to maintain the quality of rivers where the existing quality is sufficient to support the values of the river; to enhance the water quality of rivers where the existing quality is not sufficient enough to support the values of that river; to prevent or minimise accelerated eutrophication or sedimentation of lakes; and to ensure that the special values of rivers protected by national water conservation orders and local water conservation notices are maintained. The policy framework that supports the Plan objectives includes Policies 6-1 to 6-5.

Further detail on the background for the regional water management framework in the POP, and underlying this report, is contained in section 3 below, and an in-depth summary of standards from the MCWQRP and the POP can be found in Ausseil & Clark (2007b).

1.5 Acknowledgements

Many people have contributed to the development of this nutrient framework approach and report. In particular the following people have made a significant contribution:

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Chris Arbuckle
Alec Mackay
Roger Parfitt
Brent Clothier

2. Water Quality – The One Plan Management Approach

2.1 Water management zones

Underlying the development of the POP water quality policies is an integrated water management framework. The approach is based on water management zones and sub-zones, which are defined physical units, within which water quality outcomes will be managed (McArthur *et al.,* 2007).

These zones relate to water- and land-based activities, including water allocation, water quality management, hill country erosion control and biodiversity protection. For example, the Sustainable Land Use Initiative (SLUI) is being implemented by water management zone, although the outcomes include both land (ie. reduced soil erosion) and water benefits (ie. decreased sedimentation of rivers). For resource management functions some sub-zones within a zone may be amalgamated for one management purpose (ie. water quality) but separated for another (ie. surface water allocation).

A range of criteria was applied to derive the water management zones and their subsequent sub-zones (Figure 2). Forty-four water management zones (Map 1) and 117 sub-zones have been defined across the Region (Map 2).

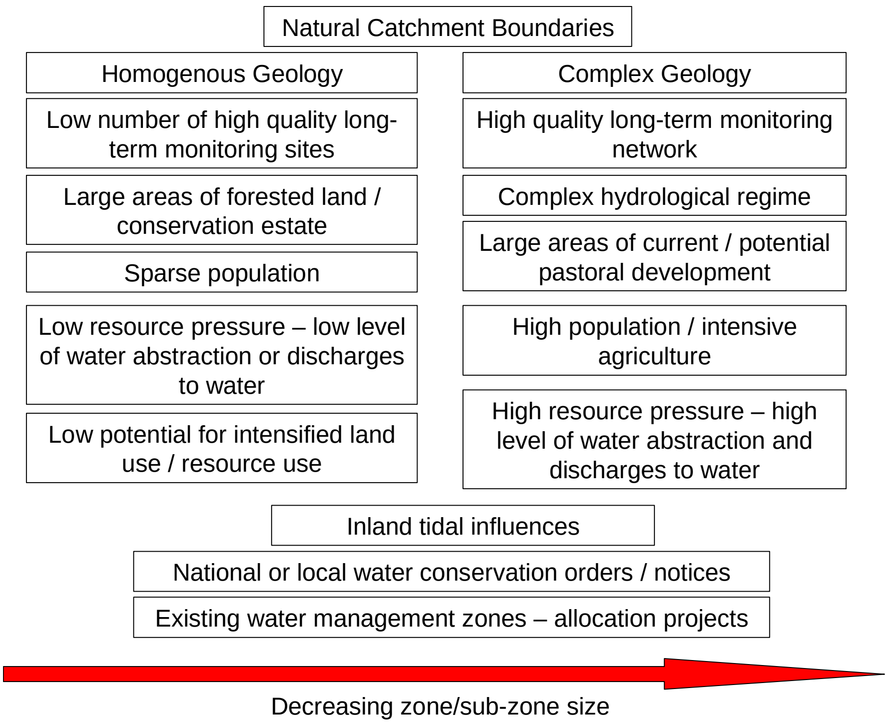
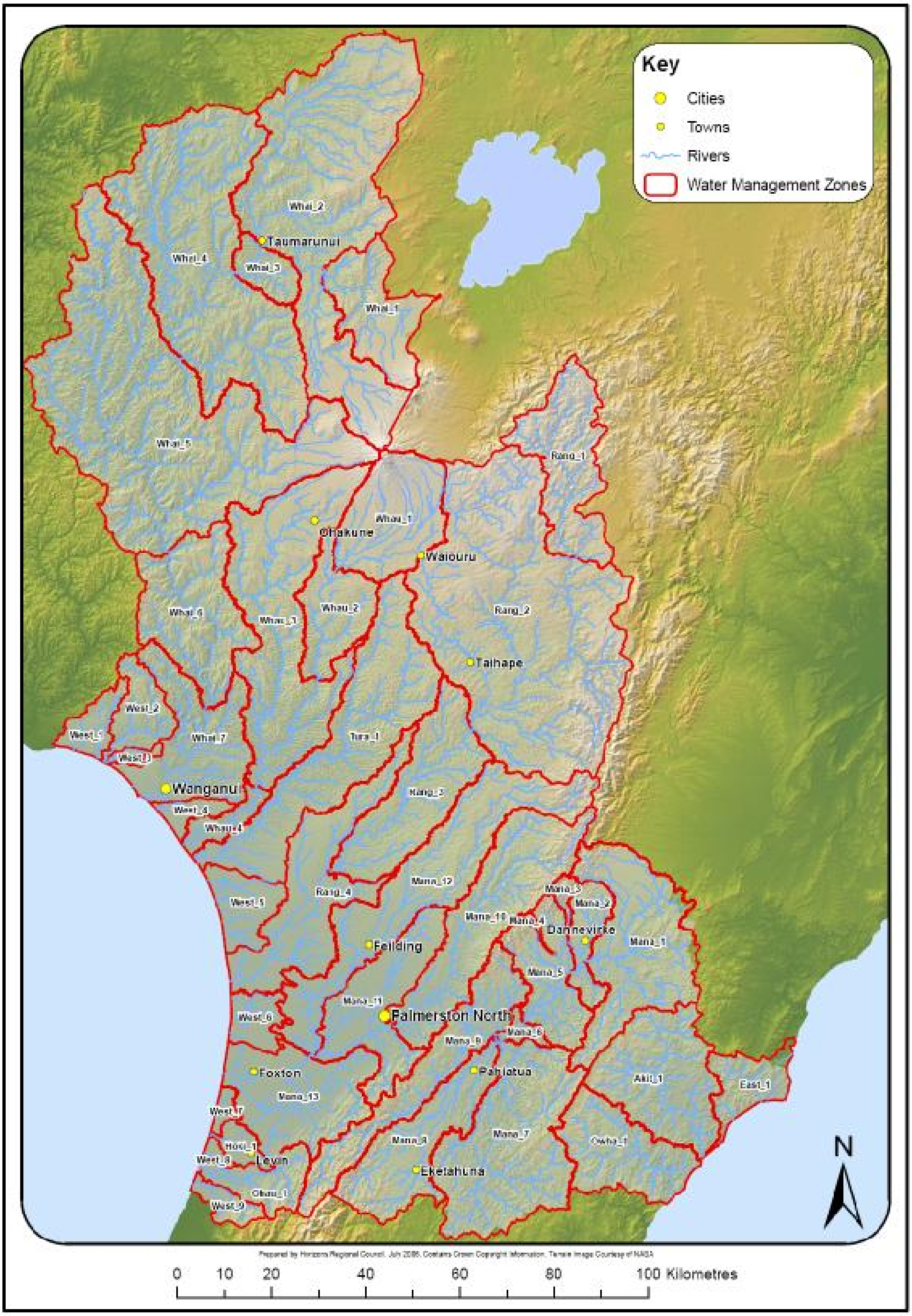
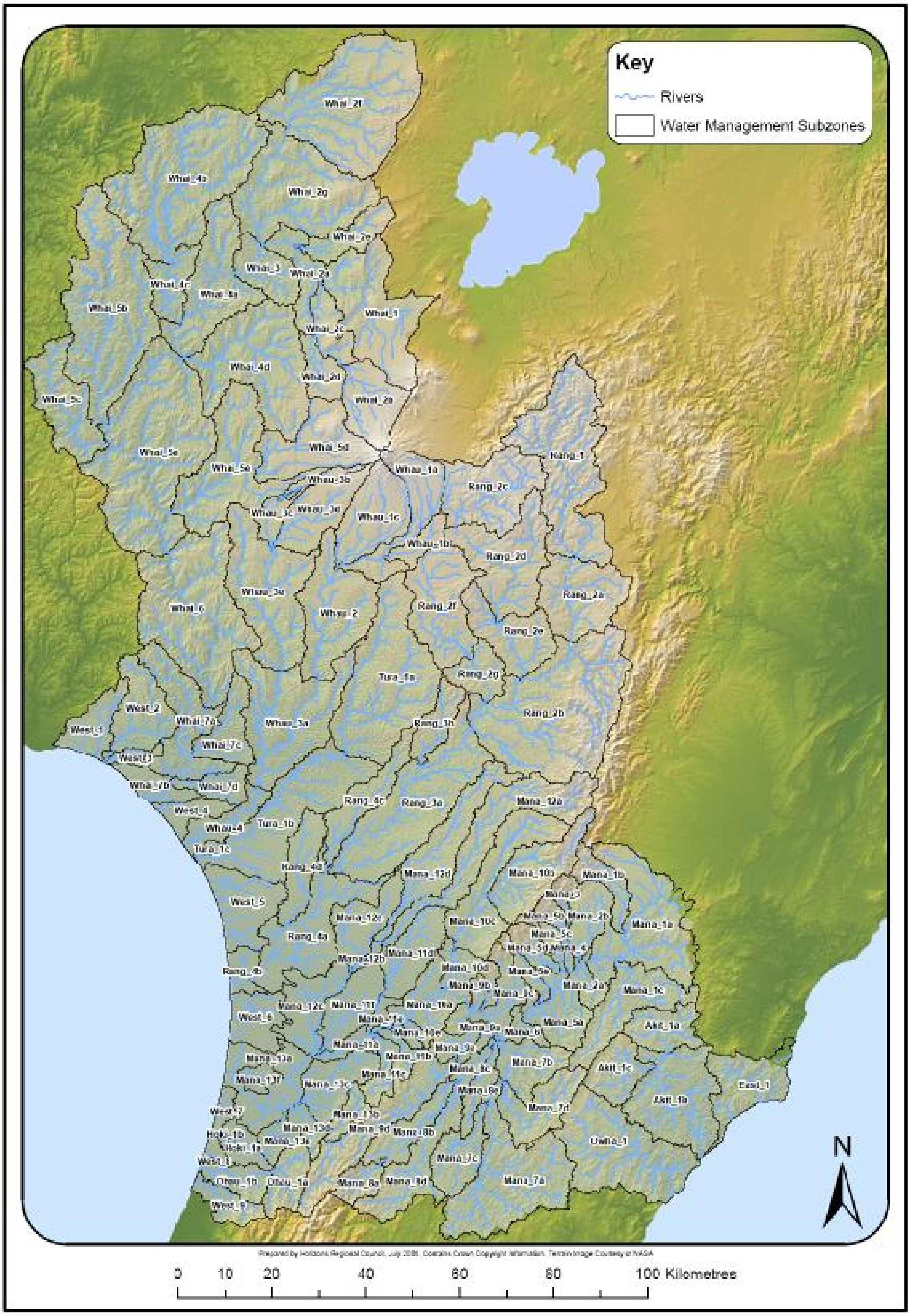


Figure 2: Major factors influencing the determination of water management zones in the Manawatu-Wanganui Region (from McArthur *et al.,* 2007).



Map 1: Water Management Zones in the Manawatu-Wanganui Region.



Map 2: Water Management Sub-zones in the Manawatu-Wanganui Region.

2.2 Water body values

A key goal for integrated catchment management is to ensure all values of rivers and lakes are maintained at, or improved to, the level identified by the water quality standards in order to meet the objectives in the Plan. Ausseil & Clark (2007a) documented the development and identification of water body values for the POP. A total of 23 different values, applying to all or parts of the Region's rivers and lakes were identified, and classed into four groups (Table 1).

The potential for conflict between the value groups is reasonably high, particularly between the "Consumptive Use" and "Social and Economic" and the "Ecosystem" and "Recreational and Cultural" groups. The values defined in the POP provide a framework for bringing together different parties to assist decision-makers in reaching balanced decisions about how the management objectives will be met (Ausseil & Clark, 2007a).

Table 1: Community water body values as proposed for the Manawatu-Wanganui Region and links to Proposed One Plan policies that will give effect to the values (from Ausseil & Clark, 2007a).

Overarching Value Groupings	Individual values		Translated into policies in One Plan Chapters				
			Water Quality	Water Allocation	BRL[1]	Living Heritage	Coastal
Ecosystem Values	NS	Natural State	ü	ü	ü	ü	
	LSC	Life-Supporting Capacity	ü	ü	ü		ü
	SOS-A	Sites of Significance-Aquatic	ü	ü	ü	ü	ü
	SOS-R	Sites of Significance-Riparian			ü	ü	ü
	NFS	Native Fish Spawning	ü	ü	ü	ü	ü
Recreational and Cultural Values	CR	Contact Recreation	ü	ü	ü		ü
	Am	Amenity			ü		
	NF	Native Fishery	ü	ü	ü	ü	ü
	Mau	Mauri	ü	ü	ü	ü	ü
	SG	Shellfish Gathering	ü				ü
	SOS-C	Sites of Significance-Cultural	ü	ü	ü	ü	ü
	TF	Trout Fishery	ü	ü	ü		
	TS	Trout Spawning	ü	ü	ü		
	AT	Aesthetics	ü	ü	ü	ü	ü
Consumptive Use Values	WS	Water Supply	ü	ü	ü		
	IA	Industrial Abstraction	ü	ü	ü		
	I	Irrigation	ü	ü	ü		
	S	Stockwater	ü	ü	ü		
Social/Economic Values	CAP	Capacity to Assimilate Pollution	ü	ü			ü
	FC	Flood Control			ü		
	EI	Existing Infrastructure			ü		
	D	Drainage			ü		
	GE	Gravel Extraction			ü		

[1] Beds of Rivers and Lakes (BRL) and associated activities

2.3 Water quality standards to protect values

One of the key principles guiding the development of the POP was to have a science-based plan with established numerical limits, avoiding the subjectivity of narrative standards. Measurable indicators will need to be used to monitor the effectiveness of water quality policies and rules in achieving the Plan objectives and environmental outcomes. Water quality standards were determined for each water management zone, based on the values within the zone using expert opinion and literature from a range of sources (Ausseil & Clark, 2007b). Determination of nitrogen and phosphorus standards is discussed below.

3. Nutrient Enrichment in the Manawatu–Wanganui Region

3.1 Why manage nutrient enrichment?

Nutrient enrichment is the contamination of freshwaters from elevated levels of nitrogen and phosphorus. Concentrations of soluble nitrogen and phosphorus in excess of natural background levels can cause nuisance periphyton (algal) proliferation on the beds of lakes, rivers and streams. Nutrient enrichment can also cause the complete smothering of stream channels by aquatic weeds or contribute to the formation of algal or cyanobacterial blooms (both suspended and benthic) that can be toxic to humans and animals.

Periphyton (and macrophytes in some waterways) are the primary productive base of the aquatic food chain (Winterbourn, 2004) and are an important aspect of functioning aquatic ecosystems. However, excess growth (proliferations) of periphyton reduces the aesthetic and recreational appeal of water bodies and can negatively impact on many values (Biggs, 2000). For example, the life-supporting capacity and aquatic biodiversity value of rivers and streams can be decreased by smothering of the substrate by periphyton. Consumptive uses can also be impacted through reduction of the potability of water for stock and human supply, or the clogging of irrigation and water supply intakes with algal or macrophyte biomass.

The open, un-shaded nature of most of the gravel-bed rivers and streams in the Horizons Region increases the risk of nuisance periphyton proliferation, particularly in summer when sunlight intensity is highest and river flows recede. The duration of time when environmental conditions are suitable for maximum periphyton growth, between high flow events which dislodge and wash away periphyton biomass, is known as the accrual period. Many rivers and streams currently experience considerable blooms of algal growth when suitable accrual conditions persist and soluble nutrient loads are high.

Nutrient sources and cycling

Nitrogen

Nitrogen is plentiful in the environment with almost 80 percent of the atmosphere by volume consisting of nitrogen gas. Nitrogen exists in many forms, several of which are usable by plants for growth. The conversion to plant-available forms in both terrestrial and aquatic environments is governed by four processes (U.S. EPA, 1999):

1. Nitrogen fixation – conversion of gaseous nitrogen to ammonia ions (NH_3 and NH_4^+) by organisms such as blue-green algae (cyanobacteria) and bacteria (*Rhizobium spp.);*

2. Ammonification - reaction in which decomposer organisms convert wastes and non-living organic tissue to amino acids, which are then converted to carbon dioxide, water and ammonium ions - ammonia is then available for absorption by plant matter;

3. Nitrification – two-step process that oxidises ammonia ions to nitrite and nitrate yielding energy for decomposer organisms; and

4. Denitrification - process by which nitrates are reduced to gaseous nitrogen by facultative anaerobes eg. fungi.

In aquatic environments nitrogen exists in several forms: dissolved nitrogen gas, ammoniacal N (NH_4+ and NH_3), nitrite (NO_2), nitrate (NO_3) and organic nitrogen in either soluble or particulate phases.

The most relevant forms of nitrogen to water quality are the soluble inorganic nitrogenous compounds (ammoniacal N + nitrites + nitrates) (Wilcock *et al.*, 2007). Particulate and organic N are not plant-available in the short term and are therefore less relevant to controlling periphyton growth in aquatic systems. Total Nitrogen is a composite measurement of all forms of nitrogen and is more applicable to confined water, or rivers and streams flowing into lake systems.

Phosphorus

Unlike nitrogen, phosphorus does not exist as a gas. Some rock types are a natural source of phosphorus to river systems and deposits are released through rock weathering, leaching and erosion. Terrestrial phosphorus cycling includes the immobilisation of inorganic phosphorus in sediments, plant uptake and the breakdown of organic phosphorus into inorganic forms. Some phosphorus is directly transported into aquatic systems by water or wind.

USEPA (1999) defines phosphorus in freshwater and marine systems which exists in two main forms:

1. Organic phosphorus - includes living or dead particulate matter and non-particulate phosphorus, such as dissolved organic phosphorus (DOP) excreted by organisms, and colloidal phosphorus compounds; and

2. Inorganic phosphorus - soluble inorganic phosphates $H_2PO_4^-$, HPO_4^{2-}, and PO_4^{3} (DRP) are readily available to plants. Inorganic particulate phosphorus includes phosphorus precipitates, phosphorus adsorbed to particulate matter (eg. bound to soils) and amorphous phosphorus.

Nutrient transport pathways to surface water

Phosphorus from non-point sources, because of its tendency to adsorb to soil particles and organic matter, tends to be transported with eroded sediments to surface water. Inorganic nitrogen on the other hand does not adsorb as strongly and substantial quantities can be transported in both particulate and dissolved forms in surface run-off and through sub-surface leaching. Gaseous nitrogen can be transported to surface water via atmospheric deposition, and phosphorus associated with fine-grained particulate matter can also be deposited in surface waters from the atmosphere. Additionally, nutrients are directly discharged to waterways from point sources eg. wastewater treatment plants, dairyshed effluent and industrial discharges.

Once in surface water, nitrogen and phosphorus behave differently. Because inorganic forms of nitrogen do not adsorb strongly to particulate matter they often remain dissolved within the water column. However, in lakes or large rivers where high phosphorus sediment deposition can occur, such as the Manawatu, DRP is adsorbed to polyvalent cations in the sediment under aerobic conditions (Parfitt *et al.,* 2007). During low river flows sediments can become anoxic and sediment-P can be reduced and released into the water column, where it is oxidised again and appears as DRP (B. Wilcock *pers. comm.* 2008).

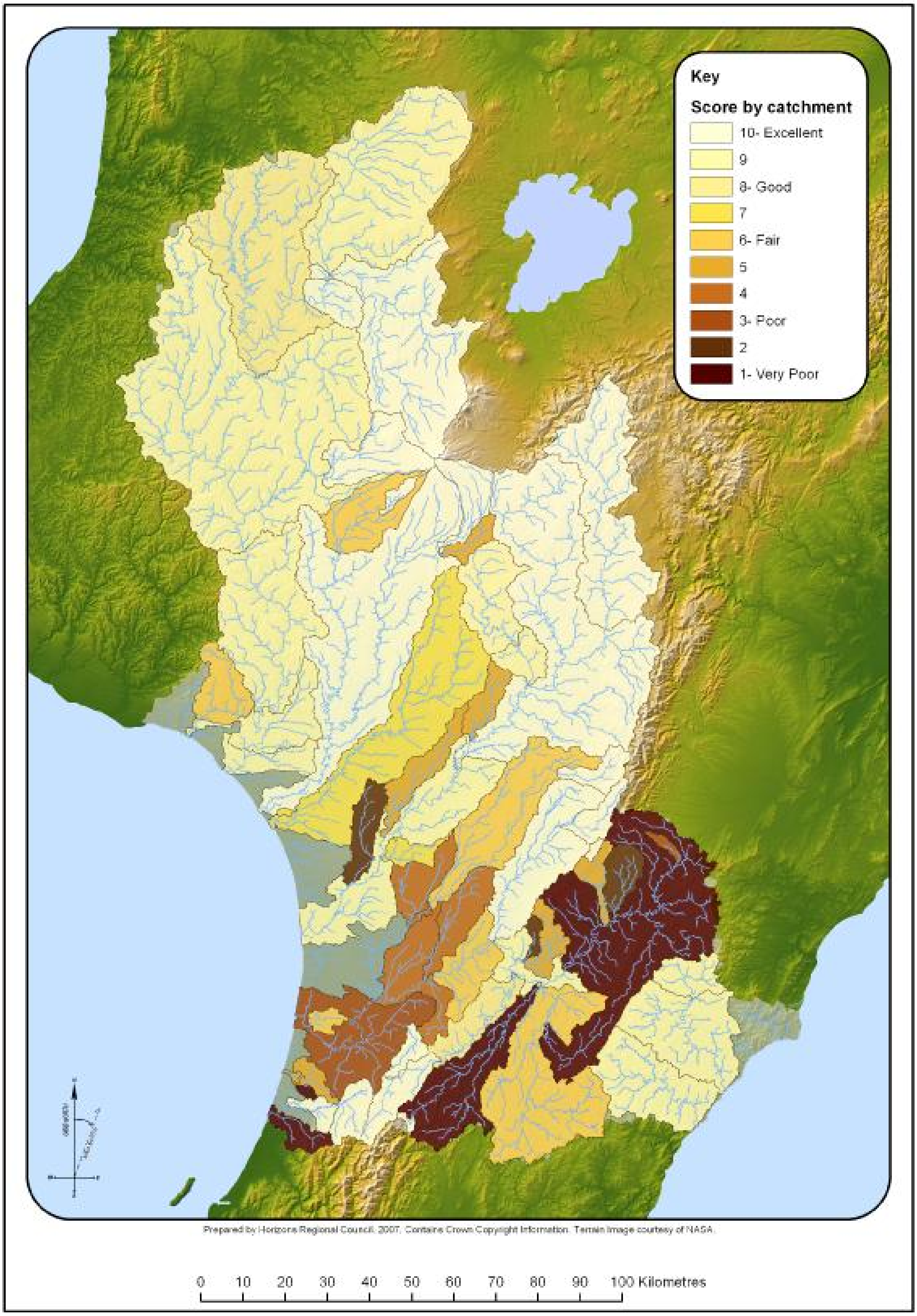
The measurement of all phosphorus forms in a water sample, including inorganic and organic particulate and soluble forms is known as total phosphorus (TP). The TP analysis does not distinguish between phosphorus that is absorbed to sediments and unavailable to plants and that which is bio-available. In streams with relatively short residence times, it is less likely that the transformation from unavailable to available forms will occur and DRP is the most accurate measure of biologically available phosphorus (Wilcock *et al.,* 2007). However, if in environments with longer residence times such as lakes or large, slow-flowing rivers during low flow, TP can be considered an adequate estimation of bio-available phosphorus.

3.2 The state of nutrient contamination of surface water in the Horizons Region

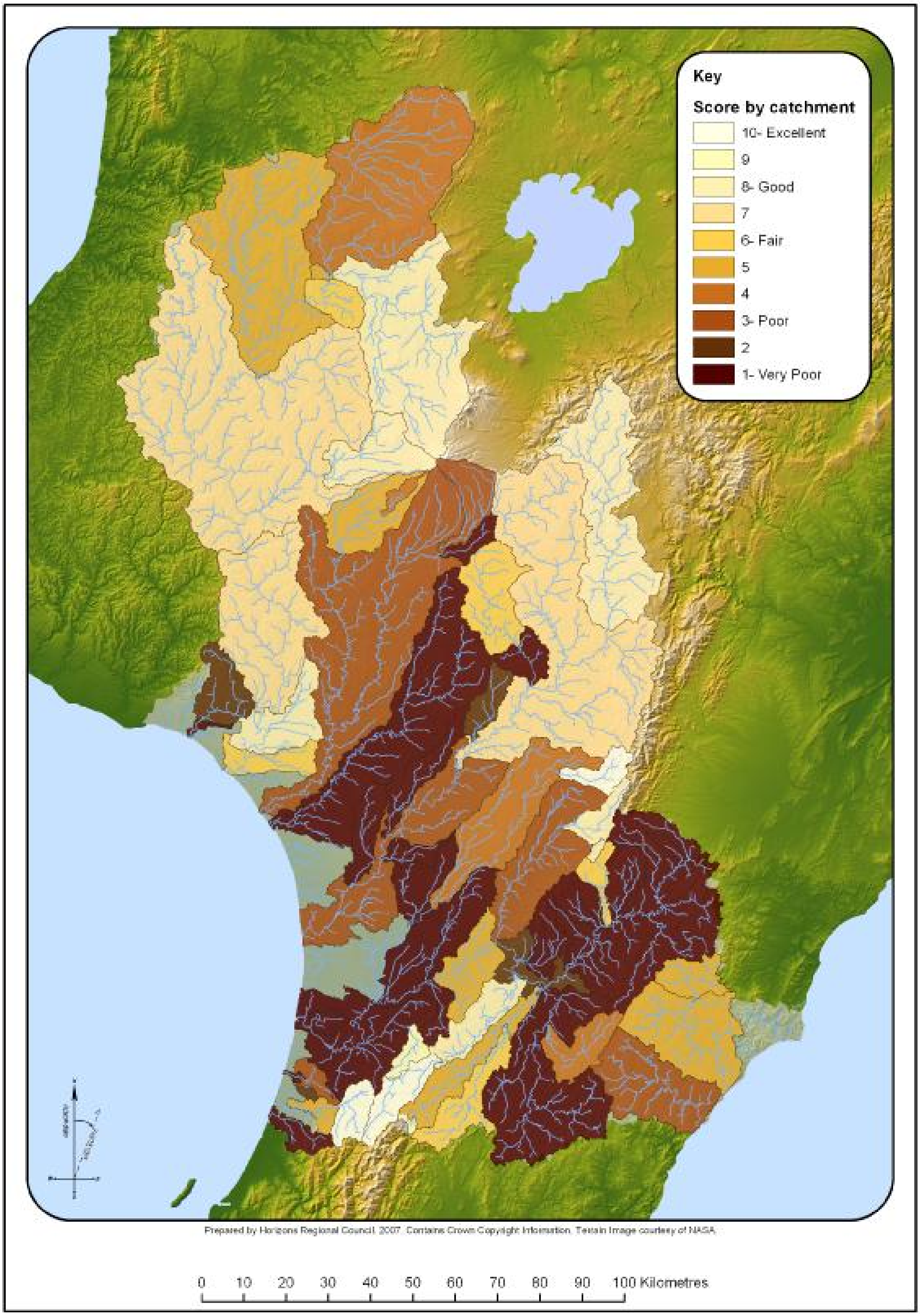
Horizons monitors water quality throughout the Region via State of the Environment (SOE) monitoring, compliance monitoring and targeted science investigations. The Horizons SOE Report (2005) compared nutrient indicator scores to the ANZECC (2000) lowland trigger values (0.444 g SIN/m^3 and 0.010 g DRP/m^3), identifying several catchment areas where water quality regularly exceeded the ANZECC guidelines for nutrient enrichment (Map 3 and Map 4). This analysis was based on a range of samples depending on the record of data for each monitoring sites. Sites with less than one year of monthly monitoring were excluded from the analysis.

Nitrate contamination was particularly prevalent in the upper Manawatu, Mangatainoka, Makuri, Waikawa, Lake Horowhenua and Tutaenui catchments.

High phosphorus concentrations in the form of DRP were found in rivers and streams throughout the Manawatu catchment, some tributaries of the lower Rangitikei River (Tutaenui, Porewa and Rangitawa Streams), the Hokio Stream (Lake Horowhenua outlet) and Waikawa Stream.



Map 3: Water quality indicator for nitrate by catchment, Horizons State of the Environment Report (2005). *Note: a score of 10 indicates > 90 % of samples were </= the ANZECC guideline, a score of 1 indicates < 10 % of samples were </= the ANZECC guideline.*



Map 4: Water quality indicator for phosphorus (DRP) by catchment, Horizons State of the Environment Report (2005). *Note: a score of 10 indicates > 90 % of samples were </= the ANZECC guideline, a score of 1 indicates < 10 % of samples were </= the ANZECC guideline.*

3.3 National and Regional trends in nutrient enrichment

The National River Water Quality Network (NRWQN), administered by NIWA, has monitored 13 water quality parameters at 77 sites throughout the country since 1989 (Scarsbrook, 2006). Seven of these sites are within the Horizons Region with two sites on the Whanganui and Rangitikei Rivers and three on the mainstem of the Manawatu. A national review of water quality trends undertaken in 2005 found highly significant correlations (P <0.001) between annual median water temperature, conductivity, visual clarity, nitrogen, phosphorus, *E. coli* and the extent of pastoral land cover within the study site catchments (Scarsbrook, 2006).

Scarsbrook (2006) also observed long-term increasing trends in total and oxidised nitrogen nationally; these trends were again strongly correlated (P <0.01 for Total N and P <0.001 for Total Oxidised Nitrogen (NOx-N)) with the extent of pastoral land use within site catchments. DRP appears to have peaked during the late 1990s in highly enriched rivers such as the Manawatu, but decreased since then, removing any long-term (1989–2003) trend in the national data. However, the Manawatu at Weber Road site in the upper Manawatu catchment showed meaningful increases in all forms of nitrogen (except ammonia) and total and dissolved phosphorus between 1989 and 2003 (Scarsbrook, 2006). This was consistent with the results of Horizons water quality trends analysis (Gibbard *et al.,* 2006).

Gibbard *et al.* (2006) analysed SOE monitoring data from between 1989 and 2004 for nitrate, DRP and turbidity for 22 sites spread throughout the four main river catchments of the Region (Rangitikei, Manawatu, Whanganui and Whangaehu) and provided statistical evidence of trends in water quality over time, where they existed, and an indication of the significance of any trends (Table 2).

For both flow-adjusted and non flow-adjusted analyses, the Manawatu at Hopelands and Mangatainoka at State Highway 2 SOE sites showed highly significant increasing trends for nitrate. The Manawatu at Hopelands site also had a highly significant increasing trend for DRP over the same time period.

These findings support national and regional shifts in resource management focus from the control of point source to non-point source nutrient contamination (Scarsbrook, 2006). However, continuing significant levels of point source phosphorus at sites subject to a number of municipal and/or industrial discharges, such as the lower Manawatu, highlights the need for continued management of point source nutrients in all catchments affected by these impacts.

3.3.1 Nutrient enrichment state and trend

The case study shows that upper Manawatu and Mangatainoka Rivers currently have poor states of water quality with respect to N and P, and highly significant increasing trends in nitrates within both catchments and DRP in the upper Manawatu (Gibbard *et al.,* 2006; Scarsbrook, 2006).

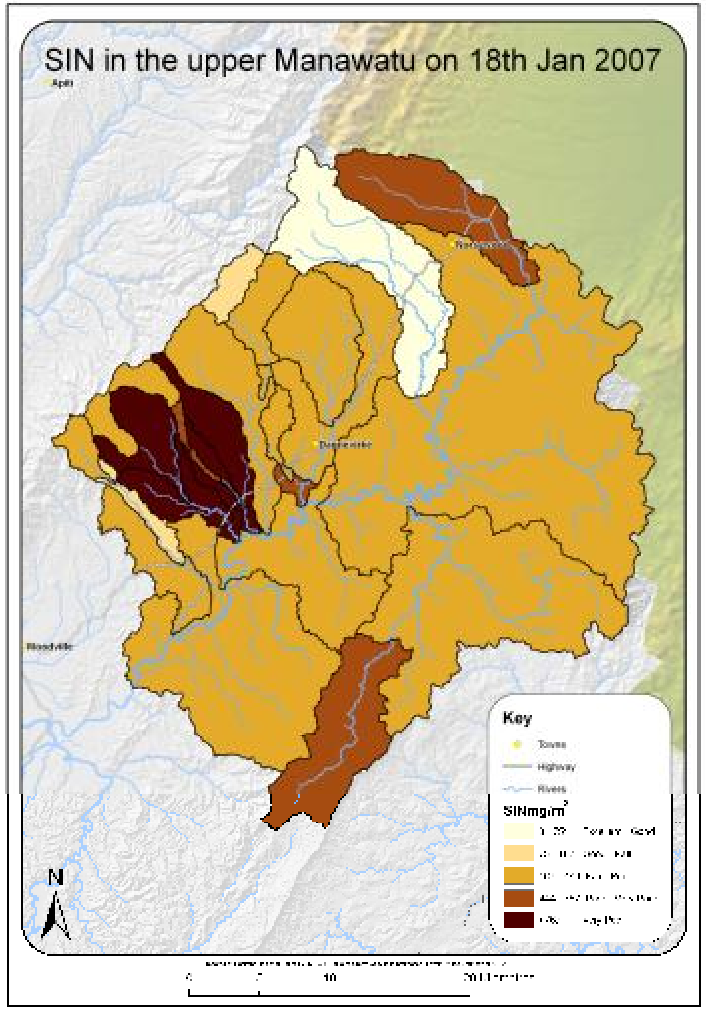
The upper Manawatu and Mangatainoka catchments are ideal case studies to test a nutrient management framework because they present a scenario where state predominantly exceeds proposed water quality standards (Map 5, Map 6, Map 7, Map 8 and Map 9) and recent trend analysis shows decreasing water quality (Table 2). Furthermore, both catchments are impacted by point and non-point source contaminants (Ledein *et al.,* 2007; McArthur & Clark, 2007).

3.3.2 Horizons monitoring of nutrient enrichment

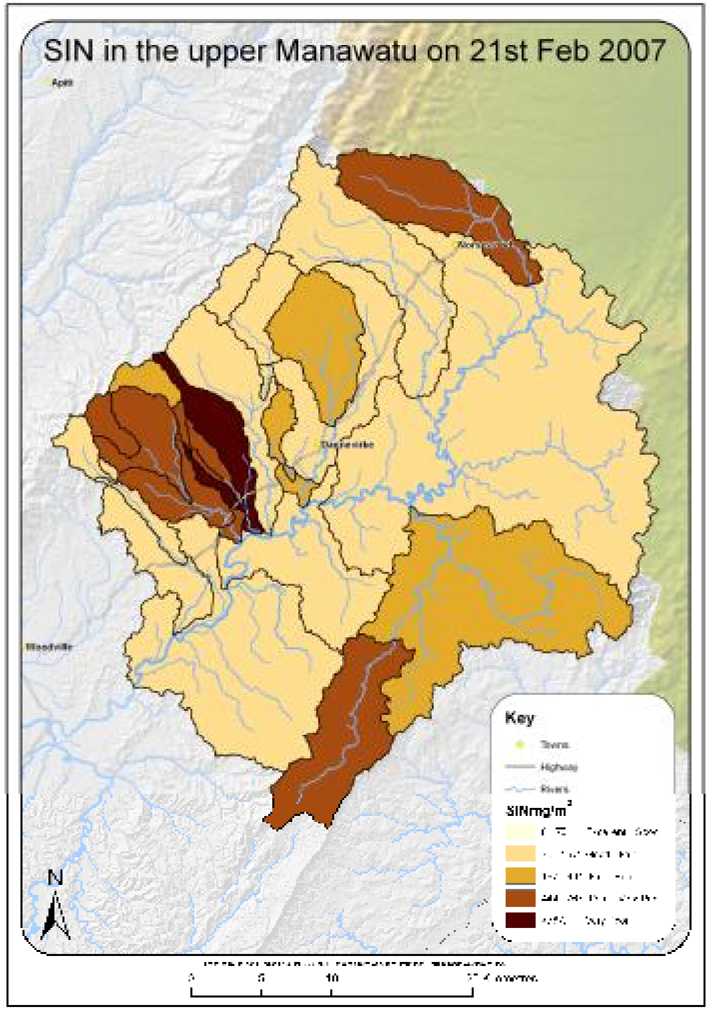
Horizons have measured nitrate, nitrite, ammoniacal nitrogen, and dissolved reactive phosphorus routinely within the State of the Environment programme. Additionally, total nitrogen and total phosphorus have been measured at the bottom of catchments, in estuaries.

Following an internal review of the SOE programme, recommendations from the work carried out by the SLURI group (Parfitt *et al*., 2007 and Clothier *et al*., 2007) and for consistency with the National Rivers Water Quality Network (NRWQN) monitored by NIWA, Horizons now measures total oxidised nitrogen, ammoniacal nitrogen, dissolved reactive phosphorus, total phosphorus and total nitrogen at all of the State of the Environment monitoring sites. These changes to water quality monitoring parameters were implemented in July 2007. More information on recent changes to the SOE monitoring programme can be found in Chapter 9 of this report.

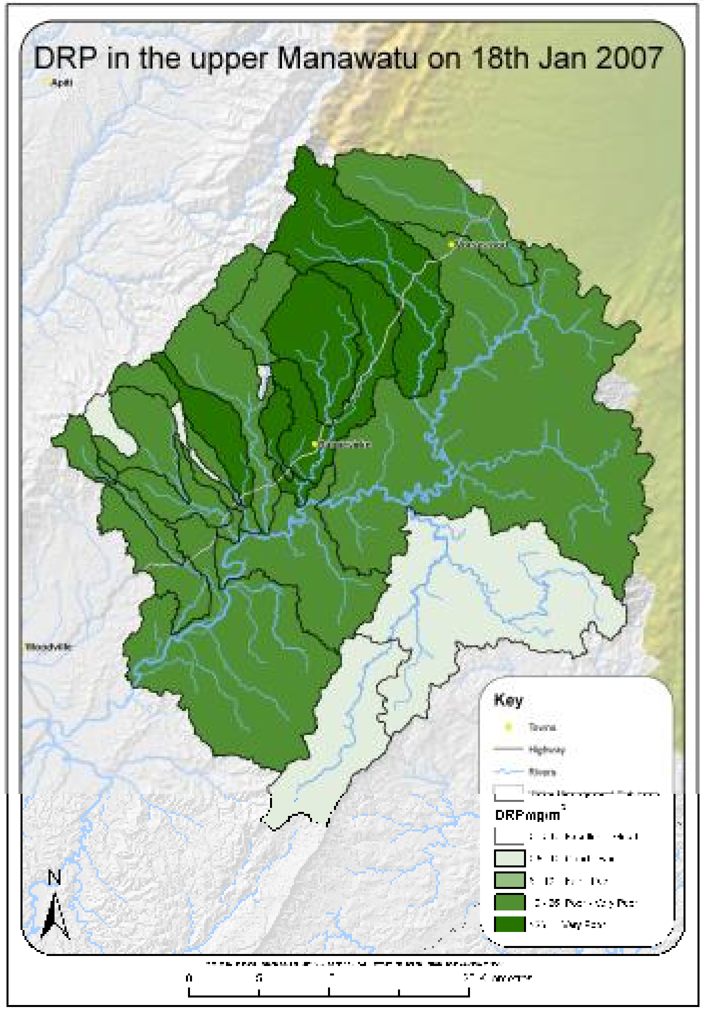
Horizons also undertakes a range of specific monitoring investigations to further understand water quality within catchments. A recent investigation during low flow conditions was carried out in the upper Manawatu (2006/2007 summer) where two water quality, flow and biomonitoring sampling runs were undertaken during low summer flows (Map 5, Map 6, Map 7, and Map 8). Another low flow investigation was completed for the Mangatainoka during the (2007/2008 summer) (Map 9). During 2008 two investigations were undertaken in the Mowhanau and Lake Horowhenua catchments; results of these studies are pending.



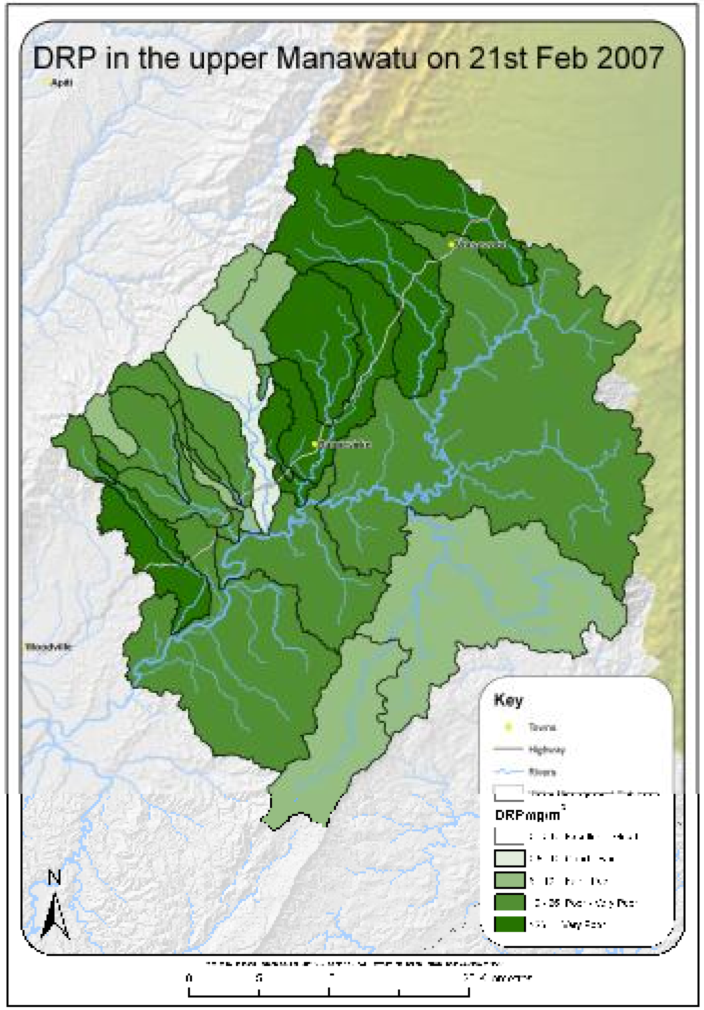
Map 5: Choropleth map of Soluble Inorganic Nitrogen (SIN) in sub-catchments of the upper Manawatu River collected on 18 January 2007.



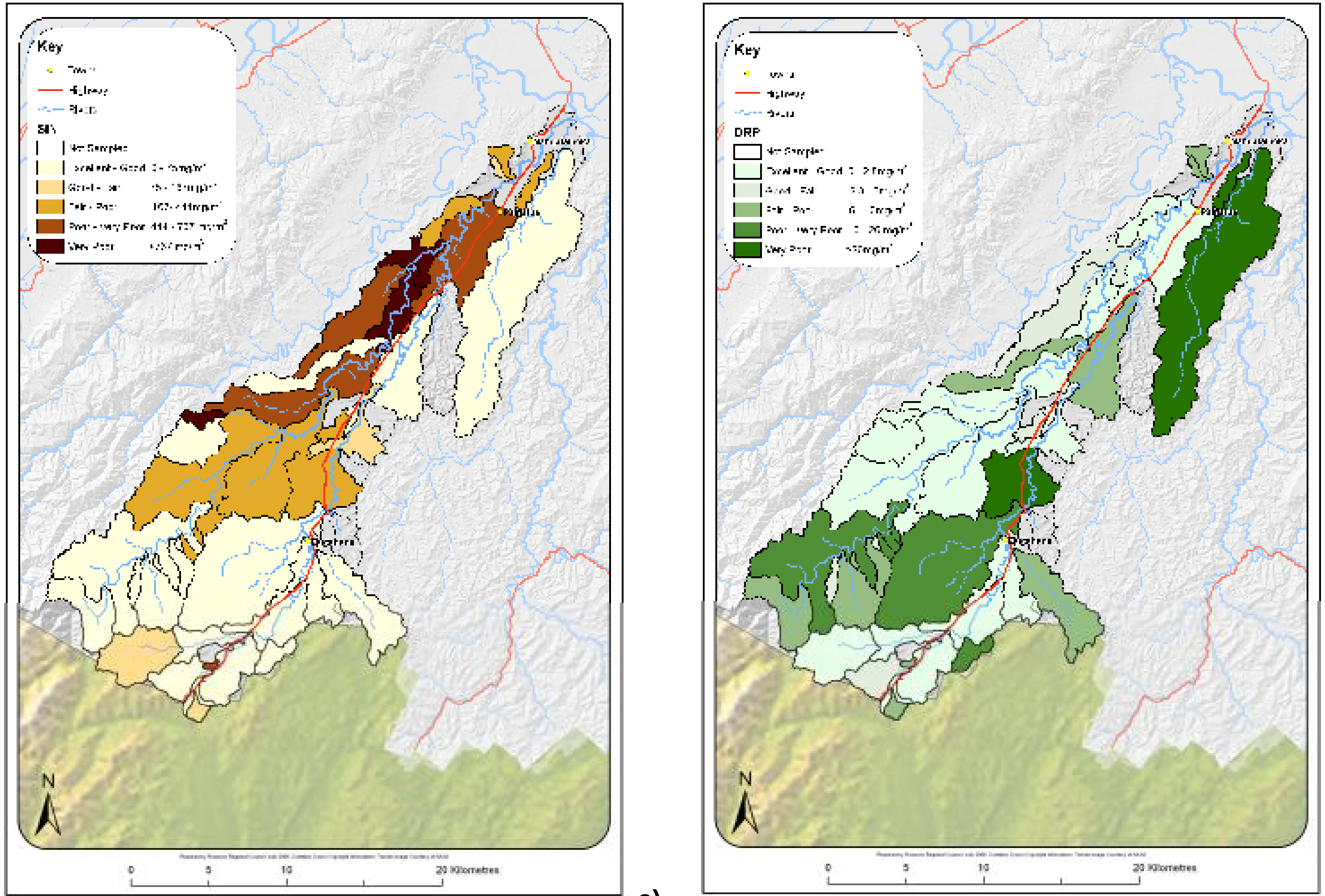
Map 6: Choropleth map of Soluble Inorganic Nitrogen (SIN) in sub-catchments of the upper Manawatu River collected on 21 February 2007.



Map 7: Choropleth map of Dissolved Reactive Phosphorus (DRP) in sub-catchments of the upper Manawatu River collected on 18 January 2007.



Map 8: Choropleth map of Dissolved Reactive Phosphorus (DRP) in sub-catchments of the upper Manawatu River collected on 21 February 2007.



a) b)

Map 9: Choropleth[2] maps of Soluble Inorganic Nitrogen (SIN) (a) and Dissolved Reactive Phosphorus (DRP) (b) in sub-catchments of the Mangatainoka River collected on 29 February 2008.

2 Choropleth. A thematic map in which areas are shaded or patterned in proportion to a measurement.

Table 2: Summary of seasonal Kendall DRP, NO_3 and TURB trend testing by site based on flow-adjusted or non flow-adjusted data (modified from Gibbard *et al.,* 2006).

SOE Site	Non flow-adjusted			Flow-adjusted		
	DRP	NO_3	TURB	DRP	NO_3	TURB
Rangitikei Catchment						
Rangitikei at River Valley	↑			↑		
Hautapu upstream at Rangitikei						
Rangitikei at Mangaweka						
Rangitikei at Vinegar Hill						
Rangitikei at Kakariki						
Rangitikei at Scotts Ferry*						
Manawatu Catchment						
Mangatera at Timber Bay	↓↓↓	↑↑				
Makakahi at Konini		↑↑		↑↑	↑↑↑	↑↑
Mangatainoka at SH2		↑↑↑			↑↑↑	
Manawatu at Hopelands	↑↑↑	↑↑↑	↑↑	↑↑↑	↑↑↑	
Manawatu at Ashhurst Domain						
Oroua at Nelson Street	↑↑		↑↑	↑↑↑	↑↑↑	↑↑
Oroua at Awahuri Bridge				↑↑↑		↑
Manawatu at Maxwell's Line					↑↑	↑↑↑
Manawatu at 42 Mile						
Manawatu at Whirokino*	↓	↑↑↑	↑↑↑			
Whanganui Catchment						
Whanganui at Retaruke						
Whanganui at Pipiriki	↑↑					↓
Whanganui at Kaiwhaiki	↑↑↑			↑↑↑		↑↑↑
Whanganui at Estuary opp. marina*			↑↑			
Whangaehu Catchment						
Mangawhero at DoC National Park			↓	↑↑		↓↓↓
Mangawhero d/s of Makotuku confl.						

* Tidal sites were not tested as part of the flow-adjusted analysis.
1. Some flow data has been supplied by Genesis Energy and NIWA.
2. Red arrows (↑) represent an increasing trend in concentration of a given water quality indicator (ie. a degradation in water quality). Green arrows (↓) represent a decreasing trend (ie. an improvement in water quality).
3. ↑/↓ indicates a significant trend (a probability of 90%)
   ↑↑/↓↓ indicates a very significant trend (a probability of 95%)
   ↑↑↑/↓↓↓ indicates a highly significant trend (a probability of 99%)

3.4 Should both N and P be managed?

In the past, reducing nutrient enrichment to control periphyton growth has often been based on Leibig's Law of the Minimum, the theory of nutrient limitation of plant growth (eg. mainly phosphorus in many New Zealand rivers [McDowell & Larned, 2008]), the theory being that controlling only the limiting nutrient is an effective management tool to reduce plant and algal growth within rivers and streams (Stumm & Morgan, 1996 *in* Wilcock *et al.,* 2007). An indicative measure of nutrient limitation in water is the Redfield Ratio (Redfield *et al.,* 1963) which was used to determine optimal relative abundance of nitrogen to phosphorus for plant growth at a molar ratio of 16:1, or by weight 7:1 (Wilcock *et al.,* 2007; McDowell & Larned, 2008).

The most conclusive method of determining a snapshot of nutrient limitation is to undertake field bioassays using nutrient diffusing substrates (NDS) (Biggs, 2000). This type of study has not been conducted in the Manawatu Catchment, where recommended periphyton biomass standards of 120 mg/m^2 chlorophyll *a* (Biggs, 2000) are regularly exceeded (Ausseil & Clark, 2007b). However, it must be stressed that an NDS study is only a snapshot of the nutrient limitation at a particular location, season and flow condition. Ausseil & Clark (2007b) undertook a desktop examination of the N:P ratio at two relatively unmodified catchment sites in the Manawatu (eg. upper Pohangina and upper Tamaki Rivers). They found ratios varied seasonally and from year to year, suggesting both N and P are likely to be limiting at different temporal and flow scales in upper catchment reference sites. Further work on this matter for sites within the Manawatu and Mangatainoka study catchments is ongoing and some preliminary results are presented for these catchments below.

Sites influenced by intensive land use (such as the lower Mangatainoka and upper Manawatu) have high N:P ratios by weight, typically between 40 and 100, suggesting phosphorus may be the limiting nutrient (McDowell & Larned, 2008), at least some of the time in catchments subject to intensive pastoral development. However, comparison between intensive pastoral catchments and reference sites indicates this may be heavily influenced by the unnaturally high inputs of soluble inorganic nitrogen (SIN) entering the rivers from non-point sources (Ledein *et al.,* 2007; McArthur & Clark, 2007).

In a national study of nutrient ratios and limitation based on Regional Council water quality data, McDowell and Larned (2008) found that P-limitation of periphyton growth was more prevalent than N-limitation. However, McDowell and Larned (2008), in recognising that effective management will rely on practical solutions, concluded that focussing management on a single limiting nutrient was "*perilous*" and that the "*prudent approach was to mitigate both N and P inputs*".

To investigate the applicability of nutrient limitation for the development of water quality standards, Horizons and Hawke's Bay Regional Councils commissioned a panel of experts from the National Institute of Water and Atmospheric Research (NIWA) and Massey University. The expert panel determined several key findings which have contributed to the nitrogen and phosphorus concentration standards adopted for the POP (Wilcock *et al.,* 2007) including:

1. Both nitrogen (N) and phosphorus (P) need to be managed in all rivers because limiting nutrient status can differ between connected catchments and within the same waterway spatially (eg. estuaries versus upland rivers) and/or seasonally. Management of only the 'limiting' nutrient was not recommended;

2. A high background concentration of a 'non-limiting' nutrient can contribute to periphyton blooms if control of the 'limiting' nutrient fails;

3. Year-round control of N and P is needed because periphyton growth and vigour are determined by the preceding nutrient conditions and the upstream presence of residual colony-forming algal material;

4. Not all rivers and streams will require nutrient management to reduce periphyton proliferation (eg. rivers with soft substrates). However, contaminant management is still required in most soft-bottomed river systems to reduce nutrient pools within sediments and provide for downstream reaches with hard substrates or estuarine/coastal waters.

Therefore it was determined that, in accordance with the above recommendations, both N and P would be managed through the application of nutrient standards and that these standards would apply all year round at all flows less than 'flood' flows.

3.4.1 Nutrient limitation in the upper Manawatu and Mangatainoka catchments

The 2007/2008 summer was unusually dry for most of the central North Island. The upper Manawatu and in particular the Mangatainoka River were at record low flows from late January to April and flow restrictions were in place for most of the Region's irrigation takes from mid-January until late April.

In the upper Manawatu catchment (above the Hopelands monitoring site), where phosphorus has historically been considered the 'limiting nutrient', DRP concentrations sampled in mid-March during extreme low flows were *higher* than the median concentration for the 12 previous monthly samples (Figure 3). These results were relatively unexpected, given the assumption that there are few mechanisms for phosphorus to reach waterways during 'drought' conditions.

SIN results for the same sample period were extremely low (below the levels of analytical detection) at all three Manawatu sites (Figure 4). These findings suggest there were two key processes at work during this low flow event in the upper Manawatu: 1) DRP was being released from bed sediments and oxidised during low flow conditions (B. Wilcock *pers. comm.*; Parfitt *et al.,* 2007), and 2) periphyton growth was potentially *nitrogen* limited.

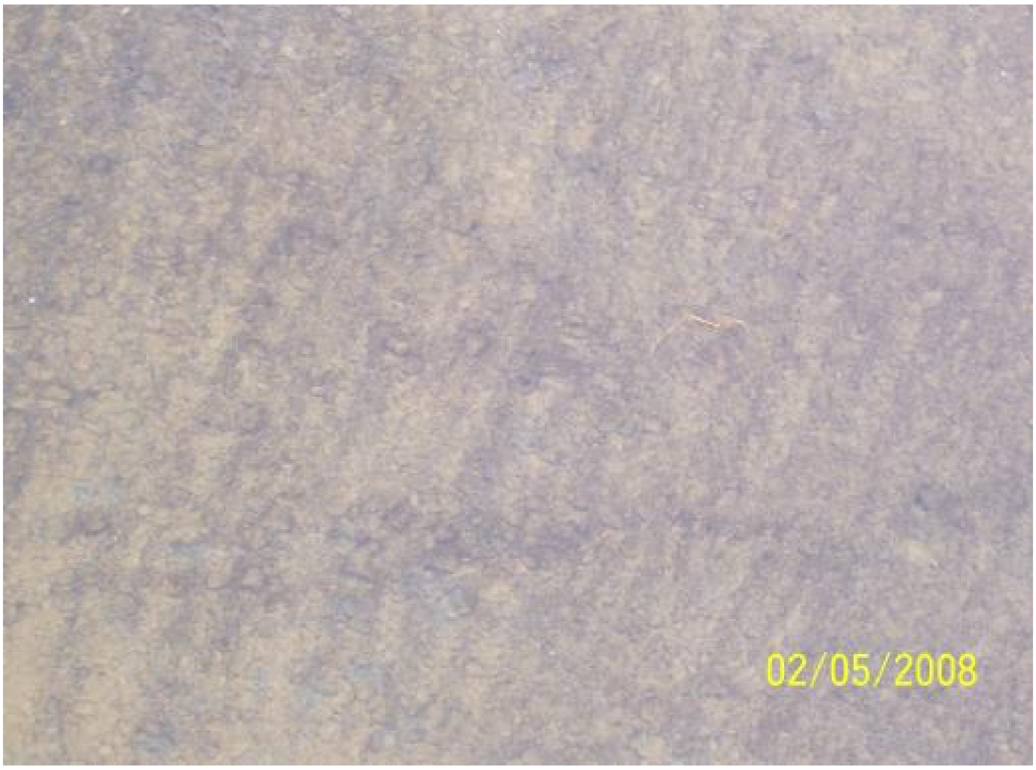


Photo 1: Bed substrate at the Manawatu at Hopelands SOE site. *Note: high level of deposited bed sediment, patchy cyanobacterial mat growth and low level of green filamentous periphyton growth.*

Photo 2: Bed substrate at the Mangatainoka at SH2 SOE site. *Note: high level of cyanobacterial mat growth in riffle habitat.*

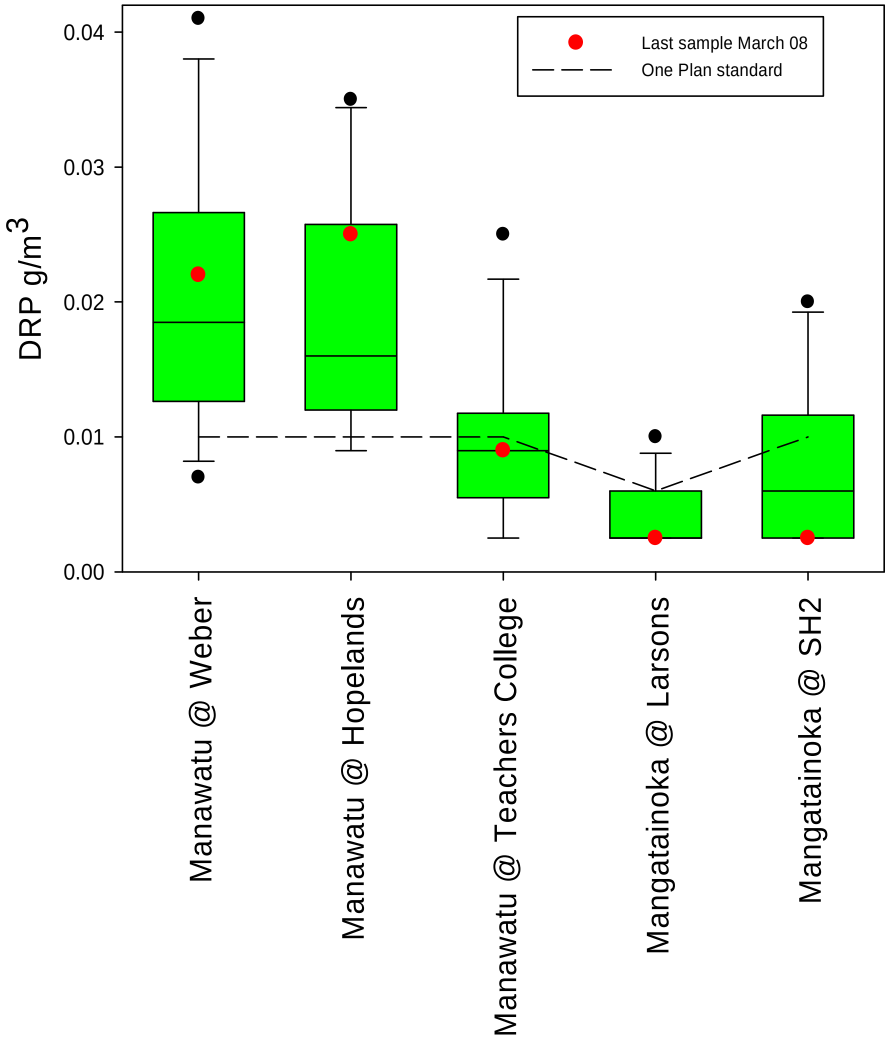


Figure 3: Box and whisker plot of Dissolved Reactive Phosphorus (DRP) concentrations at State of the Environment monitoring sites in the upper Manawatu and Mangatainoka River catchments between March 2007 and March 2008 (12 samples). Central bar denotes the median value, box denotes the inter-quartile range, black dots are outliers and the whiskers denote the 10^{th} and 90^{th} data percentiles. Red dots denote the last sample in the range collected on 10 March 2008.

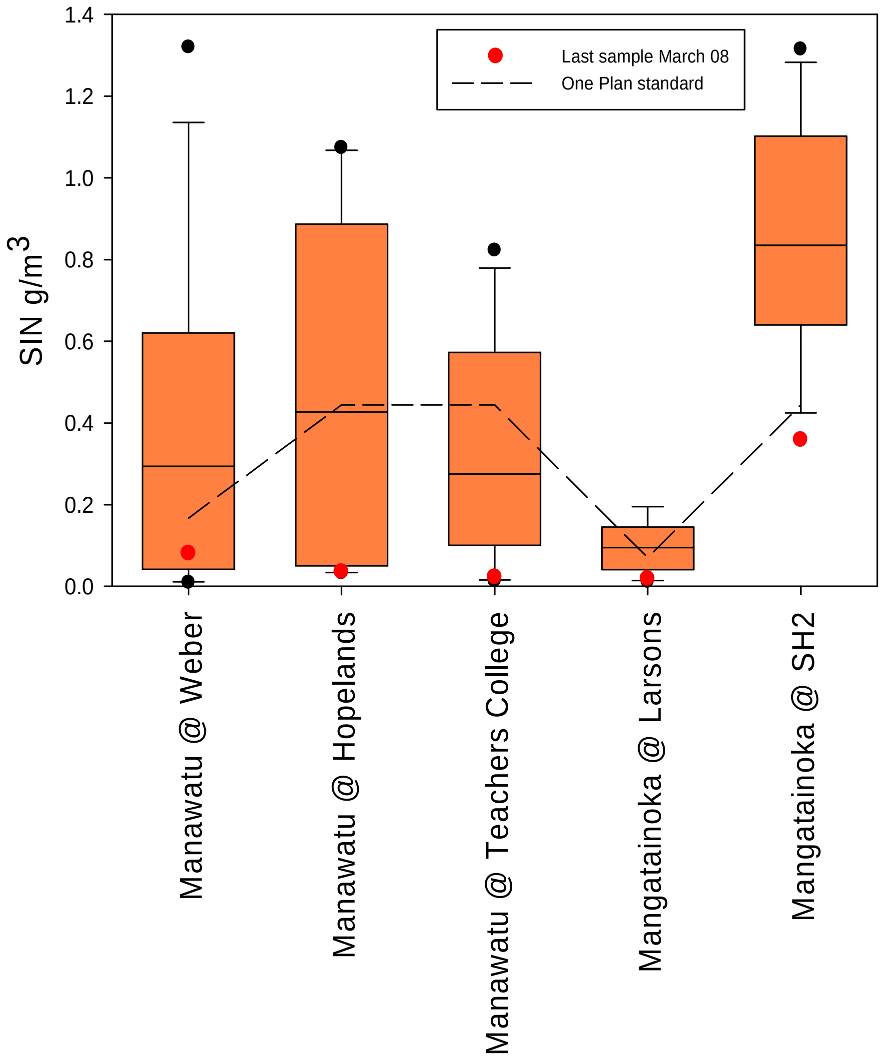


Figure 4: Box and whisker plot of Soluble Inorganic Nitrogen (SIN) concentrations at State of the Environment monitoring sites in the upper Manawatu and Mangatainoka River catchments between March 2007 and March 2008 (12 samples). Central bar denotes the median value, the box denotes the inter-quartile range, the black dots are outlier values and the whiskers denote the 10^{th} and 90^{th} data percentiles. Red dots denote the last sample in the range collected on 10 March 2008.

In the Mangatainoka catchment the results were somewhat the opposite of the Manawatu mainstem sites. Nitrogen in the Mangatainoka River can reach high concentrations at flows less than half median (McArthur & Clark, 2007). During March 2008, concentrations of both phosphorus (Figure 3) and nitrogen (Figure 4) in the Mangatainoka at Larsons site in the upper catchment were below the level of analytical detection. Although the nitrogen results from the downstream Mangatainoka at SH2 site in the lower catchment was not of a concentration that could be considered 'extremely low' when compared to the Manawatu mainstem sites (Figure 4), it was still below the 10^{th} percentile of the SIN results for the preceding twelve months.

These results suggest that any phosphorus entering the water from the Pahiatua Sewage Treatment Plant upstream of the SH2 site was being biologically attenuated by periphyton growth. These results suggest that at the same time the upper Manawatu River was nitrogen-limited, the Mangatainoka River was phosphorus-limited in the middle to lower reaches (near the SH2 site). Further investigations have shown that at any one time, different parts of the catchment are limited by different nutrient (Map 11).

The effects of nutrient limitation on periphyton communities

Horizons is in the process of developing a comprehensive monitoring strategy to model the effects of nutrient concentration on periphyton growth, as recommended by the limiting nutrients expert panel and as a requirement to monitor policy effectiveness of water quality standards in the Proposed One Plan (Kilroy *et al.,* 2008).

As part of the interim monitoring of periphyton in conjunction with annual biomonitoring survey of the Region's rivers, a visual assessment of periphyton growth was taken at the Manawatu at Hopelands and Mangatainoka at SH2 sites during late January. Anecdotal evidence suggested a high percentage cyanobacterial cover with some filamentous green algae at the Mangatainoka site (Photo 2) but a lower percentage of cyanobacterial mats at the Manawatu at Hopelands site. Photo 1 shows the high degree of deposited bed sediment at the Manawatu at Hopelands site and the patchy cyanobacterial mat growth.

Supporting the observations of periphyton cover at the time of sampling are the Stream Health Monitoring and Assessment Kit (SHMAK) visual assessment scores determined from the biomonitoring surveys (Table 3). The periphyton cover indicated that overall nutrient enrichment was low at the sample sites in late January. The SHMAK assessment supports the water quality data which indicated nutrient limitation in early March, and it is likely that the cyanobacterial growths observed in early May became dominant in the benthic community sometime between the January visual assessment and when the photos were taken in May.

Table 3: SHMAK visual assessment scores of periphyton cover at two sites in the Manawatu catchment, January 2008.

Site	SHMAK Score	Nutrient Enrichment
Manawatu at Hopelands	7.42	Moderately low
Mangatainoka at SH2	8.19	Low

Understanding nutrient limitation graphs and maps

Examining nitrogen and phosphorus concentrations in isolation from each other does not help the understanding of nutrient limitation status at a water quality monitoring site. Often, nutrient limitation is expressed as a ratio of nitrogen to phosphorus (also known as a Redfield ratio). Although these ratios adequately describe the nutrient limitation status of a particular water quality sample or the average status of a number of results, ratios are more difficult to visualise.

If we assume that either the conservative nitrogen and phosphorus standards recommended by Dr Biggs in Ausseil & Clark (2007b) or alternatively the Proposed One Plan nutrient standards, will adequately limit the growth of periphyton in rivers, then nutrient results for a site can be displayed against these standards to determine if one or other nutrient is likely to be limiting.

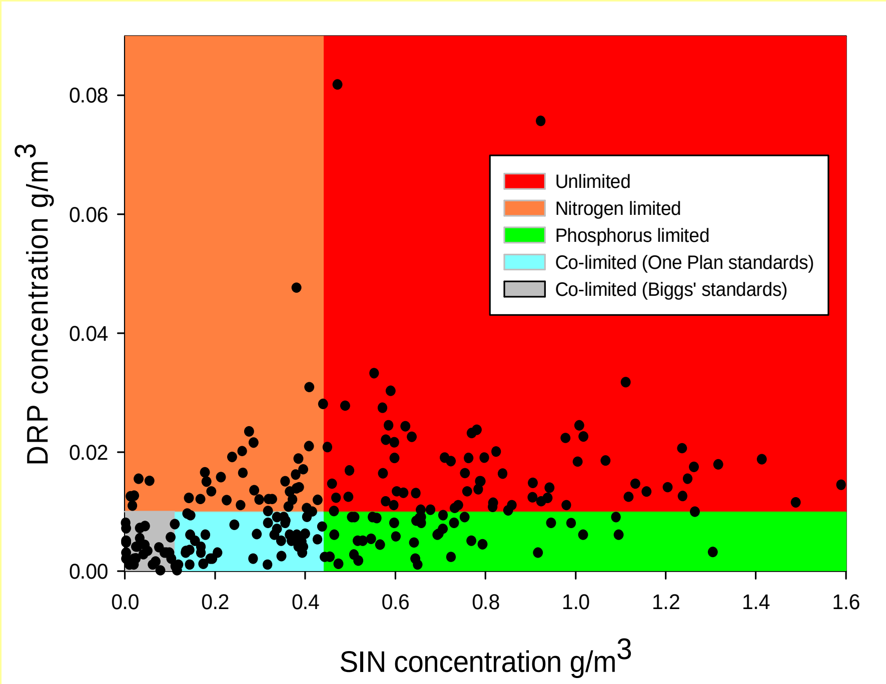


Figure: Nutrient limitation status in the Manawatu River at Weber Road monitoring site between January 1989 and December 2006 (data courtesy of NIWA).

Using an example from the upper Manawatu River at Weber Road (upstream of the Hopelands monitoring site), the area of the graph shaded grey is bounded by the SIN and DRP standards recommended by Dr Biggs. Any water quality samples with SIN and DRP concentrations that lie within this area are likely to be co-limited, meaning concentrations of nitrogen and phosphorus may be less than ideal for periphyton proliferation and growth may be limited. The blue shaded area is bounded by the Proposed One Plan SIN and DRP standards; if we consider that nutrient concentrations within these standards are also likely to limit periphyton proliferation then these observations can also be considered co-limited.

The orange shaded portion of the graph represents samples with low SIN concentrations (within the Proposed One Plan standard); these samples were collected under conditions that were likely to be nitrogen limited. Likewise, the green shaded area of the graph represents samples with low DRP concentrations (within the Proposed One Plan standard) collected under conditions that were likely to be phosphorus limited.

The red shaded area of the graph represents samples that had both high SIN and DRP concentrations. These conditions are unlikely to limit periphyton growth. Under these conditions, factors such as flow and light would be the most likely limitations to periphyton proliferation (if any). The choropleth maps in the following chapter use the same colours to denote the limiting nutrient status of sub-catchment areas from an on/off spatially spread sampling event.

Variation in nutrient limiting status

Further investigation of the long-term record of concentrations of SIN and DRP in the upper Manawatu and Mangatainoka catchments was undertaken as a result of the data gathered in March 2008. The potential for nutrient limitation was examined by applying the standards for controlling periphyton growth recommended by Dr Biggs (Ausseil & Clark, 2007b) and the Proposed One Plan nutrient standards to all SIN and DRP data collected since 1989 at the Hopelands monitoring site and since 1993 at the Mangatainoka at SH2 site.

When the data for all flows was examined for the Manawatu at Hopelands site (Figure 5) it became clear that there was no 'average' limiting nutrient status as there were observations collected that were potentially phosphorus or nitrogen limited and that this relationship may have been influenced by the flow at the time of sampling. In order to better understand the influence of flow on nitrogen and phosphorus limitation, the results were plotted according to four flow categories (Figure 6).

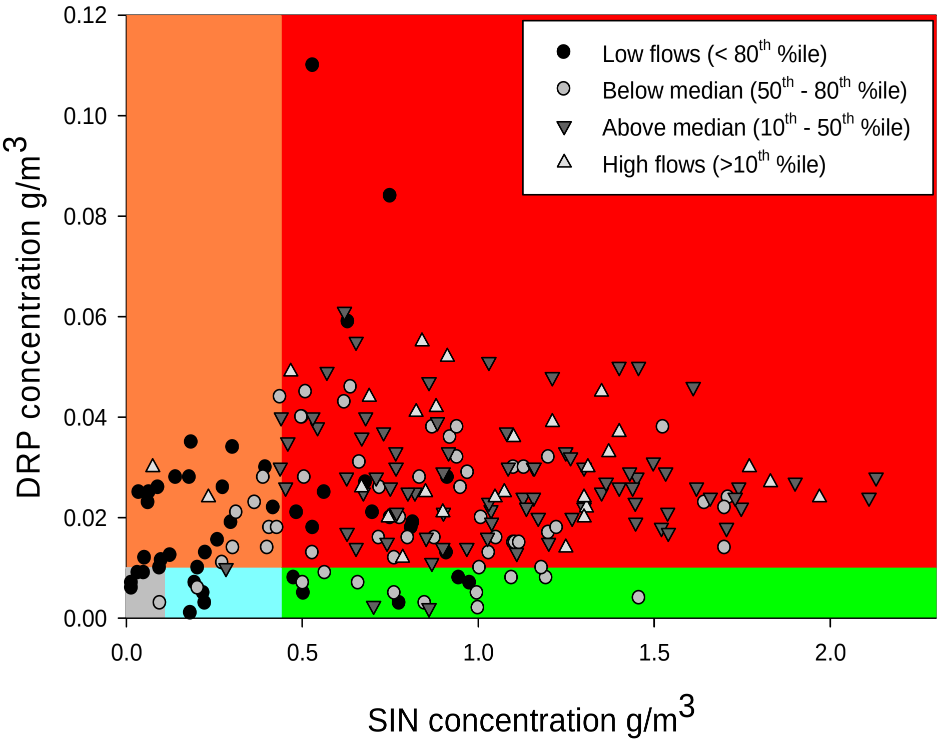


Figure 5: Soluble Inorganic Nitrogen (SIN) and Dissolved Reactive Phosphorus (DRP) concentration from samples collected monthly at Manawatu at Hopelands SOE monitoring site between 1989 and 2008. Grey box encompasses standards for SIN and DRP recommended by Dr Biggs to limit periphyton growth (co-limited), blue box denotes Proposed One Plan standards (potentially co-limited), green box denotes potential phosphorus limitation, orange box denotes potential nitrogen limitation and red box denotes no likely nutrient limitation.

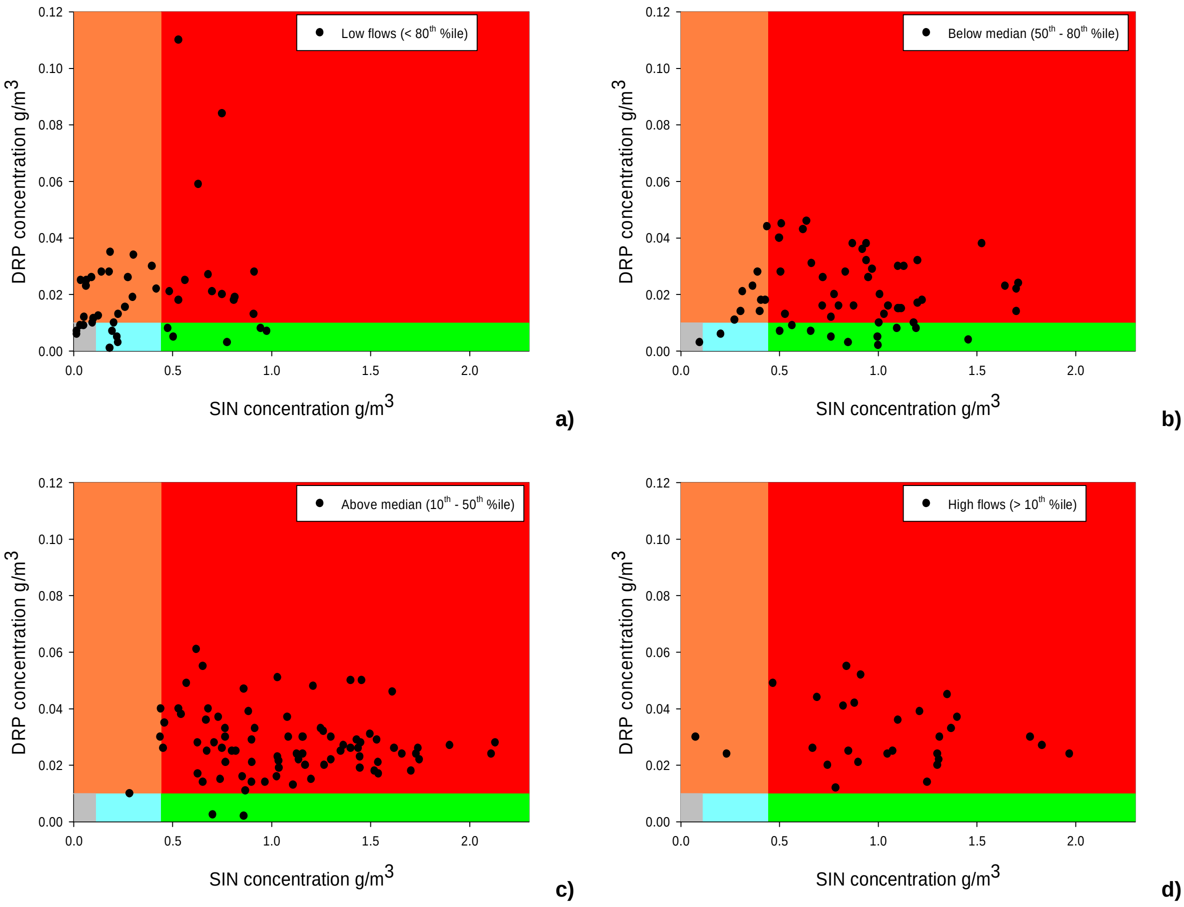


Figure 6: Soluble Inorganic Nitrogen (SIN) and Dissolved Reactive Phosphorus (DRP) concentration from samples collected at Manawatu at Hopelands SOE monitoring site between 1989 and 2008 under varying flows: a) low flows (< 80th %ile), b) flows below median (50th – 80th %ile), c) flows above median (50th – 10th %ile), and d) high flows (> 10th %ile). Grey box encompasses standards for SIN and DRP recommended by Dr Biggs to limit periphyton growth (co-limited), blue box denotes Proposed One Plan standards (potentially co-limited), green box denotes potential phosphorus limitation, orange box denotes potential nitrogen limitation and red box denotes no likely nutrient limitation.

Figure 6 shows the influence of flow on nutrient limitation status in the upper Manawatu at Hopelands. At low flows, some samples were of co-limited status (meaning there was unlikely to be enough input of both phosphorus and nitrogen to stimulate periphyton growth), some were nitrogen-limited, some phosphorus-limited and some unlimited by either nutrient. At flows less than median, there were less co-limited and more unlimited observations. Phosphorus and nitrogen limitation was still found in roughly equal numbers of samples.

For higher flows (above median) it was clear that there was little nutrient limitation of any kind observed and for flows in the top 10th percentile (exceeded 90% of the time – see section 3.4.2) all observations except two were unlimited by either nitrogen or phosphorus concentrations.

When SIN and DRP samples for all flows were examined for the Mangatainoka at SH2, the situation was quite different (Figure 7). The Mangatainoka samples showed a clear pattern of phosphorus limitation or unlimited status for most samples, with the exception of some of the high flow results. Further analysis of the influence of flow on this relationship (Figure 8) showed a similar pattern of phosphorus limitation, with very few samples being co-limited or nitrogen-limited. The elevated DRP concentrations at low flows were also of concern.

However, an investigation of water quality at low flows in the Mangatainoka catchment, undertaken during February 2008 suggests that limiting nutrient status varies spatially in the catchment under low flow conditions (Map 11).

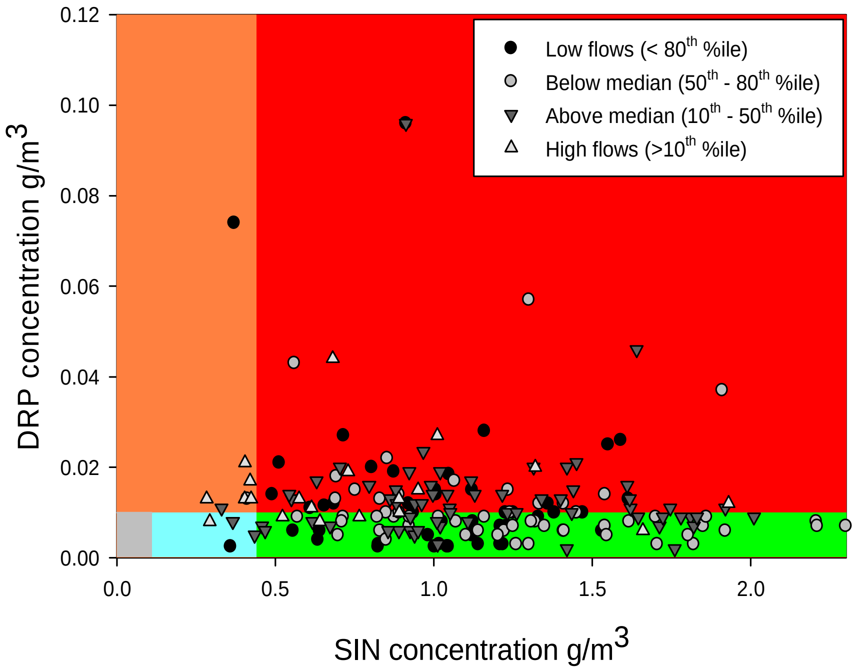


Figure 7: Soluble Inorganic Nitrogen (SIN) and Dissolved Reactive Phosphorus (DRP) concentration from samples collected at Mangatainoka at SH2 SOE monitoring site between 1993 and 2008 under varying flows: a) low flows (< 80th %ile), b) flows below median (50th – 80th %ile), c) flows above median (50th – 10th %ile), and d) high flows (> 10th %ile). Grey box encompasses standards for SIN and DRP recommended by Dr Biggs to limit periphyton growth (co-limited), blue box denotes Proposed One Plan standards (potentially co-limited), green box denotes potential phosphorus limitation, orange box denotes potential nitrogen limitation and red box denotes no likely nutrient limitation.

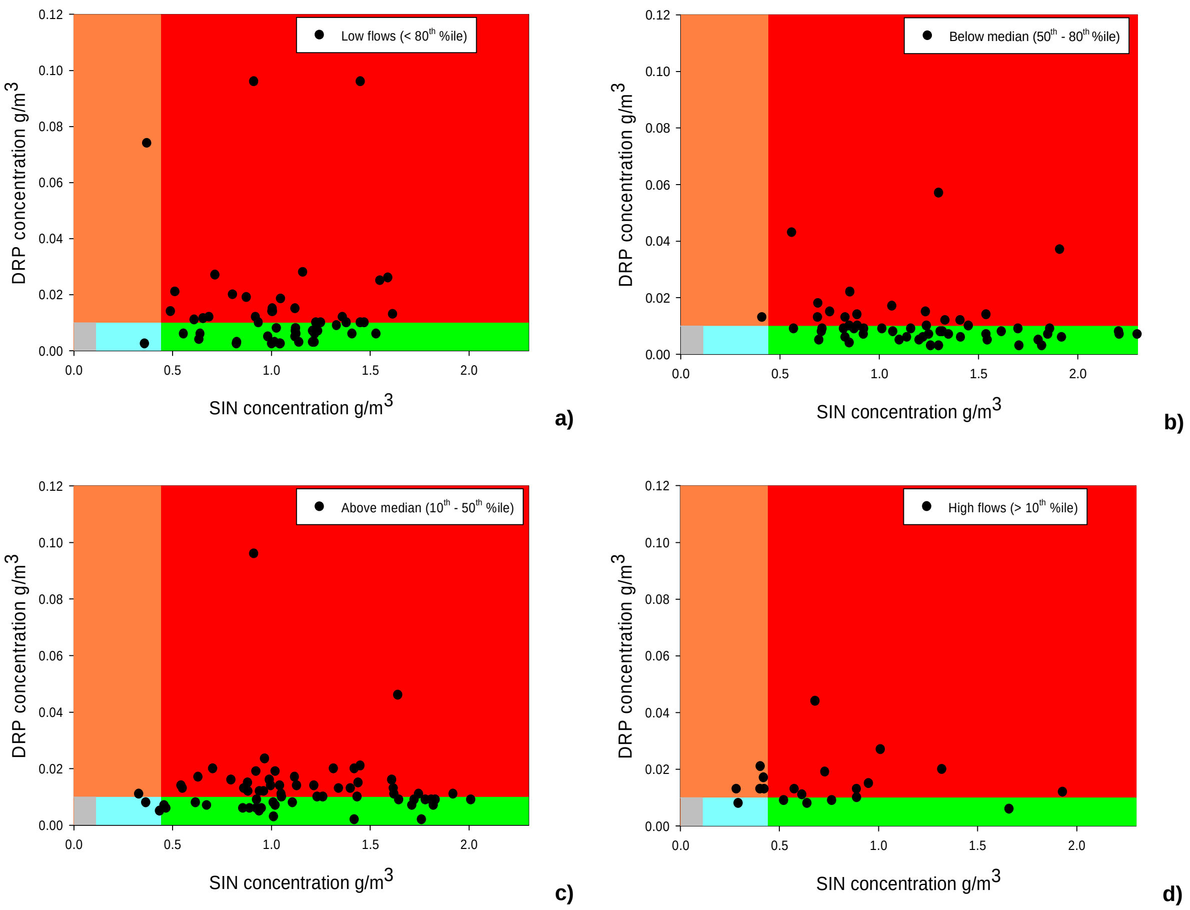
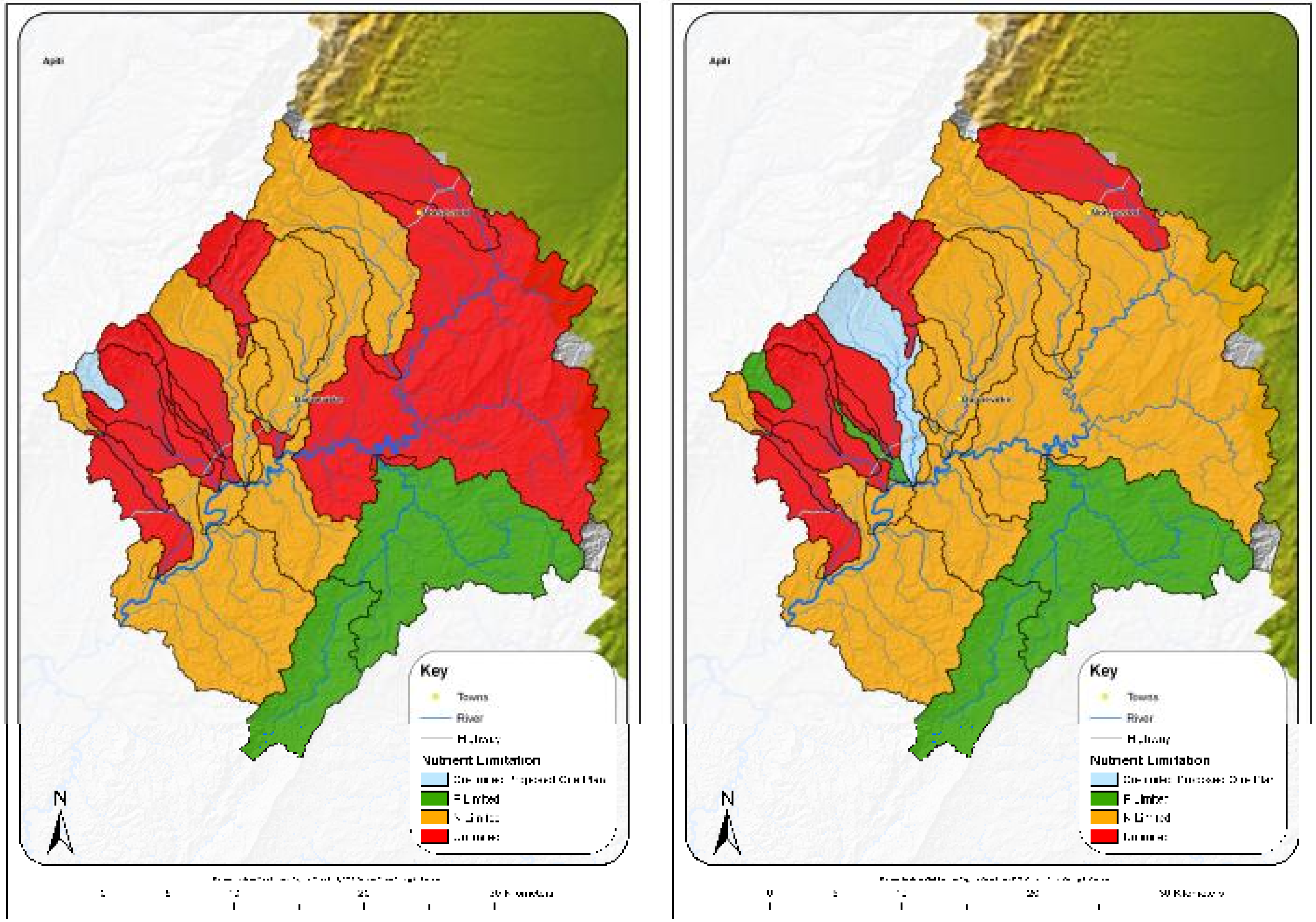


Figure 8: Soluble Inorganic Nitrogen (SIN) and Dissolved Reactive Phosphorus (DRP) concentration from samples collected at Mangatainoka at SH2 SOE monitoring site between 1993 and 2008 under varying flows: a) low flows (< 80th %ile), b) flows below median (50th – 80th %ile), c) flows above median (50th – 10th %ile), and d) high flows (> 10th %ile). Grey box encompasses standards for SIN and DRP recommended by Dr Biggs to limit periphyton growth (co-limited), blue box denotes Proposed One Plan standards (potentially co-limited), green box denotes potential phosphorus limitation, orange box denotes potential nitrogen limitation and red box denotes no likely nutrient limitation.

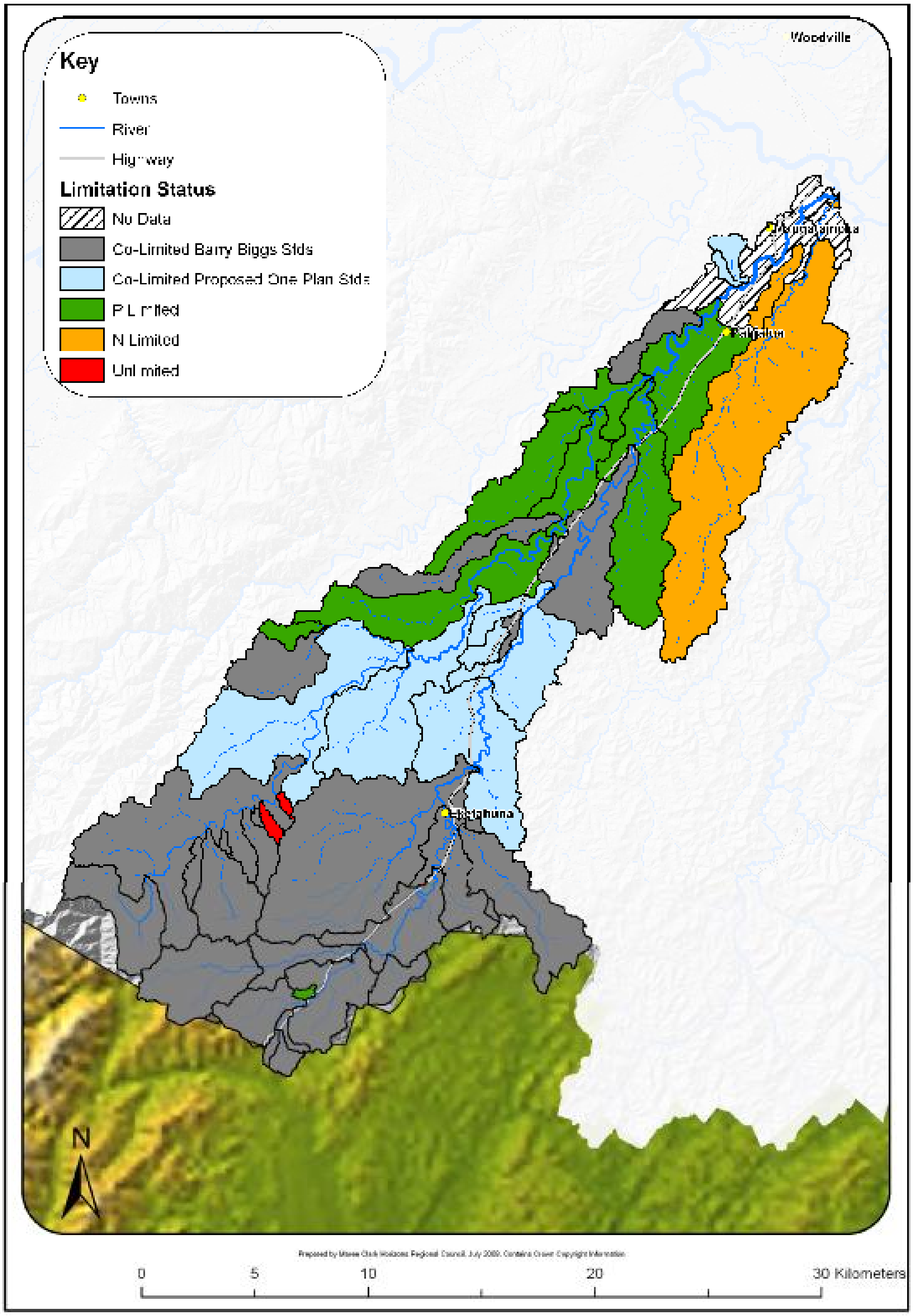
Following the recommendations of Wilcock *et al.* (2007) to manage both nitrogen and phosphorus at all flows below flood flows, Horizons has learned more about nutrient limitation in the upper Manawatu and Mangatainoka catchments through targeted investigations.

The findings of these studies have shown limiting nutrient status in the upper Manawatu and Mangatainoka catchments (and other rivers in the region) is variable:

- with flow;
- over time;
- between catchments in close proximity; and
- spatially within the same catchment on the same day.



Map 10: Choropleth maps of sub-catchment nutrient limitation status in the upper Manawatu catchment (above Hopelands) on two monitoring occasions in the 2006/2007 summer. The left map represents sampling in January 2007 at the 89th percentile of flow in the Manawatu River at Hopelands and the right map represents sampling in February 2007 at the 96th percentile of flow in the Manawatu River at Hopelands.



Map 11: Limiting nutrient status in the Mangatainoka River catchment, February 2008 during low flows (< 99th flow percentile for the Pahiatua at Town Bridge flow site).

3.4.2 Determining the flows where nutrient standards apply

The biomass of periphyton in a stream is influenced by growth rate (determined by sunlight, temperature, nutrient concentration and water velocity[3]), physical sloughing[4] and abrasion (caused by water velocity and entrained bedload movement), and by grazing macroinvertebrates. Because the avoidance of high periphyton biomass is the primary desired outcome of nutrient control, and periphyton biomass is reduced by high flows, the flow below which the nutrient standards might apply must account for periods of periphyton accrual (between flood events) and the frequency and intensity of high flow (disturbance) events.

Clausen & Biggs (1997) recommend the use of flood frequency or "FRE_3" (a calculation of the annual number of flood events that reach a flow of three times the median, (Q_{50}) as a general flow statistic to classify the flow regimes of rivers, based on disturbance to aquatic macroinvertebrates and periphyton. For further discussion on the calculation of FRE_3 statistics see Henderson & Diettrich (2007).

Henderson and Diettrich (2007), as part of a project to compile flow statistics for all sites in the Region with sufficient data, calculated FRE_3 and Mean Days of Accrual (MDA) using the same methods as the New Zealand Periphyton Guideline (Biggs, 2000). However, there were several fundamental problems with the use of Horizons periphyton biomass data and the FRE_3 statistics to model predicted nutrient concentrations against desired periphyton levels. The model did not work for the hydrological regime in the area of the central North Island volcanic plateau streams, nor did it consider reductions in biomass through macroinvertebrate grazing or physical abrasion by suspended particles and more importantly the periphyton biomass data was not sufficient to calibrate the predictive model.

Further expert advice was sought from NIWA to establish appropriate nutrient standards and to set flows below which the standards should apply. Two important points taken into consideration were:

1. the nutrient standards should apply year round, except flood flows; and
2. standards should relate to the annual average concentration based on monthly monitoring (a sampling regime common to many Regional Councils and the National River Water Quality Network (NRWQN) monitoring programme).

In most cases, the three times median flow measure fell between the 10th and 20th percentiles of the flow distribution for each site (Figure 9). Considering the limitations of using the generalised FRE_3 statistic to account for hydrological disturbance in rivers across the Region, a more precautionary approach, based on flow deciles, is recommended for the Regional application of nutrient standards. This report recommends the application of water quality standards in relation to a percentile flow measure such as the 10th or 20th exceedence percentiles.

[3] Water velocity determines the flux of nutrients that come in contact with algal mats or filaments.

[4] Sloughing is the mechanism of removal of attached periphyton, resulting from very high biomass levels in benthic mats or filamentous growths where attachment cannot be sustained due to acceleration proliferation.

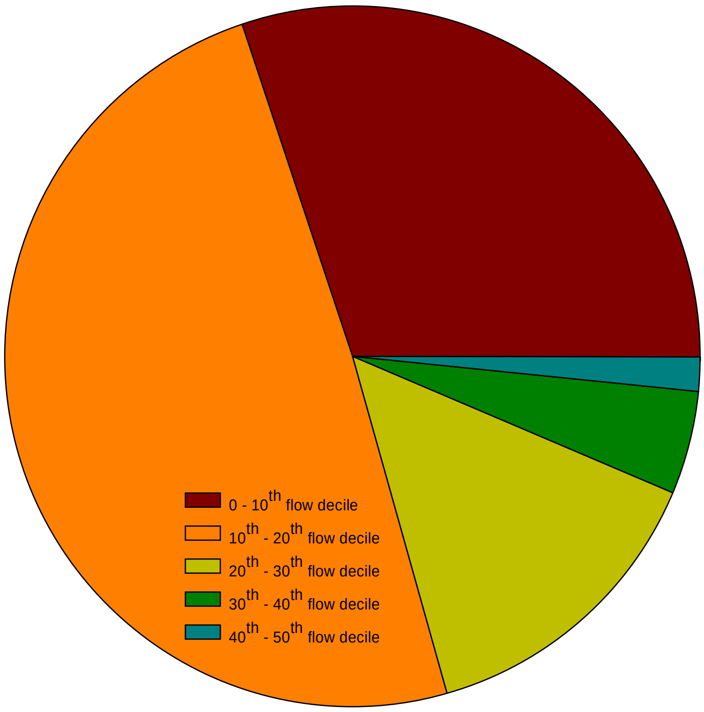


Figure 9: Comparison of 3^*Q_{50} (three times median) flow statistic to flow decile category at 63 sites in the Manawatu-Wanganui Region (flow statistics from Henderson and Diettrich, 2007).

3.4.3 What were the options for nutrient standards to meet the objectives of the One Plan?

Four main sources or methods of technical advice were used in combination to compile potential nutrient standards and recommendations for the water management zones of the Region. The four methods were:

1. the use of the periphyton model from the National Periphyton Guidelines;
2. expert opinion from Dr Barry Biggs;
3. the ANZECC guidelines for nutrient trigger values; and
4. the current enrichment state, determined from Horizons' monitoring data.

This method of tailoring water quality standards to local conditions is strongly recommended within the ANZECC framework for application of the guideline standards (ANZECC, 2000).

The process for determining the nutrient standard for each water management zone is explored in detail in Ausseil & Clark (2007b). Only a brief example of the process for choosing between options for nutrient standards is included in this report. In general, the expert advice of Dr Biggs was followed with regards to N and P standards; this advice included assessments based on risk of nuisance periphyton blooms, given local environmental conditions. In some instances significant relaxation of Dr Biggs' recommended standards were allowed where there was clear evidence that a particular nutrient was found in concentrations *significantly* higher than the proposed standard.

In locations with existing enrichment problems (ie. concentrations well in excess of ANZECC guideline values for N and/or P), the existing state was taken into account in order to set an achievable standard. Proposed standards included consideration of the potential effects of nutrients on downstream receiving environments, as per the advice of the expert panel (Wilcock *et al.,* 2007). For example, if the downstream water management zone or environment had a more stringent nutrient standard based on the values than zones upstream, waters flowing into that zone would require an equally stringent standard to reduce the potential for nutrients to be transported beyond the boundaries of that zone at a concentration likely to cause adverse environmental effect.

Also weighed up was the potential for rivers to be high risk for periphyton proliferation because of their geological and morphological characteristics. For example, large, unshaded cobble or gravel bed rivers, especially those of moderate to low gradient, have a high potential for periphyton proliferation if flow and environmental characteristics are suitable. In these cases, relaxation of the DRP standard was not considered appropriate and a more precautionary DRP standard was applied (Ausseil & Clark, 2007b).

3.4.4 Recommended nutrient standards

All water quality standards are WMZ specific to provide for the different combinations of values in each zone. The standard for each water quality parameter with the potential to affect any value within a zone was listed. The most stringent standard listed for each parameter became the water quality standard for that zone. The only exception to this was in the application of nutrient standards in catchments with significant enrichment. More pragmatism was applied to the nutrient standards in these zones to provide an achievable water quality target.

Section 6.3 of Ausseil & Clark (2007b) identifies the tiered process of the development of nutrient standards, and the options for each management zone are presented in Table 22. The options for deciding proposed nutrient standards for the upper Manawatu and Mangatainoka Rivers are included below (from Ausseil & Clark, 2007b).

Manawatu mainstem from Weber Rd to Tiraumea confluence (Mana_2a, 5a and 6):

- LSC classification: UHS (Upland Hill Sedimentary geology)
- Trout fishery classification: TF2 (Regionally Significant Trout Fishery)
- Periphyton Biomass Standard: 120 mg/m^2
- Mean monthly SIN concentration = 850 mg/m^3 (0.85 g/m^3)
- Recommended DRP standard 10 mg/m^3 (0.01 g/m^3)
- Recommended SIN standard 444 mg/m^3 (0.444 g/m^3)

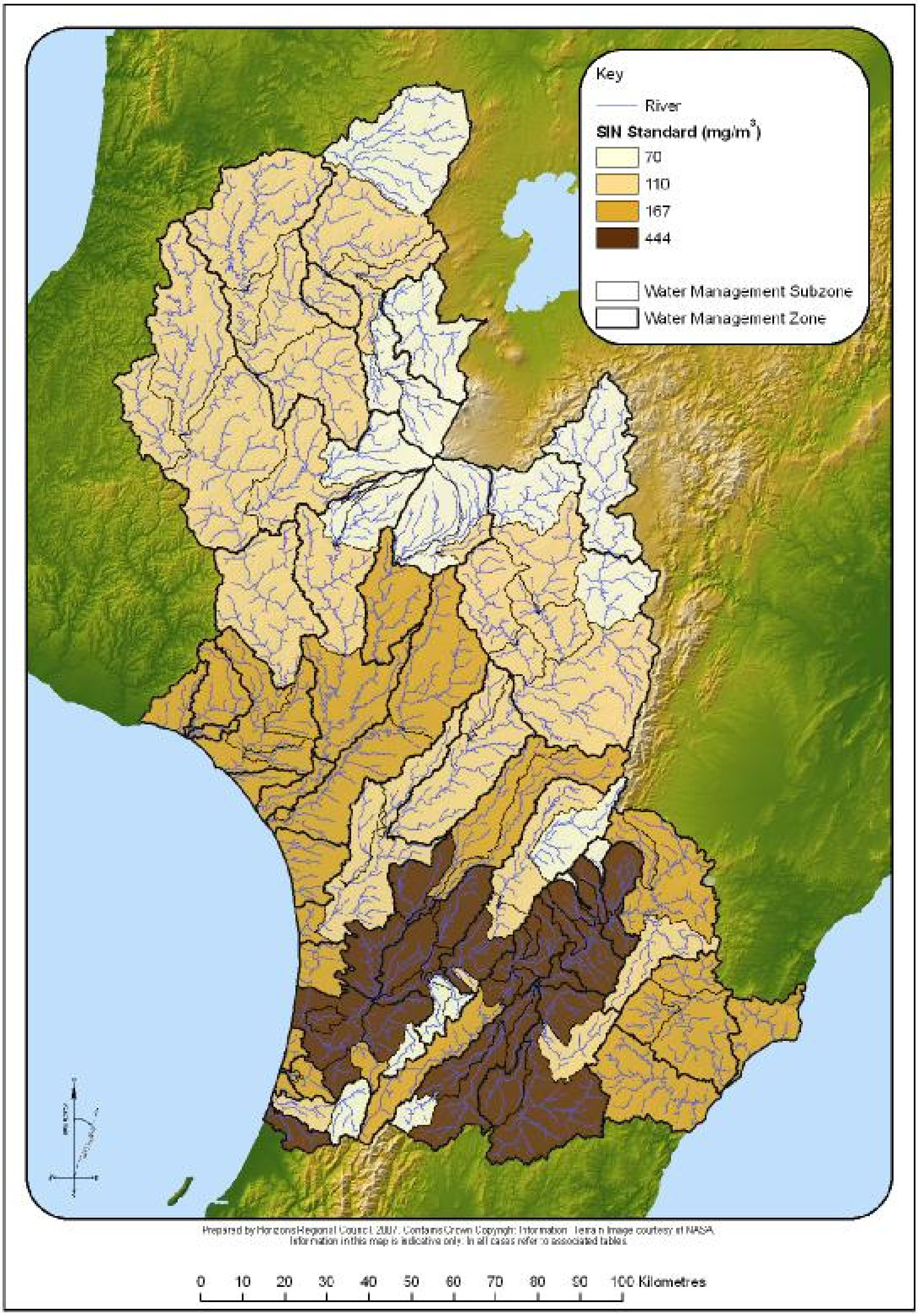
In this case, Dr Biggs' recommendations were for a SIN standard of 110 mg/m^3 and a DRP standard of 10 mg/m^3, and the periphyton guideline model standards were 45 mg/m^3 and 4.3 mg/m^3 for SIN and DRP respectively to achieve a periphyton biomass standard not exceeding 120 mg/m^2. However, due to the significantly elevated existing SIN concentrations (ie. greater than 550 mg/m^3 specified in Ausseil and Clark, 2007b), the less stringent standard of 444 mg/m^3 was applied as a pragmatic approach towards setting an achievable nitrogen target.

Middle and lower Mangatainoka and Makakahi (Mana_8b, 8c and 8d):

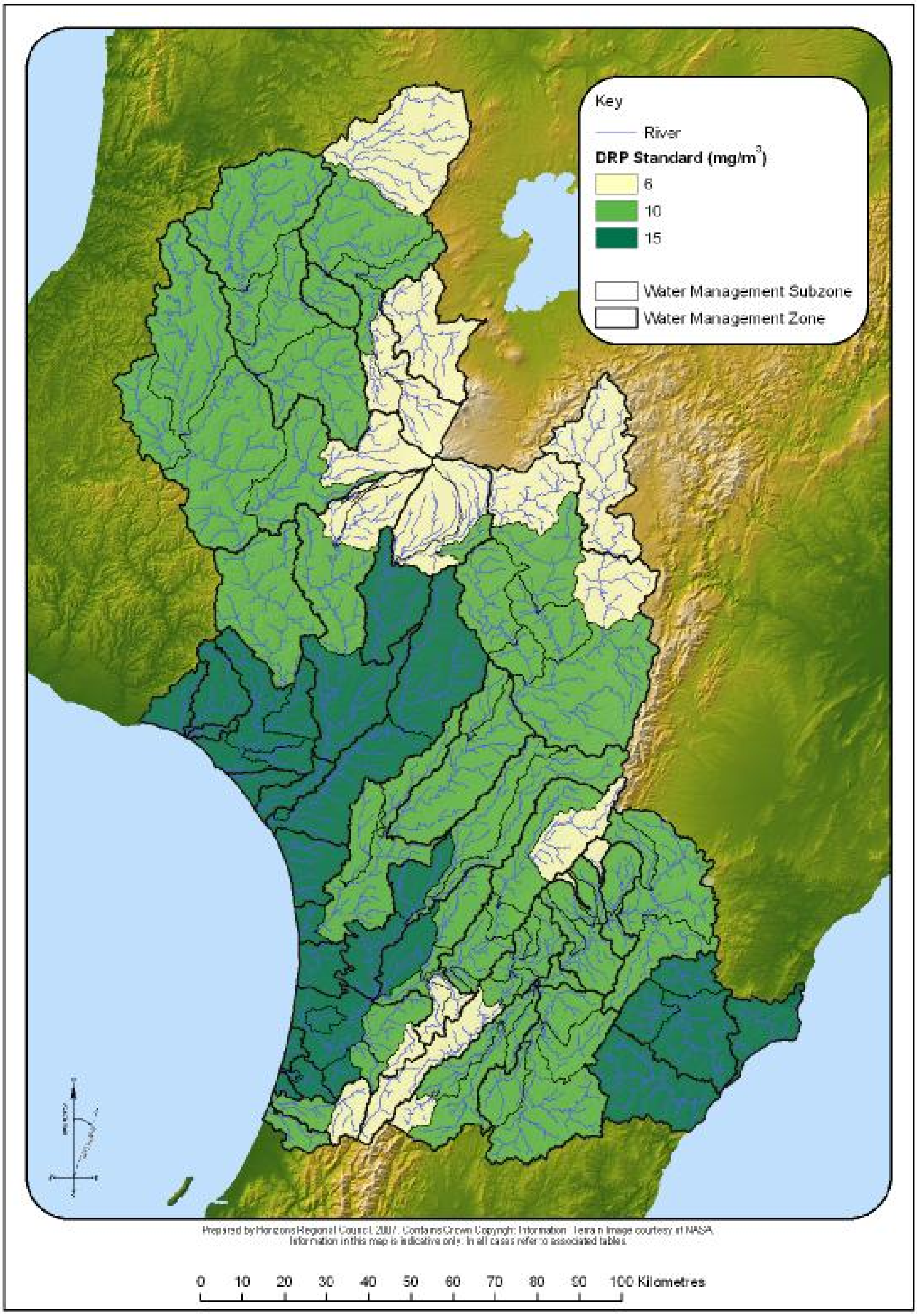
- LSC classification: HM (Hill Mixed geology)
- Trout fishery classification: TF2 (Regionally Significant Trout Fishery)
- Periphyton Biomass Standard: 120 mg/m^2
- Mean monthly SIN concentration = 800–1000 mg/m^3
- Recommended DRP standard: 10 mg/m^3
- Recommended Sin standard: 444 mg/m^3

In this case there was no chlorophyll *a* data for the Mangatainoka sites to predict standards based on the periphyton model. However, the average SIN and DRP standards for all sites in the same LSC geology class were determined as 120 and 12 mg/m^3 respectively, which was similar to Dr Biggs' recommended standards of 110 mg/m^3 SIN and 10 mg/m^3 DRP.

The recommended nutrient standards aim to balance the need for significant improvements in water quality with the definition of a demonstrably achievable water quality target. The balance between desired state and current state is particularly relevant in catchments subject to high non-point source nutrient loads, such as the upper Manawatu and Mangatainoka Rivers (Ledein *et al.,* 2007; McArthur & Clark, 2007).



Map 12: Proposed Soluble Inorganic Nitrogen (SIN) standard by water management sub-zone. SIN standards are water management zone-specific to account for the range of values and protection levels within each zone.



Map 13: Proposed Dissolved Reactive Phosphorus (DRP) standard by water management sub-zone. DRP standards are water management zone-specific to account for the range of values and protection levels within each zone.

4. Implementing N and P Standards

4.1 Defining point source (PS) and non-point source (NPS)

The New Zealand State of the Environment Report (MfE, 2007) defines point source pollution as the 'discharge of pollutants from a single fixed point, such as a pipe and identifies the major point sources in New Zealand as:

- Sewage treatment plants;
- Industrial vegetable or meat processing waste;
- Dairy shed effluent;
- Piggery effluent;
- Septic tanks; and
- Stock "crossings" over streams (eg. between milking shed and pasture).

Ledein *et al.* (2007) completed an analysis in 2005 of the sources of nutrients from non-point sources (NPS) and point sources (PS) in two catchments of the Manawatu River using a narrower definition of point sources. Ledein *et al.* (2007) considered only the "large" industrial and municipal discharges as point source, excluding those linked with farming activities. McArthur & Clark (2007) also define a similar envelope of 'significant' point source discharges to water.

For the purposes of the development of a nutrient management framework only 'significant' industrial and municipal discharges were considered PS. Nutrient loads from landfill leachate were not considered significant PS discharges due to the technical difficulties in estimating the loading from such sites. Further work is proposed through other Council monitoring programmes to better characterise landfill leachate contaminants and effects on surface waters.

Discharges directly linked with farming activities (eg. dairy shed effluent or stock crossings) were specifically excluded from the definition as it is proposed that they are encompassed and managed within a Farmer Applied Resource Management Strategy (FARM Strategy) using a whole farm approach. All nutrient inputs from farming systems will be considered collectively as NPS inputs (Clothier *et al.,* 2007). Furthermore through the introduction of Regional restrictions on dairy effluent discharges to water, the direct impacts of consented dairy effluent disposal to water have significantly decreased since 2001 (McArthur & Clark, 2007).

Diffuse NPS pollution covers a broad range of inputs, both natural (eg. geological erosion, dissolution of nutrient-rich rocks and soils) and anthropogenic in nature (eg. run-off and/or sub-surface flow from agriculture, forestry, urban land or land treatment and septic tank effluent). Due to the diffuse nature of such pollution, loads have been linked to land use capability (LUC) classes to determine relative proportions of NPS nutrient contribution per unit area of catchments. This will be covered in more detail later in this report and further information can be found in (Clothier *et al.,* 2007; Mackay *et al.,* 2008; Manderson & Mackay, 2008).

4.2 Managing the cumulative inputs from point and non-point sources

Because the mechanisms by which nutrients reach surface waters differ between point sources (PS) and non-point sources (NPS), the management approach to each will also need to be different. Of particular relevance to any proposed management framework is the unknown time-lag between the cause and effect of diffuse contamination of waterways via surface run-off or sub-surface leaching (McDowell & Larned, 2008).

The timescale for management of PS needs to be either instantaneous (to comply with concentration-based standards) or daily (to comply with daily loading standards). Daily management regimes are potentially more practical for the operation of low-tech wastewater systems that aim to discharge varying contaminant loads in relation to river flow. However, the application of a daily loading standard to meet a concentration-based standard in the river can only be applied where there is sufficient knowledge of the flow regime within the catchment, the concentration profile of a wastewater stream, and the assimilative capacity of the periphyton on the river bed.

Tools for managing non-point source nutrient losses from land are generally based on annual time steps to account for the seasonal effects of farming and cropping activities (Clothier *et al.,* 2007). Therefore, non-point source nutrient management also needs to occur on an annual timescale.

The Proposed One Plan includes a policy that sets annual loss limits for intensive land uses (ie. dairying, cropping, irrigated sheep and beef and commercial vegetable production). The loss limits in the POP policy account for every hectare of the catchment and are based on land use capability (Clothier *et al.,* 2007).

The discontinuity between PS and NPS timescales is further compounded by the application of concentration-based water quality standards, as determined by average monthly samples, over a specified flow regime (ie. $< 3 * Q_{50}$). A pragmatic approach is required in order to convert the theoretical water quality standards into achievable nutrient load targets for the management of both wastewater discharges and land use.

However, it must be noted that reduction in cumulative inputs from NPS may not be enough to meet target water quality standards in some water management zones. A methodology is required to determine the gap between current loadings and proposed standards, and a tool to assess how various policy options will change this relationship.

Given the quality of continuous flow record in many catchments throughout the Region, and the requirement for nutrient standards to apply at specified flows, a loadings-based approach, inclusive of flow effects, is recommended. Loadings can be calculated to assess the level of current nutrient contamination at SOE sites at given flows and to determine target nutrient loads from concentration standards. Loads also provide a basis for the comparison of annual inputs from NPS systems to daily inputs from PS systems, in order to manage both sources of nutrient inputs in an integrated fashion.

The next step in the development of an integrated management approach is a clear understanding of the relative contribution of each nutrient source to the measured contamination load in the river.

This chapter outlines the methodology used to calculate:

- N and P target loads to meet the Proposed One Plan concentration standards;
- N and P loads measured at SOE sites;
- N and P loads of PS discharges;
- The relative contribution of N and P loads from NPS; and
- The assessment of the current state, targets and effectiveness of various policy options

The methodologies to assess the impact of the POP rules on NPS loadings within the upper Manawatu (upstream of Hopelands) and Mangatainoka catchments, and how this relates to the POP standards, are presented in subsequent chapters.

4.2.1 Definitions

The terms used throughout this report to define various nutrient 'loads' and 'standards' are detailed in Table 4 below. For the purposes of this report, the use of the term 'nutrient load' in any form relates to the load in the river or stream, determined as concentration times flow and does not refer to a nutrient load applied to land. Nutrient load to the river or stream is sometimes referred to as a nutrient 'loss limit' from land, although this term is not preferred by the authors as the focus of this report is on water quality.

Table 4: Terms and definitions for water quality standards and loadings used in the development of a framework for managing non-point source and point source nutrient contributions to water quality.

Term	Definition
Standard load limit	The annual average in-river load limit calculated from the concentration-based nutrient *standard* and continuous flow over the period of record
Measured load	The sum of the average annual *measured* in-river load for each flow decile category, calculated from continuous flow and SOE nutrient samples over the period of record
NPS target load	The annual NPS (non-point source) *target* in-river load, predicted to occur as a result of the implementation of the FARM strategy
Nutrient loss limit	The nutrient losses expected from a farming system
Attenuation	The retention of a proportion of lost nutrient either within the landscape or the riverscape. Measured in-river loads exclude all land or riverscape attenuation.

4.3 Converting concentration-based water quality standards to 'standard load limits'

Nutrient management models such as Overseer®[5] determine nutrient outputs or losses from farming systems. Because the role of Regional Councils is primarily focused on the effect of farming losses on water quality, an output-based approach such as that proposed in Rule 13-1 of the One Plan is preferred over input-based models.

However, Overseer® nutrient outputs are determined on an annual time scale, making it difficult to relate nutrient losses expressed in annual loads to instantaneous, concentration-based water quality standards.

Concentration-based water quality standards are used to set limits on water quality that are relevant to the environmental condition an aquatic organism experiences in the river. For example, the concentration of nutrients and the flux of nutrient concentration will influence the rate of periphyton biomass growth (Biggs, 2000). With regard to toxic contaminants like ammonia, the concentration that an organism experiences can be critical to whether or not that organism will suffer acute or chronic effects (Hickey, 2000).

However, the management of nutrient inputs to water, to maintain specific concentrations of nutrients within the river or stream, is very difficult to do on an instantaneous basis. Point source inputs are generally managed on a daily basis (although automated discharge controls are becoming more sophisticated to accurately manage discharges in relation to near real-time river flow). Non-point source contamination of water can be predicted from land output models such as Overseer® but the outputs, consistent with the seasonal management of a farming system, are determined on an annual basis. A project to move the Overseer® model to a monthly time-step is currently underway.

The load of a particular contaminant that a river can receive and still remain within a concentration standard depends on the flow in the river. When the river is at higher flow it takes a greater quantity of nutrient to make the river reach the defined concentration threshold.

For example, assuming there is no nutrient uptake within the river by biological organisms, the ANZECC guideline for SIN in lowland river sites is 0.444 g/m^3. To be within this nutrient standard at a flow of 2 m^3/s the loading input of SIN to a river must be less than 0.888 g/s (2 m^3/s * 0.444 g SIN/m^3) which equates to a maximum limit of 76 kg SIN/day if the flow remains at 2 m^3/s and the SIN contribution is assumed to be constant. Table 5 shows how the loading input of SIN changes as river flow increases from the minimum to the maximum recorded flow, assuming no biological assimilation of nitrogen.

[5] Overseer® is a registered trademark of AgResearch Ltd.

Table 5: Theoretical SIN loads (kg/day) at different river flow statistics to meet concentration based water quality standard of 0.444g SIN/m^3 in the Manawatu River at Hopelands.

	Flow m^3/s	SIN load kg/day
Minimum	2	76
MALF	4	140
Median	16	602
Maximum	1670	64050

4.3.1 Annual limits and flow-related application

Calculating annual Standard load limits

Converting the concentration-based standard to an accurate annual Standard load limit is relatively simple when the river in question has a continuous flow record, using Equation 1:

Equation 1

$$Load(year_i) = \int_{01/01/year_i}^{31/12/year_i} [Pollut](t) \cdot Flow(t) \cdot dt$$

In simple terms, the annual loading conversion from a concentration-based standard is determined by summing the volume of water flowing past a recorder site for every 15-minute interval of a year. This cumulative flow volume is multiplied by the concentration standard (g/m^3) to reach the maximum allowable annual contaminant load, or Standard load limit. To calculate the long-term average in tonnes/year, each of the 15-minute interval loadings can be summed for an annual total for each year and then averaged over the period of record (Equation 1).

For example if the flow at 10:00 am was 1.5 m^3/s and the flow at 10:15am was 1.1 m^3/s, the average flow for that 15-minute period would equal (1.5 m^3/s + 1.1 m^3/s)/2 = 1.3 m^3/s. To find the *cumulative* flow for that 15-minute period, the average flow 1.3 m^3/s is multiplied by 900 (seconds in 15 minutes) to equal 1170 m^3. To find the maximum standard load limit for that 15-minute period to not exceed the concentration standard (0.444 gN/m^3), the standard is multiplied by the cumulative volume of flow for that 15 minutes (1170 m^3) = 519.5 gN/15min.

Every 15-minute load can be summed for the entire cumulative water year to reach a maximum annual Standard load limit in tonnes/year. The average of each of the years of record can then be calculated to establish the long-term Standard load limit for a catchment (results are shown in a latter section of the report following a description of the other methodologies applied).

The cumulative annual flow from each 15-minute record was calculated for the 15-minute standard loads for each interval between flow records, and each of these standard loads was automatically assigned to flow exceedence deciles or 'bins' for each year (flow decile 'bins' are explained in more detail below).

4.3.2 Removing the flows that occur when the standard does not apply

Annual nutrient loads are required to quantify and account for variation in NPS nutrient effects over the seasonal scale of land use activities and climatic effects. Relating the concentration-based standard to an annual NPS Target load is further complicated by the application of nutrient standards below specified flows (eg. 0.015 g DRP/m^3 at flows below half the median flow in the MCWQRP[6] or an average concentration of 0.010 g DRP/m^3 at flows below three times the median flow [$3*Q_{50}$], as proposed in the One Plan (Ausseil & Clark, 2007b).

The recommended nutrient standards in Schedule D of the POP apply only at flows less than $3*Q_{50}$, (Ausseil & Clark, 2007b) as flood flows are unlikely to increase the risk, biomass or duration of nuisance periphyton blooms due to the high levels of abrasion and scouring during these events (Wilcock *et al.,* 2007). To calculate a target loading from a concentration standard which applies below a specified flow, the periods of flow record above that threshold should be removed from the calculation. To simplify the statistic representing a disturbance event or flood flow, the decile equivalents of three times the median were calculated for each site (see inset). As an example, the Manawatu at Hopelands site has a three times median flow ($3*Q_{50}$) that is exceeded approximately 12% of the time, therefore the proposed nutrient standards in the One Plan will not apply 12% of the time.

To simplify the relationship between the $3*Q_{50}$ for the purposes of this report the 10th percentile of flow (the flow exceeded 90% of the time) is used as the threshold at which the One Plan standards apply. This approach is also congruent with the use of 10th percentile (decile) 'bins' or categories of flow to calculate nutrient loads.

[6] Manawatu Catchment Water Quality Regional Plan, Horizons Regional Council 1998.

Flow Distribution and Exceedence Percentiles

The table below displays an example of a flow distribution for the Manawatu at Hopelands site (located at the bottom of the upper Manawatu case study catchment). The 100th percentile (lowest flow recorded) is 2.005 m^3/s, the 1st percentile is 176.177 m^3/s and the 0 percentile (highest flow recorded) is 1669.642 m^3/s. The flow exceeds the 0 percentile 0% of the time and exceeds the 100th percentile flow 100 percent of the time. This flow distribution is based on the instantaneous flow record (recorded every 15 minutes) as recorded, with no averaging. [Note that the terminology used here is consistent with that of Henderson and Dietrich, 2007.]

The median flow (Q_{50}) or 50th percentile for the Manawatu at Hopelands site is 15.4 m^3/s, therefore three times the median flow ($3 * Q_{50}$) is 46.2 m^3/s. This flow is exceeded between 11 and 12 percent of the time according to the flow exceedence percentiles.

Table: Flow distribution for the Manawatu at Hopelands site using instantaneous data.

~~~ Hilltop Hydro ~~~ Version 5.40
~~~ PDist Version 3.1 ~~~
Source is N:\water\Loadings\hopelands.hts
Flow (m³/s) at Manawatu at Hopelands_no1992
From 6-Jul-1989 16:00:00 to 1-Jul-2005 00:00:00

Exceedence percentiles

	0	1	2	3	4	5	6	7	8	9
0	1669.642	176.177	121.278	96.864	81.694	72.070	65.158	59.679	55.676	52.191
10	49.496	47.088	44.699	42.770	40.953	39.156	37.502	36.154	34.964	33.801
20	32.653	31.531	30.487	29.597	28.758	27.960	27.170	26.387	25.629	24.938
30	24.289	23.642	23.060	22.487	21.915	21.386	20.881	20.420	19.960	19.533
40	19.106	18.691	18.280	17.861	17.482	17.128	16.779	16.401	16.049	15.705
50	15.400	15.073	14.768	14.449	14.147	13.844	13.548	13.255	12.978	12.698
60	12.422	12.161	11.905	11.646	11.376	11.108	10.861	10.608	10.351	10.111
70	9.900	9.677	9.449	9.219	8.976	8.744	8.521	8.335	8.136	7.931
80	7.712	7.470	7.239	7.018	6.789	6.557	6.333	6.119	5.910	5.680
90	5.439	5.192	4.922	4.658	4.388	4.157	3.889	3.595	3.274	2.864
100	2.005									

Mean = 25.575 Std Deviation = 43.672
5473 days 07:45:00 hhmmss of data analysed
365 days 00:15:00 hhmmss of missing record
The distribution was calculated over 2000 classes in the range 2.005 to 258.751 m³/s

Note: the flow percentiles shown in this report differ from those of Roygard et al. (2006) and Henderson & Diettrich (2007) due to the removal of the 1992 partial year.

Flow percentiles for the Manawatu at Hopelands site

To demonstrate how percentiles relate to river flows as recorded, the percentile flows that mark the boundaries of flow for the Manawatu at Hopelands site are plotted over the long-term flow record in the figures below.

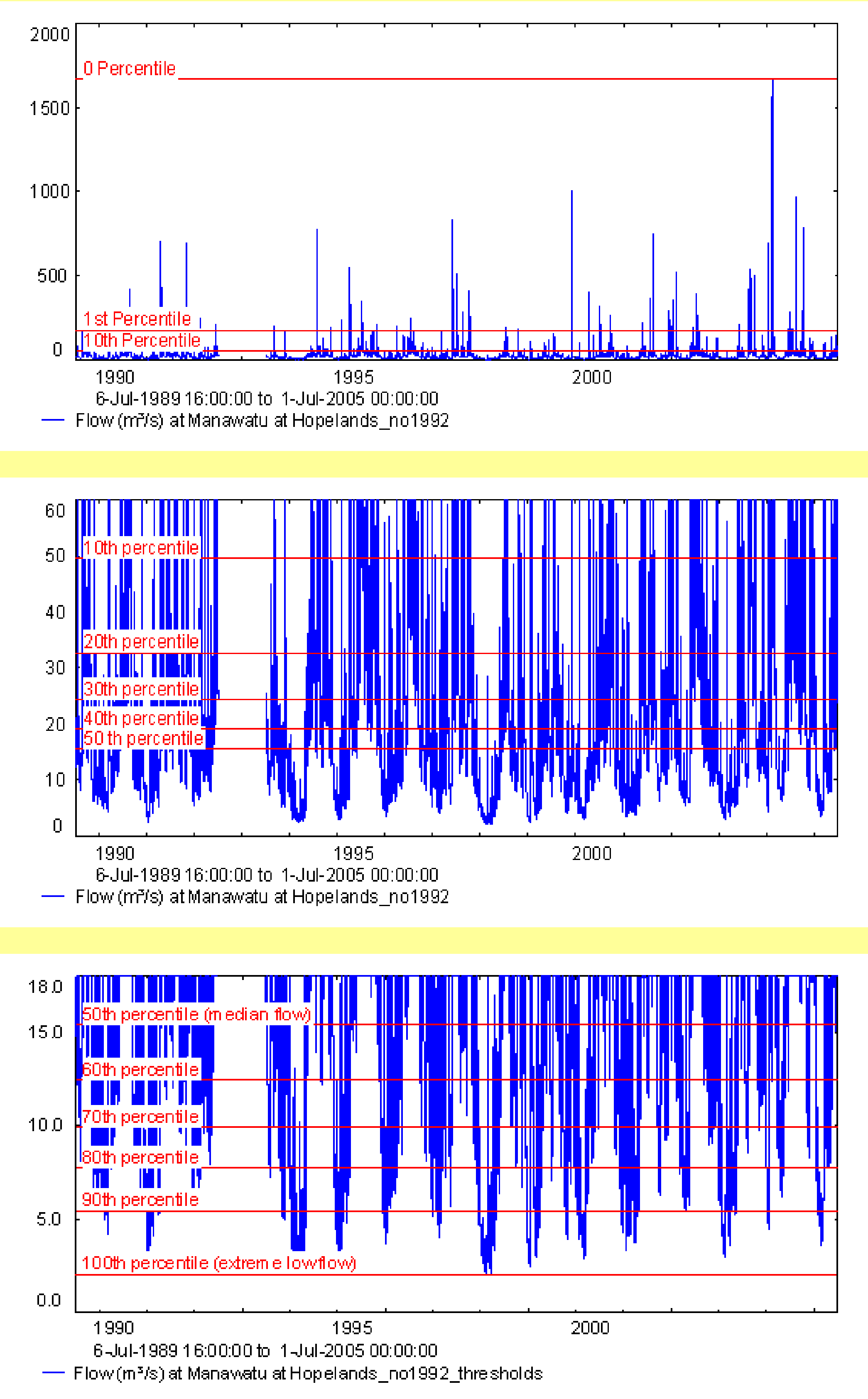


Figure: Flow record for the Manawatu at Hopelands showing instantaneous data in relation to flow percentiles.

As discussed above, modeling predicted nutrient standards that will limit nuisance periphyton growth to within guideline recommendations (Biggs, 2000), and using the flow statistic $3*Q_{50}$ as a surrogate for a benthic disturbance flow has proved problematic for rivers in the Horizons Region (see section 3.4.2).

The approach proposed is to use a percentile based flow statistic as the threshold below which nutrient standards should apply. In the absence of a detailed study of flows that cause mobilisation of bedload at each site, the 10th flow percentile, determined by a long-term flow record is recommended as a sensible threshold for the application of nutrient standards.

Separating the flows which exceed the 10th percentile flow removes a large proportion of the annual load of nutrients, particularly phosphorus, because of the scale of hydraulic transfer of nutrients from the surrounding landscape. Even if, for the sake of argument, nutrient transfer mechanisms were constantly low at all flows, the huge increases in river volume would still greatly increase the measured load when compared to flows in lower decile bins (Table 5). The flows in the 0-10% bin include flows that are orders of magnitude higher than the 10-20% bin or lower. For example, the highest flow in the 10-20% bin at the Manawatu at Hopelands is 1670 m^3/s, whereas the 20-30% bin has a maximum flow of 53 m^3/s and the 10th-20th decile has a maximum flow of 49.5 m^3/s.

These huge flow differences between floods and medium to high flows highlights the need for river water quality studies to put considerable effort into sampling during high flows to truly characterize contaminant loads. However, if sampling is at fixed intervals over time, all events will be sampled proportionate to their occurrence. The effect of removing nutrient loads associated with flows above the 10th percentile is described in detail below.

4.4 Measuring N and P loads at SOE monitoring sites

Horizons, like most other regional councils and the National River Water Quality Network administered by NIWA (Scarsbrook, 2006) measures water quality once a month ie. 12 samples per year. Although monthly sampling is cost effective and adequate to provide long-term water quality state and trend data that is randomised against flow, the contaminant concentrations and load variation with flow are unknown during the time between samples.

Monthly monitoring programmes are not ideally suited to calculate nutrient load estimates over the long-term and were not originally designed for this specific purpose (Ferguson, 1987). Programmes with monthly or quarterly sampling have been shown to give load estimates biased low by more than 35% as much as 50% of the time (Richards and Holloway, 1987 as cited in Richards, 1998). In the United States many of the Rural Clean Water programmes and similar projects have been unable to document clear water quality benefits from land management changes because of insufficient sampling frequency (Gale *et al.,* 1992).

Ideally, continuous monitoring technologies, when combined with instantaneous flow records, would accurately measure *actual* contaminant loads. Continuous monitoring technologies are well established for turbidity, temperature and dissolved oxygen within the Horizons SOE[7] programme. A trial of continuous nutrient monitoring equipment was undertaken at the Manawatu at Teachers College site (Peters, 2007). An in-depth analysis of results from the trial has not been undertaken as the use of this equipment was dogged by operational and maintenance issues. The current cost of this equipment is prohibitively expensive for SOE monitoring. However, technological improvement and decreasing costs for this type of equipment are likely in the medium to long-term, increasing the viability of continuous monitoring for SOE purposes in the future. Horizons is progressing further investigations into continuous nutrient monitoring technologies.

Because technology is more advanced in the continuous measurement of flow rather than of nutrient, nutrient concentration data is naturally less available (in terms of the number of observations over a given period of record) than measurements of flow. Richards (1998) identified three basic approaches to address load estimation in this situation:

1. Find a way to estimate 'missing' concentrations ie. for Horizons data this would require estimating nutrient concentrations for each 15-minute flow observation collected by continuous flow recorders;

2. Abandon most of the continuous flow data and calculate the load using the concentration data and paired flows, observed at the time the samples were collected; or

3. Do something in between, ie. find some way to use detailed knowledge of flow to adjust the load estimate determined from matched pairs of concentration and flow.

In discussing these options Richards (1998) concluded "*the second approach is usually totally unsatisfactory because the frequency of chemical observations is inadequate to lead to a reliable load estimate when simple summation is used. Thus almost all of the load estimation approaches which have been shown to give good results are variants of approaches 1 or 3.*"

McArthur & Clark (2007) found the second approach to be the only method able to be practically applied in relation to monitoring point source discharges for a given flow situation (eg. all samples for flows <½ median) because of the lack of sample frequency for many discharge and some SOE sites in the Manawatu-Wanganui Region.

4.4.1 Flow and concentration relationships

The choice of the best method to calculate loads from water quality and flow data is strongly influenced by the nature of the relationship between flow and nutrient concentration. Ledein *et al.* (2007) examined several methods for calculating loads including the regression approach, the Beale ratio estimator and the averaging approach. Before deciding on a method of load calculation

[7] State of the Environment monitoring.

for this management framework, the flow vs. concentration relationship for each nutrient of interest at each river site required examination.

The major factors which influence the relationship between flow and nutrient concentration vary from site to site, including:

- Catchment geology and land use;
- Sampling during rising or receding flow;
- Seasonality and rainfall;
- Irrigation;
- Variation in proportions of PS and NPS inputs;
- Biomass of periphyton or macrophytes ie. dissolved nutrient uptake; and
- Release and oxidation of DOP (dissolved organic phosphorus) from river sediment during low flows in rivers with high deposited sediment.

Rising or falling flow

The variation between flow and concentration relationships with rising or falling stage (river level) can occur when river flows are very low and rain occurs within the catchment, inducing nutrient run-off from the landscape and causing river flow to increase. Samples collected during such an event may have very different nutrient concentrations from those collected at the same flow during a dry period flow recession. Variability in concentration with rising or falling stage depends largely on the contaminant of interest and the transport mechanisms for that contaminant (eg. *E. coli* [Muirhead *et al.,* 2004]). Walling & Web (1981) as cited in Ferguson (1987) used rating curves to separate data into rising and falling stage categories to reduce noise in stage and flow relationships with nutrient concentration. Rising and falling flow will contribute to the scatter in the deciles.

Seasonality

The possible effect of season on flow and concentration relationships is another factor requiring consideration. Contaminant loads from the first flush of nutrient from the landscape in autumn may potentially have a more marked effect than a small rising stage event. In agricultural landscapes, this flush of nutrient occurs when rain causes the soil moisture to exceed the field capacity, leading to drainage of the soil profile beyond the root zone. While these events can be seasonally associated, they can also occur to varying degrees at any time of the year following a dry period and fertiliser application.

In an analysis of nutrient loads at low flows, McArthur & Clark (2007) found average nitrogen concentrations in the Mangatainoka case study catchment were more than 1.5 times the ANZECC guideline during flows less than half median. This indicates that regardless of any rainfall and seasonality effects, nitrogen is still leaching from the landscape at a significant rate during dry periods in some catchments.

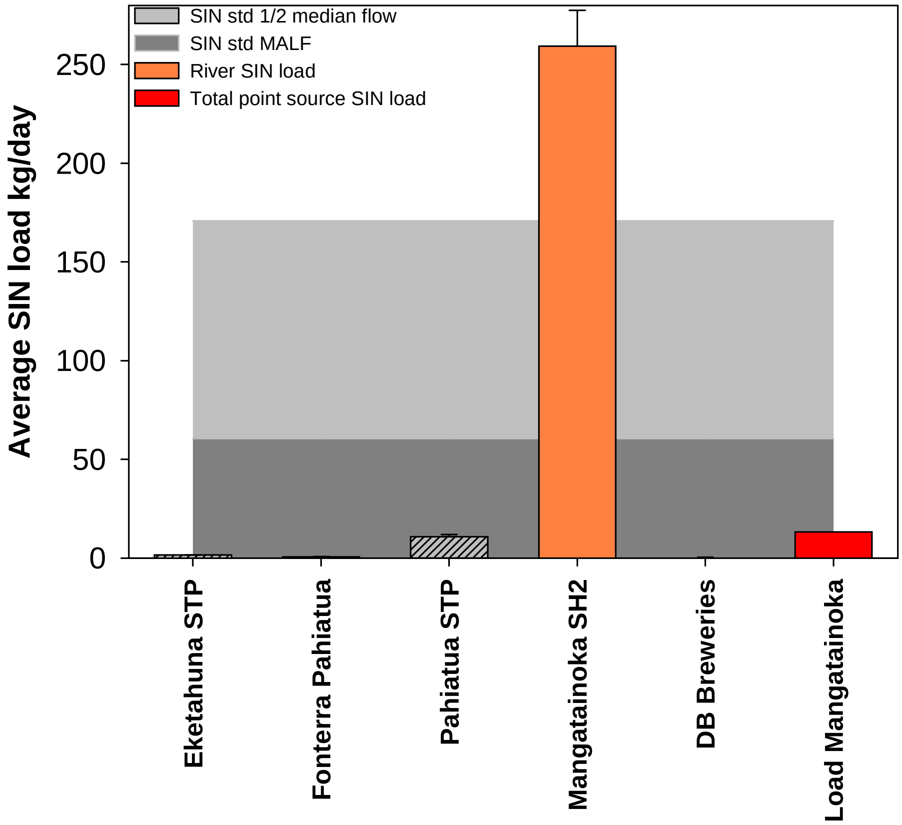
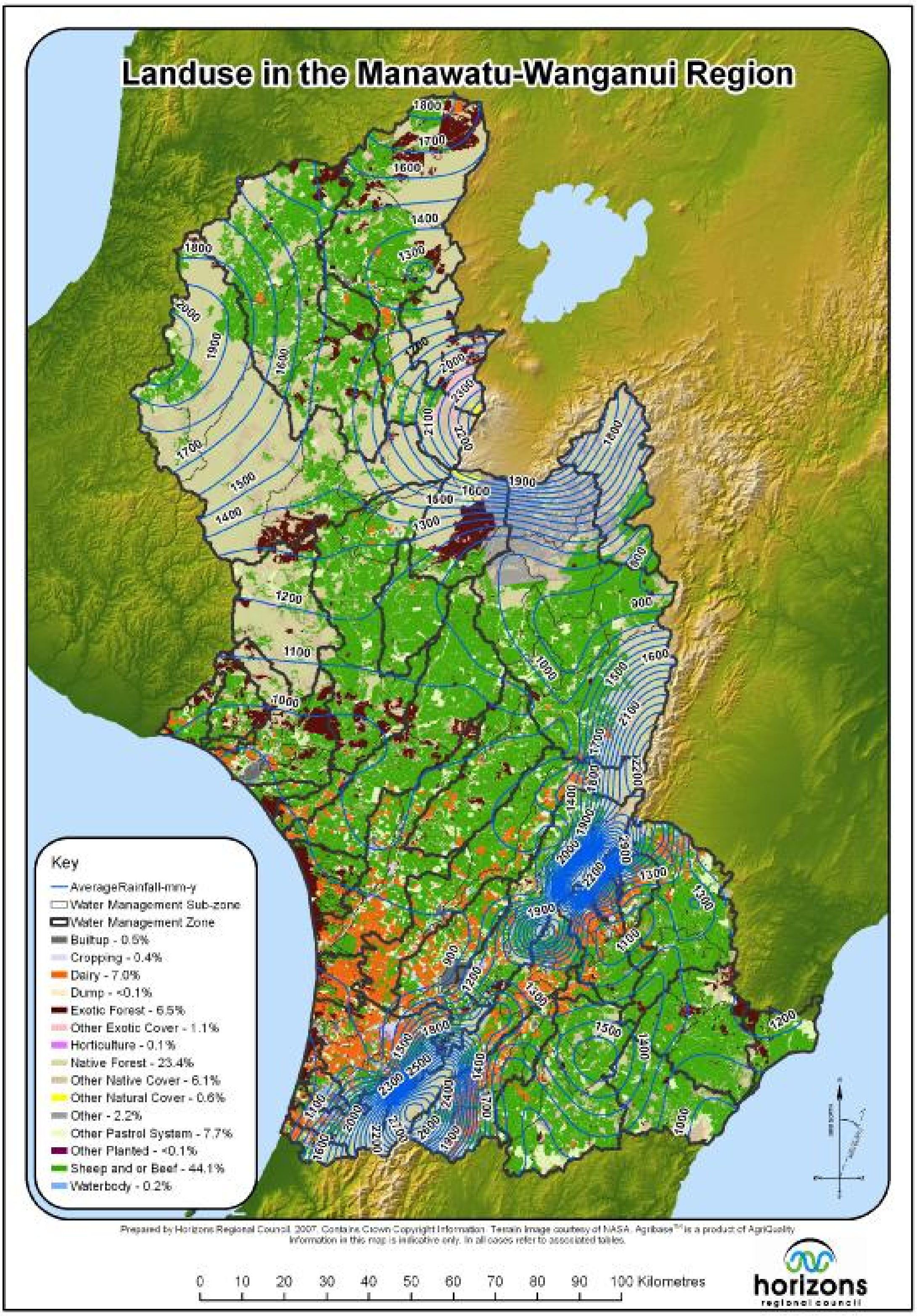


Figure 10: Average daily SIN loadings at SOE sites (orange bars ±1SE - from samples collected below ½ median flow) and from point source discharges (hashed bars – individual estimated loads, red bars – cumulative loads) in the Mangatainoka catchment, January 1989 – July 2005. SIN standards (grey scale areas) are calculated for the flow statistics at each SOE site (*Source: McArthur & Clark, 2007*).

Use of long-term nutrient data and calculation of loadings on an annual basis may reduce the influence of seasonality on calculated nitrogen loads. However, to allow for a seasonal component into a flow-stratified nutrient management framework will introduce a large degree of complexity and reduce the practical viability of applying the framework to a real scenario.

High intensity rainfall events do occur during low flows or ‘dry’ seasons in the Horizons Region, for example the February 2004 storm event, or rainfall events that break droughts. Therefore, nutrients can potentially reach surface water via run-off and leaching in any month of the year if there is a high rainfall event, further reducing the effect of seasonality. Long-term monthly datasets should capture any residual seasonal variation over the period of record.



Map 14: Land use in comparison with rainfall in the Manawatu-Wanganui Region.

Confounding effects of PS and NPS influences

Any seasonality in NPS nutrient concentration may be exacerbated or reduced by PS nitrogen inputs. Depending on the nature of the discharge, PS inputs may increase at the same seasonal scale as NPS inputs (ie. wastewater discharge from dairy production) or increase during dry periods (ie. abattoirs). Increasingly, resource consents for wastewater discharge are requiring the removal of discharges at low flows (ie. Fonterra Longburn and AFFCO Feilding) to meet Regional Plan standards. Thus the relationship between season, flow and source of nutrient is unclear.

Remineralisation of dissolved organic phosphorus in river sediments

There is some evidence to suggest dissolved organic phosphorus (DOP) stored within benthic sediments is remineralised during periods of stable low flow into reactive phosphorus in the Manawatu River (Hedley, 1978; Parfitt *et al.,* 2007; B. Wilcock *pers. comm.* 2008). Further detailed investigation of this process is required; however, Parfitt *et al.* (2007) have estimated the contribution of dissolved phosphorus from DOP in benthic sediments during low flows to be as much as 4 tonnes per year for the upper Manawatu.

4.5 The regression or rating approach

Because of the highly variable relationship between nutrient concentration (both N and P) and flow at the Manawatu at Hopelands SOE site, a regression method for calculating loads was not considered appropriate (Figure 11 and Figure 12). Across all flows the regression coefficients were not indicative of any strong linear relationships between concentration and flow ($R^2_{(SIN\ vs.\ flow)}$ = 0.003, $R^2_{(DRP\ vs.\ flow)}$ = 0.1). Log transformation of flow data further reduced the R^2 values and did not explain the relationship any better than the raw data.

Whilst the regression coefficients for flow versus concentration again did not yield clear linear relationships for samples collected at flows less than the 10th percentile (ie. when the proposed standard applies) ($R^2_{(SIN\ vs.\ flow)}$ = 0.001, $R^2_{(DRP\ vs.\ flow)}$ = 0.002), the nature of the relationship between nutrient concentration and flow was more clearly displayed (Figure 13 and Figure 14). Again PS discharge at low flows has a major influence over flow-nutrient relationships in these catchments. Removal of estimated PS concentration from measured SOE data may yield better relationships between NPS nutrient concentration and flow; however the attenuation of nutrients by periphyton and potential release of DRP from sediments may confound this relationship. Further investigation of 'naturalisation' of NPS nutrient loads is warranted.

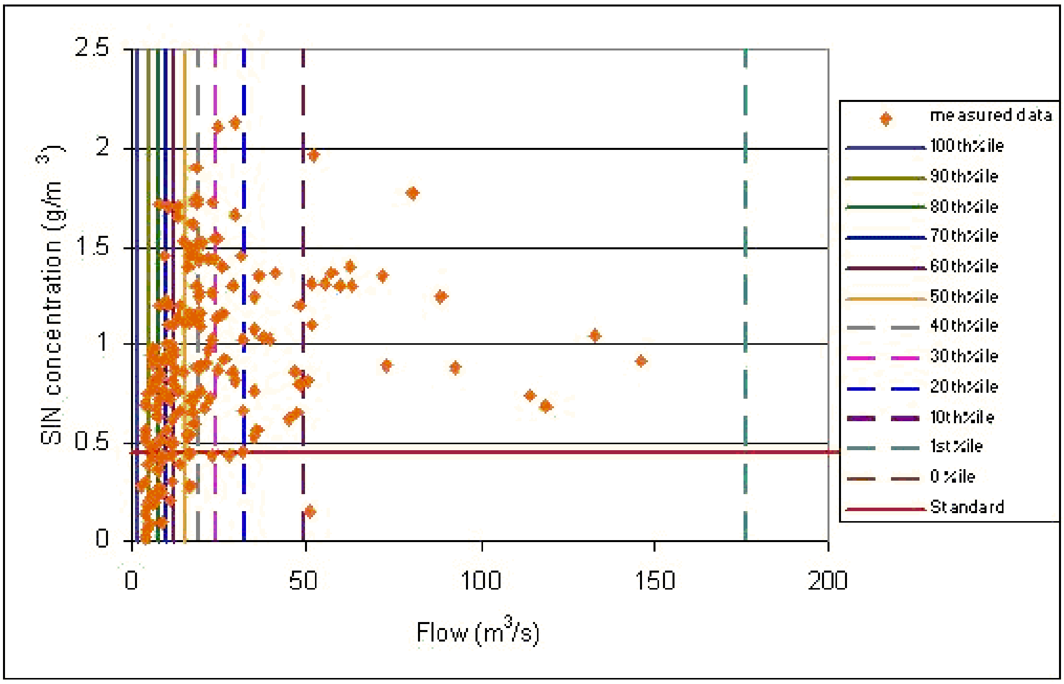


Figure 11: Soluble inorganic nitrogen (SIN) concentration in samples collected from the Manawatu River at Hopelands SOE site, 1989–2005. Flow data at the time of sampling is taken from continuous measurements.

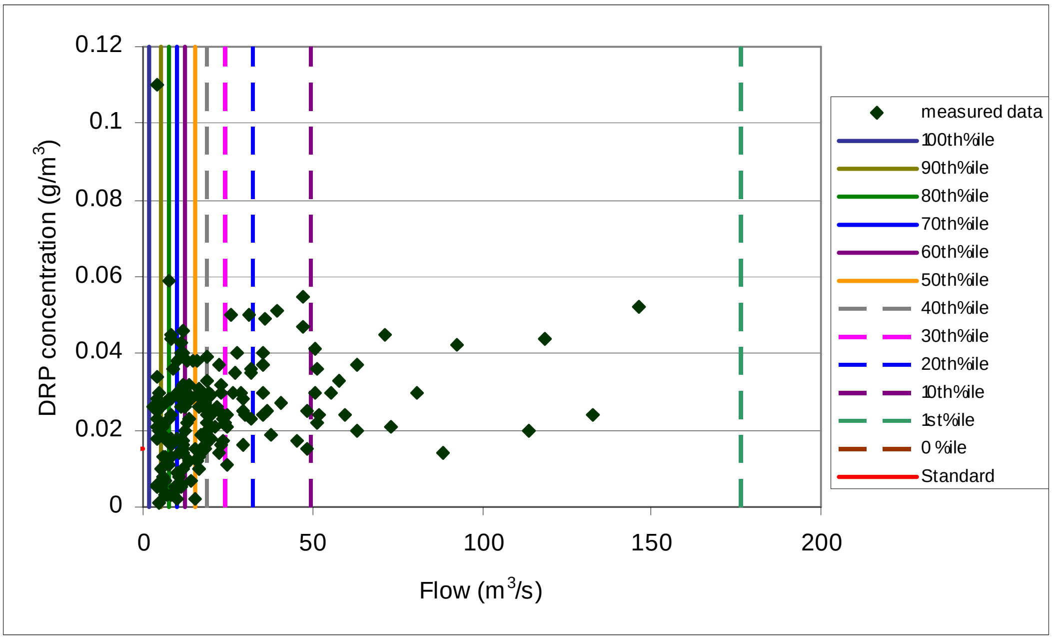


Figure 12: Dissolved reactive phosphorus (DRP) concentration in samples collected from the Manawatu River at Hopelands SOE site, 1989–2005. Flow data at the time of sampling is taken from continuous measurements.

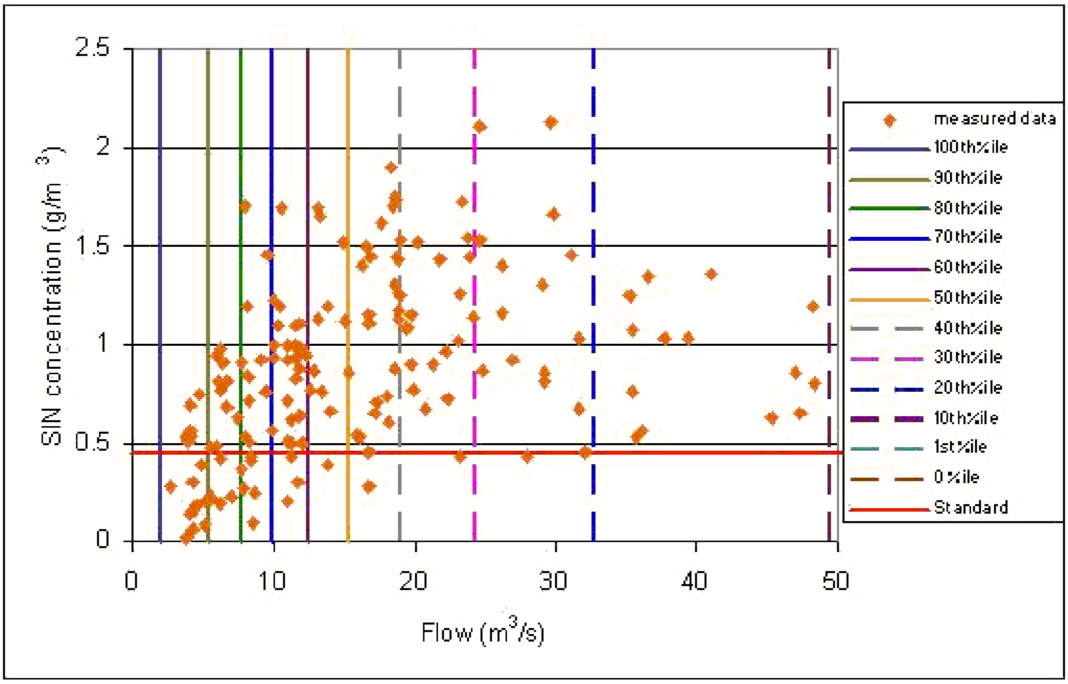


Figure 13: Soluble inorganic nitrogen (SIN) concentration in samples collected from the Manawatu River at Hopelands SOE site, 1989–2005 at flows less than 10th percentile. Flow data at the time of sampling is taken from continuous measurements.

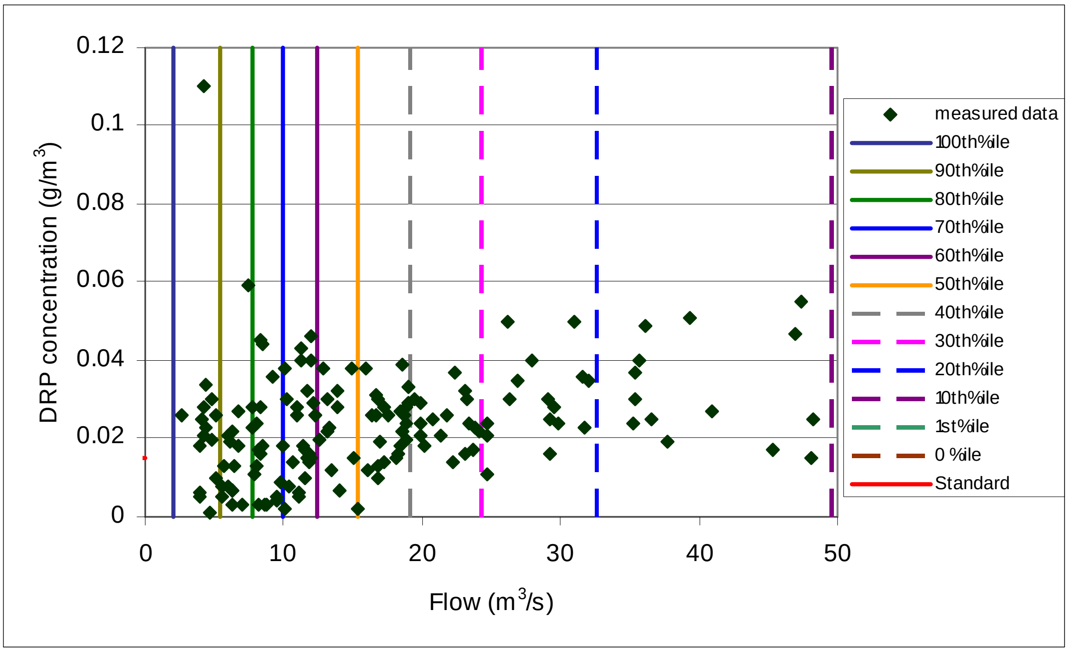


Figure 14: Dissolved reactive phosphorus (DRP) concentration in samples collected from the Manawatu River at Hopelands SOE site, 1989–2005 at flows less than the 10th percentile. Flow data at the time of sampling is taken from continuous measurements.

4.5.1 The averaging approach

The averaging approach assumes no relationship between flow and concentration and has been used in recent studies in New Zealand (Monaghan *et al.,* 2006; Wilcock *et al.,* 2007b). This approach calculates a monthly load from the concentration and flow data in that month. This type of approach was trialled for the upper Manawatu using a limited data set (Ledein *et al.,* 2007) for the period 1989 to 2005 in the upper Manawatu case study (Appendix 5). This report has also trialled this approach (Appendix 6).

The averaging approach does not allow for interpretation of relative inputs of NPS and PS or to look at loadings over various flows in comparison with POP standards. It does not provide for a management mechanism to be utilised for the management of point and NPS. However, an advantage of this approach is that it does offer a pragmatic method for the calculation of monthly loads from monthly water quality monitoring.

Using the mean weighted discharge version of the averaging approach (Wilcock *et al.,* 2007b; Monaghan *et al.,* 2006; Ferguson, 1987) the average annual loadings for SIN and DRP to the upper Manawatu catchment upstream of Hopelands are 962.8 tonnes SIN/year and 26.8 tonnes DRP/year. The assumptions and applicability of the averaging approach are further discussed in Appendix 6.

4.6 Flow stratification of Standard load limits

4.6.1 What are flow decile bins?

Flow ‘bins’ were created by dividing the flow distribution into 10 categories with equal frequency of occurrence. The decile flow categories were defined by the 10^{th}, 20^{th}, 30^{th}…100^{th} percentile flows to create flow categories for the 0-10^{th}, 10^{th}-20^{th}, 20^{th}-30^{th} … 90^{th}-100^{th} percentile flows. Measured nutrient loads were then calculated for each of these flow deciles (see below) to assess measured loads against the Standard load limit for each flow category (decile). The flow bins are categories of flow that occur for equal periods of time over the length of the flow record (ie. flow is in each of the decile bins 10% of the time).

4.6.2 Benefits of flow stratification

Stratifying each of the 15-minute observations of flow into decile categories was undertaken to increase our understanding of measured nutrient load occurrence over different portions of the flow distribution, and to calculate a Standard load limit for each decile category of flow. Standard load limits determined for each flow decile have little relevance for non-point source activities, which operate on an annual timescale. Instead, non-point source loads are relevant to Measured *annual* loads and can be compared to the Standard *annual* load limit. However, the Standard load limit, split for each flow decile bin may be more applicable to point source discharge operations, enabling the management of nutrient loads to the river, in relation to river flow, on a daily basis.

In addition to enabling the assessment of Measured nutrient loads against Standard load limits (derived from concentration-based water quality standards) and removal of the data from high flow events, the stratification of nutrient loads into flow decile bins provides a method to investigate the behaviour of nutrient transport and input mechanisms at different flows.

For example, NPS phosphorus is positively related to flow because the transport of phosphorus from the landscape to the river occurs mainly during high rainfall and flood events. However, DRP concentrations were also high during low flows (< ½ median) at sites subject to PS discharges throughout the Region as a result of reduced dilution from flow (McArthur & Clark, 2007).

Flow stratification, using flow distributions determined from instantaneous flow records, facilitates investigation of the complex proportional changes in load source (NPS or PS) and magnitude with flow. Flow distributions can also be calculated for daily average flows or over any other defined time period. Using a load-based method that relies on daily or monthly average flow distributions (as opposed to instantaneous flow distributions) has the advantage of reducing the influence of extreme floods on the flow distribution. However, instantaneous flow distributions better describe the in-river extremes that occur by encompassing the true peak flow and lowest recorded flow within the data. Ecologically speaking, the effect of actual load and flow events on aquatic organisms may be more relevant than ‘averaged conditions’.

In its broadest sense stratification of nutrient loads by flow provides a way of managing both N and P loads, from different sources, over different flow categories and management timescales, using a consistent methodology to achieve concentration-based standards in the river. For example, if the flow is between X and Y flow deciles then the loading the river can receive to stay within nutrient standards is Z. The loading ‘Z’ can then be ‘allocated’ between NPS and PS inputs for each decile of flow.

4.7 Flow-stratified loading method

The averaging approach to nutrient load calculation is built on the concept of a total load (the load for the period of interest) and a unit load (the loading for each individual interval of the calculation that is summed to calculate the total load). For example, if the total load is annual then the unit load may be a monthly load (Richards, 1998), with each month summed to create an annual load.

This report advocates a framework which, although built on monthly water sampling, does not identify a monthly unit load, but applies an approach that collects observations of the range of concentrations within a given flow condition (decile category). For example, when a sample is collected, the concentration of that sample is representative of the concentrations that can occur at that flow. Over time the flow decile categories are populated with concentrations that have occurred within that flow range.

This flow-stratified approach of calculating loadings recognises that, although a linear relationship between flow and concentration does not occur over the whole flow regime, relationships can occur within the bounds of one or several consecutive flow deciles. These ‘within decile’ relationships differ depending on the nutrient of interest and the sources of contaminants. The application of flow decile categories is a somewhat arbitrary way of defining the many relationships between concentration and flow that occur throughout various mechanisms of nutrient transport in catchments. The method also provides a mechanism to manage inputs in relation to concentration-based standards. It also enables separating out the loads that occur when the standards do not apply.

4.7.1 Calculating a measured unit load for each flow decile bin

Monthly samples were converted to loads using the nutrient concentration (g/m^3) and flow recorded at the time of sampling (m^3/s). An 'instantaneous' unit load was expressed in g/s, which was then multiplied by the number of seconds in a day (86,400) to units of kg/day. The kg/day unit was easier to conceptualise than an instantaneous load in g/s and was more convenient for conversion to an annual load. The use of instantaneous flow at the time of sampling is assumed to be the most accurate estimate of the load that can be measured compared to using an average daily flow or average monthly flow.

Given the various conditions which influence N and P concentrations a range of nutrient concentrations populated each decile bin. Each flow decile bin was then populated with the kg/day loads. To account for this variation, a measure of central tendency such as the median or mean unit load in kg/day was required for each flow decile bin. The range in unit load within each bin was expressed by recording the maximum, minimum and number of samples (*n*) from which the summary statistics were calculated.

4.7.2 Converting the unit load for each flow decile bin to an annual load

By stratifying flow exceedence percentiles from flow duration curves into 10 decile categories, we can consider each decile bin to represent the flow that occurs for 10% of the flow record, or 10% of any year. To convert the daily unit load to an annual load for each site, the unit load was multiplied by the annual frequency of the flow decile category in days (ie. kg nutrient/day * 36.5 days (10%) flow duration/year.

To estimate the nutrient load for the whole year (or over the whole flow distribution for a given year) each flow decile summary statistic was summed. Summing the maximums, averages, medians and minimums was the simplest approach that provided an estimate of these statistics for the whole year or flow distribution. Loads calculated from summed means or medians of each decile bin should be considered *estimated* nutrient loads, limited by the number of observations and the error associated with calculations of this nature.

The annual nutrient load estimate is considered best expressed by the sum of the median loads for each percentile bin. The median is potentially the more appropriate measure of central tendency for water quality measures as it is less influenced by extreme values (Scarsbrook & McBride, 2007). However, the water quality standards recommended in the Proposed One Plan are based on annual 'average' nutrient concentration standards from samples collected monthly (Ausseil, 2007b). Both the median and mean estimates of annual nutrient load are presented within this report.

4.7.3 Assumptions and limitations of the flow stratification method

Because the relationship between flow and nutrient concentration is very complex, some assumptions need to be made in order to simplify the relationship for the purposes of management of water quality. This report assumes no assimilation of nutrients by plants, algae or sediments within the river between nutrient sources and monitoring sites. Although these processes are undoubtedly occurring in all streams and rivers to a greater or lesser degree, the extent and variation of nutrient assimilation, also referred to as nutrient spiraling length (McDowell *et al.,* 2004), is difficult to quantify on a catchment scale. The implications of this assumption are that loads may be generally underestimated, particularly from NPS inputs. Chemical or biological remineralisation is also assumed not to influence nutrient loads, although evidence suggests this occurs to a minor degree in the upper Manawatu at low flows (Parfitt *et al.,* 2007).

5. Results: The Upper Manawatu and Mangatainoka Case Studies

5.1 Calculating a Standard load limit for all flows: the Hopelands example

To undertake load calculations for the Manawatu at Hopelands SOE site, the continuous flow record from 1989 to 2005 was used. A total of 193 nutrient concentration observations for this site were collected from September 1989 to October 2005. Complete water years are considered to be data recorded for the year between 1 July and 1 July the following year. The flow duration curves were calculated from data recorded between 6 July 1989 and 1 July 2005, excluding the 1 July 1992 to 1 July 1993 water year (see Appendices).

The 1989 water year started on 6 July as this was the date of site reestablishment since the 1940s and 50s. Earlier records from this time were not used because there were no accurate records of low flows; during this period the Hopelands flow recorder was primarily used to measure floods and high flow events.

In order to understand the variability in the average Standard load limit derived from a concentration-based nutrient standard, the averages from all years (and the whole flow duration) were compared to Standard load limit calculated for the flows in each individual year. The concentration-based standards for the Manawatu at Hopelands water management zones were calculated using the following nutrient concentrations from the POP: 0.444 g SIN/m^3 and 0.010 g DRP/m^3.

These concentration-based standards translate to average Standard load limits for all flows (including flows greater than the 10^{th} percentile) of 358 tonnes SIN/year and 8.1 tonnes DRP/year (Table 6) with standard deviation of 89 and 2 tonnes per year for SIN and DRP respectively. The Standard load limits calculated for each individual year ranged from 45% less than the average to 54% greater for the 15 individual years (Table 6). Therefore, applying this as the Standard nutrient load limit sets a benchmark that would be required to be achieved in eight out of 15 years, based on the last 15 years of record.

Table 6 provides a summary of this data for each individual year and shows the proportion of years that the Standard load limit calculated for each year is above or below the average Standard load limit. Further comparison of the difference between the Standard load limit for any given year and the average Standard load limit from the whole period of record should be seriously considered. The Mangatainoka at SH2 monitoring site (a tributary catchment of the upper Manawatu downstream of Hopelands) has more than 50 years of hydrological record and provides an ideal test case for investigating these relationships.

Table 6: Comparison of Standard load limits from individual years to average Standard load limits calculated from all years of record at the Manawatu at Hopelands monitoring site between 1989 and 2005. Standard load limits are determined from concentration-based nutrient standards in the Proposed One Plan (0.444 g SIN/m^3 and 0.010 g DRP/m^3) and are expressed in tonnes per year (t/y). Percentile loads were calculated across all years of record.

SIN				DRP			
Water Year	**Standard load (All flows)**	Comparison to Mean		Water Year	**Standard load (All flows)**	Comparison to Mean	
		diff. t/y	% diff.			diff. t/y	% diff.
Jul-93 - Jul-94	198	-160	-45%	Jul-93 - Jul-94	4.5	-3.6	-45%
Jul-99 - Jul-00	264	-94	-26%	Jul-99 - Jul-00	5.9	-2.1	-26%
Jul-97 - Jul-98	276	-82	-23%	Jul-97 - Jul-98	6.2	-1.8	-23%
Jul-98 - Jul-99	283	-75	-21%	Jul-98 - Jul-99	6.4	-1.7	-21%
Jul-00 - Jul-01	307	-51	-14%	Jul-00 - Jul-01	6.9	-1.2	-14%
Jul-02 - Jul-03	317	-41	-11%	Jul-02 - Jul-03	7.14	-0.9	-11%
Jul-89 - Jul-90	325	-33	-9%	Jul-89 - Jul-90	7.3	-0.7	-9%
Jul-92 - Jul-93	--	--	--	Jul-92 - Jul-93	--	--	--
Jul-91 - Jul-92	388	30	8%	Jul-91 - Jul-92	8.7	0.7	8%
Jul-96 - Jul-97	389	31	9%	Jul-96 - Jul-97	8.8	0.7	9%
Jul-90 - Jul-91	390	32	9%	Jul-90 - Jul-91	8.8	0.7	9%
Jul-01 - Jul-02	396	38	10%	Jul-01 - Jul-02	8.9	0.8	10%
Jul-94 - Jul-95	406	48	13%	Jul-94 - Jul-95	9.1	1.1	13%
Jul-95 - Jul-96	425	67	19%	Jul-95 - Jul-96	9.6	1.5	19%
Jul-04 - Jul-05	453	95	27%	Jul-04 - Jul-05	10.2	2.1	27%
Jul-03 - Jul-04	553	195	54%	Jul-03 - Jul-04	12.5	4.4	54%
Mean load	**358**			**Mean load**	**8.1**		
Standard deviation	89			Standard deviation	2.0		
Median load	**388**			**Median load**	**8.7**		
	Standard load	Comparison to Mean			**Standard load**	Comparison to Mean	
Load Percentile		diff. t/y	% diff.	Load Percentile		diff. t/y	% diff.
0	198	-160	-45%	0	4.5	-3.6	-45%
10	269	-89	-25%	10	6.0	-2.0	-25%
20	282	-76	-21%	20	6.3	-1.7	-21%
30	309	-49	-14%	30	7.0	-1.1	-14%
40	322	-36	-10%	40	7.3	-0.8	-10%
50	388	30	8%	50	8.7	0.7	8%
60	389	31	9%	60	8.8	0.7	9%
70	394	36	10%	70	8.9	0.8	10%
80	410	52	14%	80	9.2	1.2	14%
90	442	84	23%	90	10.0	1.9	23%
100	553	195	54%	100	12.5	4.4	54%

Percentile values in Table 6, Figure 15 and Figure 16 show the distribution of annual Standard load limits, based on flow for those water years. This table provides a description of the potential variation in Standard load limit over time and is useful for decision-makers to explore possible levels of achievement of the standard on an annual basis. It is noted that compliance with the Standard load limit for any given year will not be known until the year's flow is measured. Long-term averages will be more appropriate to compare changes in Measured loads against Standard load limits. The long-term average annual Standard load limit for all flows can be simply calculated by multiplying the mean flow by the concentration standard. However, such a method provides little context for the annual variation in Standard load limits from year to year for decision-makers.

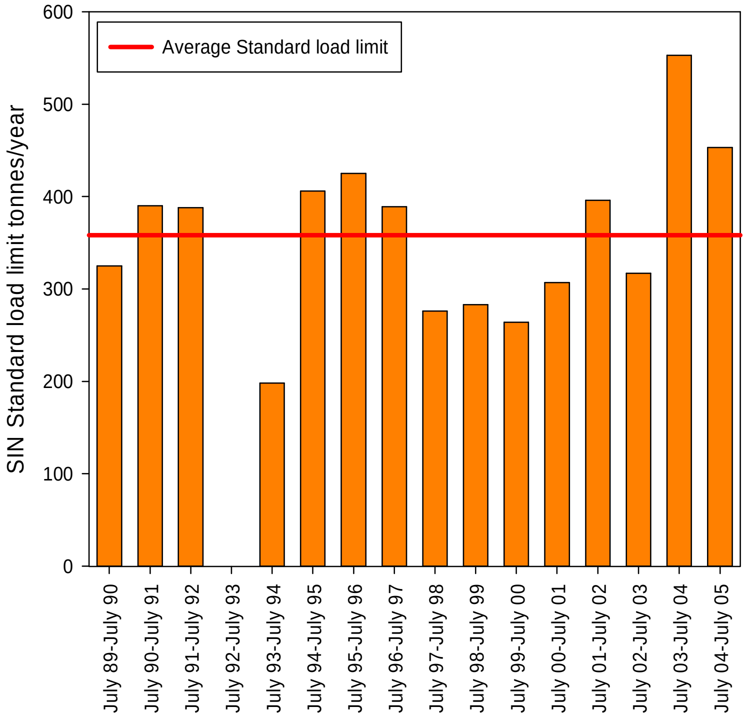


Figure 15: Annual variation in Soluble Inorganic Nitrogen (SIN) Standard load limit for the Manawatu at Hopelands between 1989 and 2005. *(Note: the 2002-2003 data is excluded due to lack of flow information for that water year.)*

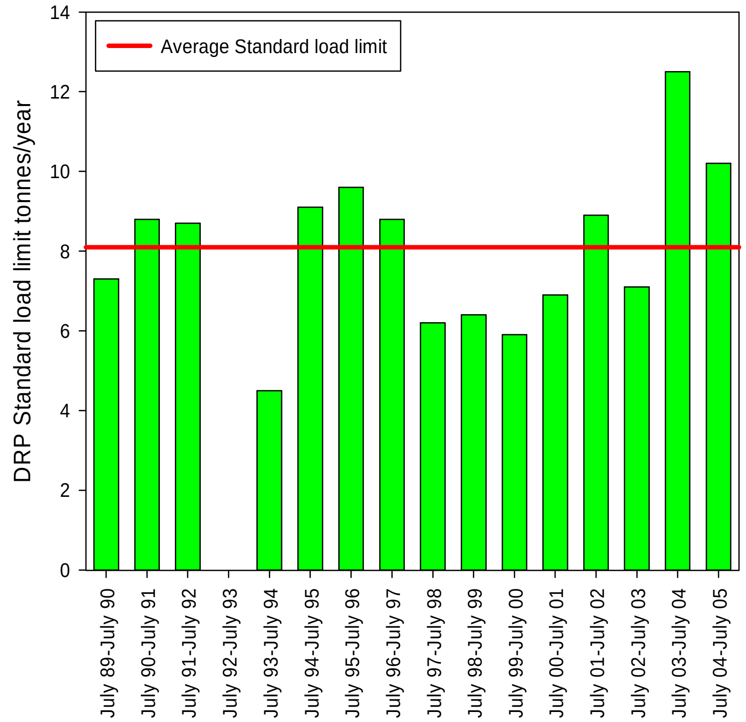


Figure 16: Annual variation in Dissolved Reactive Phosphorus (DRP) Standard load limit for the Manawatu at Hopelands between 1989 and 2005. *(Note: the 2002-2003 data is excluded due to lack of flow information for that water year.)*

5.1.1 Removal of high flows from the Standard load limit at Hopelands

Because concentration-based nutrient standards in the One Plan are proposed not to apply at flood flows, the Standard load limit from all flows overestimates the load required to comply with the standards at flows less than the 10^{th} exceedence percentile. To understand the potential impact of how the concentration–based nutrient standards, applying at flows less than the 10^{th} percentile, would relate to an annual Standard load limit, the standard load limits for each year were determined using the Manawatu at Hopelands flow series.

Removal of the load of nutrient that corresponded to the concentration-based nutrient standard at flows exceeded 10% of the time (eg. column 2 of Table 7 and Table 8) significantly reduced the Standard load limit for each year. Forty-one percent of the average Standard load limit across all years (calculated from the concentration-based standard and the recorded flows) occurs in the highest flow decile (0 – 10^{th}) (Table 7 and Table 8), whilst only 2% of the average Standard load limit across all years occurs at flows equal to the 90^{th} exceedence percentile or less.

The percentage of the average Standard load limit across all years that occurs within each flow decile bin is identical for both SIN and DRP because the Standard load limit is calculated using the same flow series. When Standard load limits for flows exceeded only 10% of the time were removed from the average Standard load limit across all years, the average SIN load limit dropped from 358 to 211.3 tonnes SIN/year (Table 7). Removal of the load carried at flows exceeded 10 percent of the time caused the DRP average Standard load limit to drop from 8.1 to 4.8 tonnes DRP/year (Table 8). Additionally, the median and average Standard load limits for flows less than the 10^{th} percentile category are very comparable, confirming the large skew in the flows series within the highest flow decile category.

Flow stratification method

By stratifying the annual Standard load limit for the Manawatu at Hopelands site by flow decile, we can determine that flows below median (column 7 Table 7 and Table 8) account for only 17% of the average Standard load limit (Figure 17). Examining the Standard load limit against flow decile also shows us that 5% of the Standard load limit could occur during the lowest 20% of flows (Table 7 and Table 8). However, despite gaining a better understanding of the implications of removing the Standard load limits resulting from the top 10% of flows, the practical applicability of removal these loads on an annual basis remains unresolved. Figures for the average Standard load limit at all flows are referred to as the Standard load limits throughout the remainder of this report.

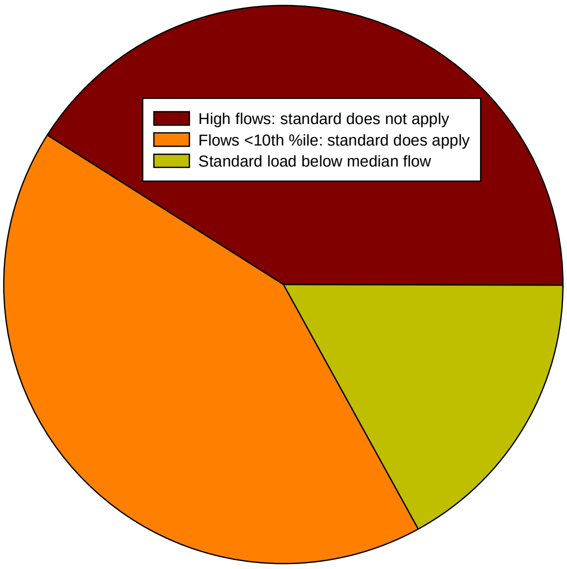


Figure 17: Proportion of Standard load limit (SIN and DRP) in relation to flow for the Manawatu at Hopelands.

Table 7: Soluble Inorganic Nitrogen (SIN) Standard load limits for flow in each percentile category measured at the Manawatu at Hopelands monitoring site between 1989 and 2005. All loads are expressed as tonnes per year (t/y); flow percentile categories are expressed as flows that are exceeded for the specified percentage of time over the total period of record. *Note: highlighted cells are discussed within the text.*

Water Year	Standard load limits of SIN (t/y) for flow percentile categories											
	0-10th	**10th-20th**	**20th-30th**	**30th-40th**	**40th-50th**	**50th-60th**	**60th-70th**	**70th-80th**	**80th-90th**	**90th-100th**	**Standard load (t/y)** All Flows	**Standard load (t/y)** Flows less than 10th percentile
Jul-89 - Jul-90	125	43	33	26	25	25	18	16	13	2.2	325.4	200.7
Jul-90 - Jul-91	178	63	39	24	21	17	19	15	8	5.1	389.7	211.5
Jul-91 - Jul-92	158	53	46	39	30	23	21	14	4	0.0	388.3	230.6
Jul-92 - Jul-93	--	--	--	--	--	--	--	--	--	--	--	--
Jul-93 - Jul-94	25	21	28	27	27	17	16	13	8	15.2	198.2	172.8
Jul-94 - Jul-95	172	82	45	36	27	14	7	7	8	6.6	405.9	233.5
Jul-95 - Jul-96	191	80	50	36	18	14	11	11	8	2.8	424.7	233.6
Jul-96 - Jul-97	160	72	45	30	23	21	16	11	7	3.7	389.2	229.2
Jul-97 - Jul-98	104	37	30	21	19	20	12	9	10	13.6	276.1	172.1
Jul-98 - Jul-99	73	48	35	32	30	18	19	12	7	7.3	283.3	210.0
Jul-99 - Jul-00	86	26	23	25	19	21	24	18	14	8.2	263.6	178.1
Jul-00 - Jul-01	98	47	37	37	27	19	11	12	12	7.2	306.6	208.3
Jul-01 - Jul-02	164	65	41	35	28	24	17	11	12	0.1	395.6	231.4
Jul-02 - Jul-03	123	48	32	26	24	21	13	10	14	7.6	317.1	194.2
Jul-03 - Jul-04	335	62	43	27	23	25	18	12	6	1.4	552.8	217.7
Jul-04 - Jul-05	207	89	63	29	19	13	11	12	5	5	453.1	246
Median Standard load – All Years (t/y)	**157.7**	**53.2**	**39.1**	**29.3**	**23.7**	**20.4**	**15.8**	**11.8**	**8.4**	**5.1**	**388.0**	**211.5**
Average Standard load - All Years (t/y)	**146.7**	**55.7**	**39.3**	**30.1**	**24.0**	**19.4**	**15.5**	**12.3**	**9.2**	**5.7**	**358.0**	**211.3**
Percentage of Average Standard load -All Flows	41%	16%	11%	8%	7%	5%	4%	3%	3%	2%	100%	59%
Percentage of Average Standard load - this flow percentile category or less	100%	59%	43%	32%	24%	17%	12%	8%	5%	2%		

Table 8: Dissolved Reactive Phosphorus (DRP) Standard load limits for flow in each percentile category measured at the Manawatu at Hopelands monitoring site between 1989 and 2005. All loads are expressed as tonnes per year (t/y); flow percentile categories are expressed as flows that are exceeded for the specified percentage of time over the total period of record. *Note: highlighted cells are discussed within the text.*

Water Year	Standard load limits of DRP (t/y) for flow percentile categories											
	0-10th	**10th-20th**	**20th-30th**	**30th-40th**	**40th-50th**	**50th-60th**	**60th-70th**	**70th-80th**	**80th-90th**	**90th-100th**	**Standard load (t/y)** All Flows	**Standard load (t/y)** Flows less than 10th percentile
Jul-89 - Jul-90	2.8	1.0	0.7	0.6	0.6	0.6	0.4	0.4	0.3	0.0	7.3	4.5
Jul-90 - Jul-91	4.0	1.4	0.9	0.5	0.5	0.4	0.4	0.3	0.2	0.1	8.8	4.8
Jul-91 - Jul-92	3.6	1.2	1.0	0.9	0.7	0.5	0.5	0.3	0.1	0.0	8.7	5.2
Jul-92 - Jul-93	--	--	--	--	--	--	--	--	--	--	--	--
Jul-93 - Jul-94	0.6	0.5	0.6	0.6	0.6	0.4	0.4	0.3	0.2	0.3	4.5	3.9
Jul-94 - Jul-95	3.9	1.8	1.0	0.8	0.6	0.3	0.2	0.2	0.2	0.1	9.1	5.3
Jul-95 - Jul-96	4.3	1.8	1.1	0.8	0.4	0.3	0.3	0.3	0.2	0.1	9.6	5.3
Jul-96 - Jul-97	3.6	1.6	1.0	0.7	0.5	0.5	0.4	0.3	0.2	0.1	8.8	5.2
Jul-97 - Jul-98	2.3	0.8	0.7	0.5	0.4	0.5	0.3	0.2	0.2	0.3	6.2	3.9
Jul-98 - Jul-99	1.7	1.1	0.8	0.7	0.7	0.4	0.4	0.3	0.2	0.2	6.4	4.7
Jul-99 - Jul-00	1.9	0.6	0.5	0.6	0.4	0.5	0.5	0.4	0.3	0.2	5.9	4.0
Jul-00 - Jul-01	2.2	1.1	0.8	0.8	0.6	0.4	0.2	0.3	0.3	0.2	6.9	4.7
Jul-01 - Jul-02	3.7	1.5	0.9	0.8	0.6	0.5	0.4	0.2	0.3	0.0	8.9	5.2
Jul-02 - Jul-03	2.8	1.1	0.7	0.6	0.5	0.5	0.3	0.2	0.3	0.2	7.1	4.4
Jul-03 - Jul-04	7.5	1.4	1.0	0.6	0.5	0.6	0.4	0.3	0.1	0.0	12.5	4.9
Jul-04 - Jul-05	4.7	2.0	1.4	0.7	0.4	0.3	0.3	0.3	0.1	0.1	10.2	5.5
Median Standard load – All Years (t/y)	**3.55**	**1.2**	**0.88**	**0.66**	**0.53**	**0.46**	**0.36**	**0.27**	**0.19**	**0.11**	**8.7**	**4.8**
Average Standard load - All Years (t/y)	**3.30**	**1.25**	**0.89**	**0.68**	**0.54**	**0.44**	**0.35**	**0.28**	**0.21**	**0.13**	**8.1**	**4.8**
Percentage of Average Standard load – All Flows	41%	16%	11%	8%	7%	5%	4%	3%	3%	2%	100%	59%
Percentage of Average Standard load - this flow percentile category or less	100%	59%	43%	32%	24%	17%	12%	8%	5%	2%		

The relationship between nutrient concentration standards, flow and Standard load limits: Manawatu at Hopelands

The relationship between three different SIN and DRP concentration standards and the Standard load limit was calculated for the Manawatu at Hopelands flow record (see Table below).

The three SIN standards trialed were 0.444 g SIN/m^3, 0.167 g SIN/m^3 and 0.110 g SIN/m^3. The 0.444 g SIN/m^3 and 0.167 g SIN/m^3 are the lowland and upland ANZECC guidelines respectively (ANZECC, 2002). The ANZECC guidelines determine the threshold between lowland and upland as an altitude of 150 m above sea level. The Manawatu at Hopelands site is approximately 100 m above sea level so the 0.444 g SIN/m^3 standard is appropriate to this site and the 0.167 g SIN/m^3 is more applicable to the higher altitude Weber Road site upstream. The figures below display the comparison of the results for each nutrient concentration and year.

The 0.110 g SIN/m^3 standard was also selected for further consideration because it is a standard of SIN concentration, which in combination with a DRP standard of 0.010 g DRP/m^3 was recommended by Dr Barry Biggs for the mainstem of the Manawatu River at the Hopelands site (Ausseil & Clark, 2007b).

DRP standards selected for comparison were 0.015 g DRP/m^3, 0.010 g DRP/m^3 and 0.006 g DRP/m^3. These standards reflect current nutrient management rules for the Manawatu River catchment (as defined in the Manawatu Catchment Water Quality Plan) (0.015 g DRP/m^3), the lowland ANZECC guideline (0.010 g DRP/m^3) and a reference condition background concentration estimate for the Manawatu at Hopelands site in the absence of any nutrient enrichment (0.006 g DRP/m^3). The upland ANZECC standard for DRP of 0.009 g/m^3 was not tested.

Average Standard load limits varied for each concentration standard in direct proportion to the flow for the period of record (see Table below). SIN standards of 0.444, 0.167 and 0.110 g SIN/m^3 translated to average Standard load limits of 358, 135 and 89 tonnes/year respectively across all flows. DRP standards of 0.015, 0.010 and 0.006 g DRP/m^3 translated to average Standard load limits of 12.1, 8.1 and 4.8 tonnes/year respectively across all flows.

At the Manawatu at Hopelands site, for every 0.001 g/m^3 increase in the concentration-based water quality standard a nutrient load increase of 0.8 tonnes/year is added to the average Standard load limit. This relationship is the same for both SIN and DRP, but will be unique for each SOE site because of variability in the flow regime and thereby the flow record used to develop the Standard load limit.

Table: A comparison of annual nutrient Standard load limits, calculated from potential concentration-based nitrogen and phosphorus standards and actual flow records from the Manawatu at Hopelands site between 1989 and 2005.

	SIN standards g/m³			DRP standards g/m³		
	0.444	0.167	0.110	0.015	0.010	0.006
Water Year	**Standard Load Limit (tonnes / year)**					
Jul-89 - Jun-90	325	122	81	11.0	7.3	4.4
Jul-90 - Jun-91	390	147	97	13.2	8.8	5.3
Jul-91 - Jun-92	388	146	96	13.1	8.7	5.2
Jul-92 - Jul-93	–	–	–	–	–	–
Jul-93 - Jul-94	198	75	49	6.7	4.5	2.7
Jul-94 - Jun-95	406	153	101	13.7	9.1	5.5
Jul-95 - Jun-96	425	160	105	14.3	9.6	5.7
Jul-96 - Jun-97	389	146	96	13.1	8.8	5.3
Jul-97 - Jul-98	275	104	68	9.3	6.2	3.7
Jul-98 - Jun-99	283	107	70	9.6	6.4	3.8
Jul-99 - Jun-00	264	99	65	8.9	5.9	3.6
Jul-00 - Jun-01	307	115	76	10.4	6.9	4.1
Jul-01 - Jun-02	396	149	98	13.4	8.9	5.3
Jul-02 - Jul-03	317	119	79	10.71	7.14	4.29
Jul-03 - Jun-04	553	208	137	18.7	12.5	7.5
Jul-04 - Jun-05	453	170	112	15.3	10.2	6.1
Average Standard load limit (All years)	355	133	89	12.0	8.1	4.8
Median Standard load limit (All years)	388	146	96	13.1	8.7	5.2

5.2 Calculating a Standard load limit for all flows: the Mangatainoka example

Complete water years are considered to be data recorded for the year between 1 July and 1 July the following year. The flow duration curves and exceedence percentiles for the Mangatainoka at Pahiatua Town Bridge (All) series were calculated from a long flow series dating from 1 July 1954 to 1 July 2005. To undertake Standard load limit calculations for the Mangatainoka at State Highway Two (SH2) Bridge SOE site (just downstream of the Pahiatua Town Bridge flow site), a proportion of the continuous flow record (from July 1993 to July 2005) was used that was consistent with the 155 nutrient concentration observations for this site.

In order to understand the variability in the average Standard load limit derived from a concentration-based nutrient standard, the long-term average and median over all years of SOE sampling were compared to Standard load limits calculated for the flows which occurred in each of the 12 individual years. The concentration-based standards for the middle and lower Mangatainoka water management zones were calculated using the following nutrient concentrations from the POP of 0.444 g SIN/m^3 and 0.010 g DRP/m^3.

The concentration-based standards translated to average Standard load limits for all flows (including flows greater than the 10^{th} percentile) of 266.3 tonnes SIN/year and 6.0 tonnes DRP/year (Table 9) with a standard deviation of 55 and 1.2 tonnes per year of SIN and DRP respectively. The Standard load limits calculated for each individual year ranged from 32% less than the average to 41% greater for the 12 individual years. Therefore, applying the average load as the Standard nutrient load limit sets a benchmark that would be required to be achieved in 6 out of 12 years, based on the last 12 years of record. Figure 18 and Figure 19 provide a summary of this data for each individual year and show the proportion of years that the Standard load limit calculated for each year is above or below the average Standard load limit.

Table 9: Comparison of Standard load limits from individual years to average Standard load limits calculated from all years of record at the Mangatainoka at SH2 monitoring site between 1993 and 2005. Standard load limits are determined from concentration-based nutrient standards in the Proposed One Plan (0.444 g SIN/m^3 and 0.010 g DRP/m^3) and are expressed in tonnes per year (t/y). Percentile loads were calculated across all years of record and flows.

SIN				DRP			
Water Year	**Standard load (All flows)**	Comparison to Mean		Water Year	**Standard load (All flows)**	Comparison to Mean	
		diff. t/y	% diff.			diff. t/y	% diff.
Jul-93 - Jul-94	182	-84	-32%	Jul-93 - Jul-94	4.1	-1.9	-32%
Jul-99 - Jul-00	208	-58	-22%	Jul-99 - Jul-00	4.7	-1.3	-22%
Jul-97 - Jul-98	224	-42	-16%	Jul-97 - Jul-98	5.0	-1	-16%
Jul-01 - Jul-02	225	-41	-15%	Jul-01 - Jul-02	5.1	-0.9	-15%
Jul-02 - Jul-03	229	-37	-14%	Jul-02 - Jul-03	5.1	-0.9	-14%
Jul-00 - Jul-01	264	-2	-1%	Jul-00 - Jul-01	5.9	-0.1	-1%
Jul-98 - Jul-99	292	26	10%	Jul-98 - Jul-99	6.6	0.6	10%
Jul-94 - Jul-95	294	28	11%	Jul-94 - Jul-95	6.6	0.6	11%
Jul-95 - Jul-96	295	29	11%	Jul-95 - Jul-96	6.6	0.6	11%
Jul-04 - Jul-05	300	34	13%	Jul-04 - Jul-05	6.8	0.8	13%
Jul-96 - Jul-97	311	45	17%	Jul-96 - Jul-97	7.0	1	17%
Jul-03 - Jul-04	374	108	41%	Jul-03 - Jul-04	8.4	2.4	41%
Mean load	**266**			**Mean load**	**6.0**		
Standard deviation	55			Standard deviation	1.2		
Median load	**278**			**Median load**	**6.26**		
	Standard load	Comparison to Mean			**Standard load**	Comparison to Mean	
Load Percentile		diff. t/y	% diff.	Load Percentile		diff. t/y	% diff.
0	182	-84	-32%	0	4.1	-1.9	-32%
10	209	-57	-21%	10	4.7	-1.3	-22%
20	224	-42	-16%	20	5.0	-1	-16%
30	226	-40	-15%	30	5.1	-0.9	-15%
40	243	-23	-9%	40	5.5	-0.5	-8%
50	278	12	5%	50	6.3	0.3	5%
60	293	27	10%	60	6.6	0.6	10%
70	295	29	11%	70	6.6	0.6	11%
80	299	33	12%	80	6.7	0.7	12%
90	310	44	17%	90	7.0	1	17%
100	374	108	41%	100	8.4	2.4	41%

Percentile values in Table 9, Figure 18 and Figure 19 show the distribution of annual Standard load limits based on flow for those water years. This table provides a description of the range of variation in Standard load limit over time and is useful for decision-makers to explore potential levels of achievement of the standard on an annual basis in the Mangatainoka River catchment.

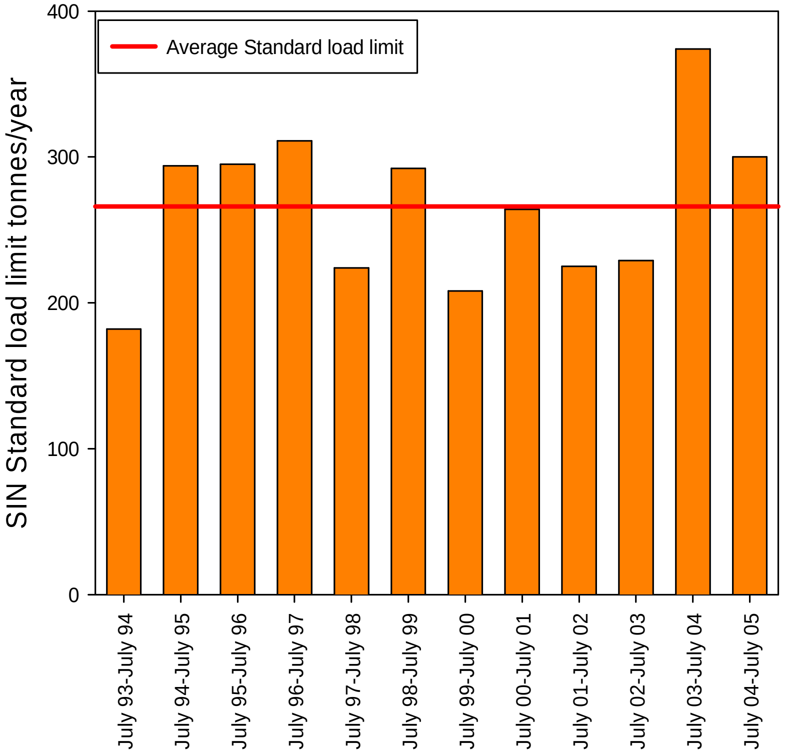


Figure 18: Annual variation in Soluble Inorganic Nitrogen (SIN) Standard load limit for the Mangatainoka at SH2 between 1993 and 2005.

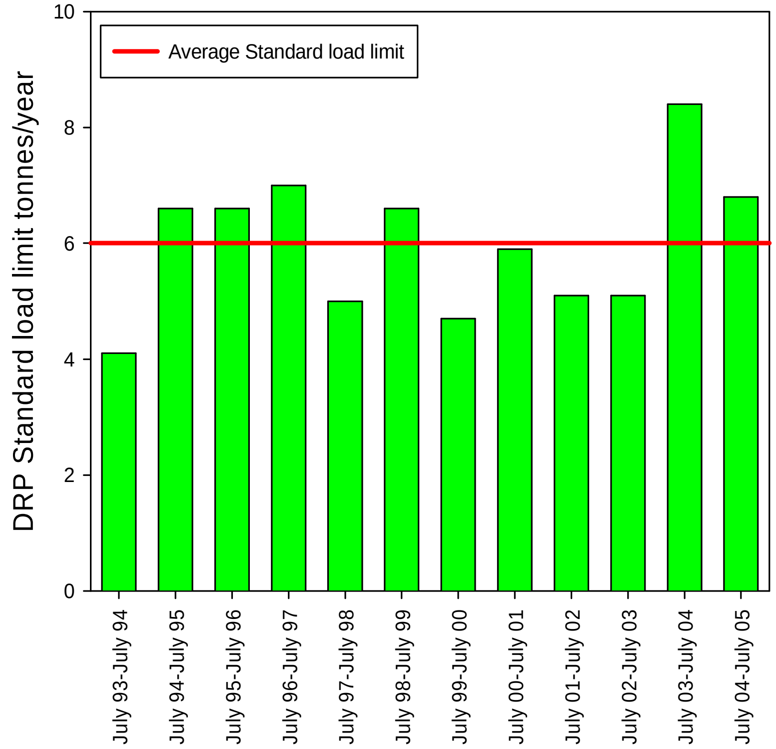


Figure 19: Annual variation in Dissolved Reactive phosphorus (DRP) Standard load limit for the Mangatainoka at SH2 between 1993 and 2005.

5.2.1 Removal of high flows from the Standard load limit for the Mangatainoka

Removal of the load of nutrient that corresponded to the concentration-based nutrient standard at flows exceeded 10% of the time (eg. column 2 of Table 10 & Table 11) reduced the Standard load limit for each year, although not to the same degree as in the Manawatu at Hopelands analysis. Thirty-eight percent of the average Standard load limit across all years (calculated from the concentration-based standard and the recorded flows) occurs in the highest flow decile (0 – 10^{th}), whilst only 4% of the average Standard load limit across all years occurs at flows equal to the 90^{th} exceedence percentile or less.

When Standard load limits for flows exceeded only 10% of the time were removed from the average Standard load limit across all years for the Mangatainoka at SH2, the average SIN Standard load limit dropped from 266 to 166 tonnes SIN/year. Removal of the load carried at flows exceeded 10 percent of the time caused the DRP average Standard load limit to drop from 6 to 3.7 tonnes DRP/year, a 38% decrease. Unlike the Manawatu at Hopelands site, the Mangatainoka at SH2 median Standard load limits were lower than the average Standard load limits for the higher flow decile categories, but lower for the median Standard load limit over all flows. This shows the importance of analysing every site individually to understand the implications of using the median or average Standard load limit statistic.

Flow stratification method

By stratifying the Standard load limit for the Mangatainoka at SH2 site by flow decile for each individual year, we can determine that flows below median (column 7 Table 10 and Table 11 and Figure 20) account for only 23% of the average Standard load limit. Examining the Standard load limit against flow decile also shows us that 8% of the Standard load limit could occur during the lowest 20% of flows. As mentioned above the practical applicability of removal these loads on an annual basis remains unresolved.

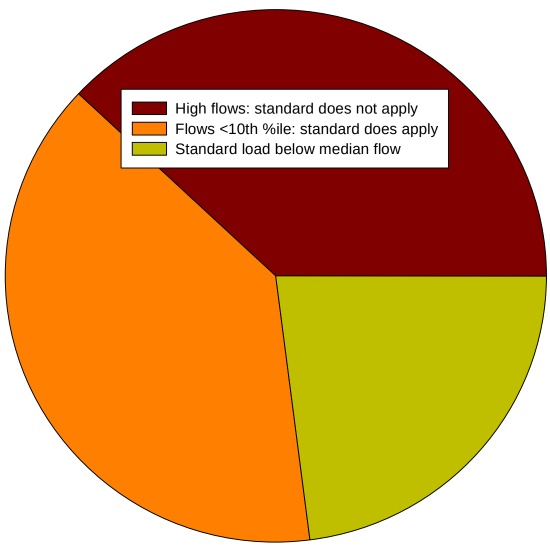


Figure 20: Proportion of Standard load limit (SIN and DRP) in relation to flow for the Mangatainoka at SH2.

Table 10: Soluble Inorganic Nitrogen (SIN) Standard load limits for flow in each percentile category measured at the Mangatainoka at SH2 monitoring site between 1993 and 2005. All loads are expressed as tonnes per year (t/y); flow percentile categories are expressed as flows that are exceeded for the specified percentage of time over the total period of record. *Note: highlighted cells are discussed within the text.*

Water Year	Standard load limits of SIN (t/y) for flow percentile categories											
	0-10th	**10th-20th**	**20th-30th**	**30th-40th**	**40th-50th**	**50th-60th**	**60th-70th**	**70th-80th**	**80th-90th**	**90th-100th**	**Standard load (t/y)** All Flows	**Standard load (t/y)** Flows less than 10th percentile
Jul-93 - Jul-94	60	19	18	14	12	9	9	14	14	11	182	121
Jul-94 - Jul-95	111	48	35	24	18	18	14	11	7	8	294	184
Jul-95 - Jul-96	81	70	48	28	18	13	10	9	9	10	295	214
Jul-96 - Jul-97	123	47	26	23	20	18	16	16	16	6	311	188
Jul-97 - Jul-98	67	29	24	19	18	13	13	13	13	14	223	157
Jul-98 - Jul-99	138	38	23	21	16	15	11	11	10	9	292	154
Jul-99 - Jul-00	58	30	19	16	17	13	13	11	17	13	208	150
Jul-00 - Jul-01	134	20	17	13	12	12	16	12	12	16	264	130
Jul-01 - Jul-02	69	34	23	17	12	13	11	16	14	16	225	156
Jul-02 - Jul-03	75	38	25	23	19	17	11	6	4	9	228	153
Jul-03 - Jul-04	178	52	38	23	23	19	13	11	9	9	374	197
Jul-04 - Jul-05	114	42	35	31	21	16	14	11	6	10	300	186
Median Standard load - All Years (t/y)	**96**	**38**	**24**	**22**	**18**	**14**	**13**	**11**	**11**	**10**	**278**	**156**
Average Standard load - All Years (t/y)	**100**	**39**	**28**	**21**	**17**	**15**	**13**	**12**	**11**	**11**	**266**	**166**
Percentage of Average Standard load - All Flows	38%	15%	10%	8%	6%	5%	5%	4%	4%	4%	100%	62%
Percentage of Average Standard load - this flow percentile category or less	100%	62%	48%	37%	29%	23%	17%	13%	8%	4%		

Table 11: Dissolved Reactive Phosphorus (DRP) Standard load limits for flow in each percentile category measured at the Mangatainoka at State Highway 2 (SH2) monitoring site between 1993 and 2005. All loads are expressed as tonnes per year (t/y); flow percentile categories are expressed as flows that are exceeded for the specified percentage of time over the total period of record. *Note: highlighted cells are discussed within the text.*

Water Year	Standard load limits of DRP (t/y) for flow percentile categories											
	0-10th	**10th-20th**	**20th-30th**	**30th-40th**	**40th-50th**	**50th-60th**	**60th-70th**	**70th-80th**	**80th-90th**	**90th-100th**	**Standard load (t/y)** All Flows	**Standard load (t/y)** Flows less than 10th percentile
Jul-93 - Jul-94	1.4	0.4	0.4	0.3	0.3	0.2	0.2	0.3	0.2	0.2	4.1	2.7
Jul-94 - Jul-95	2.5	1.1	0.8	0.5	0.4	0.4	0.3	0.2	0.2	0.2	6.6	4.1
Jul-95 - Jul-96	1.8	1.6	1.1	0.6	0.4	0.3	0.2	0.2	0.2	0.2	6.6	4.8
Jul-96 - Jul-97	2.8	1.1	0.6	0.5	0.5	0.4	0.4	0.3	0.1	0.1	7.0	4.2
Jul-97 - Jul-98	1.5	0.7	0.5	0.4	0.4	0.3	0.3	0.3	0.3	0.3	5.0	3.5
Jul-98 - Jul-99	3.1	0.9	0.5	0.5	0.4	0.3	0.3	0.3	0.2	0.2	6.6	3.5
Jul-99 - Jul-00	1.3	0.7	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	4.7	3.4
Jul-00 - Jul-01	3.0	0.5	0.4	0.3	0.3	0.3	0.4	0.3	0.4	0.4	5.9	2.9
Jul-01 - Jul-02	1.5	0.8	0.5	0.4	0.3	0.3	0.3	0.4	0.4	0.4	5.1	3.5
Jul-02 - Jul-03	1.7	0.8	0.6	0.5	0.4	0.4	0.3	0.1	0.2	0.2	5.1	3.5
Jul-03 - Jul-04	4.0	1.2	0.8	0.5	0.5	0.4	0.3	0.2	0.2	0.2	8.4	4.4
Jul-04 - Jul-05	2.6	0.9	0.8	0.7	0.5	0.4	0.3	0.2	0.2	0.2	6.8	4.2
Median Standard load - All Years (t/y)	**2.2**	**0.9**	**0.5**	**0.5**	**0.4**	**0.3**	**0.3**	**0.3**	**0.3**	**0.2**	**6.3**	**3.5**
Average Standard load - All Years (t/y)	**2.3**	**0.9**	**0.6**	**0.5**	**0.4**	**0.3**	**0.3**	**0.3**	**0.2**	**0.2**	**6.0**	**3.7**
Percentage of Average Standard load - All Flows	38%	15%	10%	8%	6%	5%	5%	4%	4%	4%	100%	62%
Percentage of Average Standard load - this flow percentile category or less	100%	62%	48%	37%	29%	23%	17%	13%	8%	4%		

The relationship between nutrient concentration standards, flow and Standard load limits: Mangatainoka at State Highway 2 Bridge

Three different SIN and DRP concentration standards were trialled as Standard load limits based on flow information for the Mangatainoka River at Pahiatua Town Bridge flow series. A comparison of the results for each year is displayed in the figures below. At the Mangatainoka River site, for every 0.001 g/m^3 increase in the concentration-based water quality standard there was an average Standard load limit increase of 0.6 tonnes/year. This is 75% less than the increase for the Manawatu at Hopelands site of 0.8 tonnes/year, reflecting the difference in mean flow between the two sites (ie. the mean flow of the Mangatainoka River measured at Pahiatua Town Bridge is 74.5% of the mean flow of the Manawatu River at Hopelands).

Table: A comparison of annual nutrient Standard load limits, calculated from potential concentration-based nitrogen and phosphorus standards and actual flow records from the Mangatainoka at SH2 Bridge site between 1993 and 2005.

	SIN standards g/m^3			DRP standards g/m^3		
	0.444	0.167	0.110	0.015	0.010	0.006
Water Year	Standard Load Limit (tonnes / year)					
Jul-93 - Jul-94	152	62	45	[illegible]	4.1	2.5
Jul-94 - Jun-95	294	111	73	9.9	6.6	4.0
Jul-95 - Jun-96	295	111	73	10.0	6.6	4.0
Jul-96 - Jun-97	[illegible]	117	77	10.5	7.0	4.2
Jul-97 - Jul-98	223	84	55	7.6	5.0	3.0
Jul-98 - Jun-99	292	110	72	9.9	6.6	3.9
Jul-99 - Jun-00	208	78	51	7.0	4.7	2.8
Jul-00 - Jun-01	264	99	65	8.9	5.9	3.6
Jul-01 - Jun-02	225	84	55	7.6	5.1	3.0
Jul-02 - Jul-03	225	86	57	7.7	5.1	[illegible]
Jul-03 - Jun-04	374	141	93	12.5	8.2	[illegible]
Jul-04 - Jun-05	300	113	74	10.1	6.6	[illegible]
Average Standard load limit (All years)	266	100	65	9.0	6.0	3.6
Median Standard load limit (All years)	275	105	69	9.4	6.3	3.8

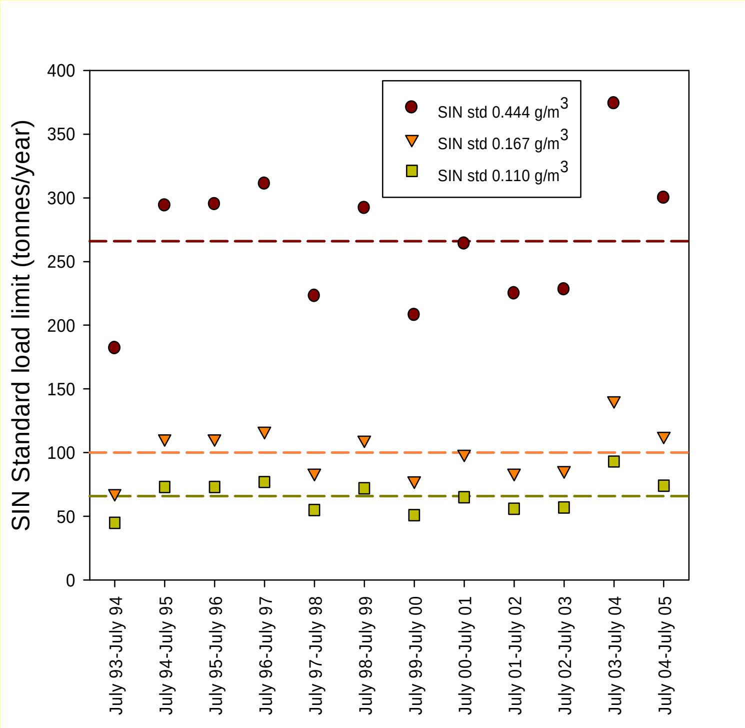


Figure: Comparison of potential Standard load limits for the Mangatainoka at SH2 based on varying concentration standards for SIN between 1993 and 2005. Dashed lines refer to the average Standard load limit relative to concentration standard (ie. Dark red = 0.444 gSIN/m^3, Orange = 0.167 g SIN/m^3 and Yellow = 0.110 g SIN/m^3).

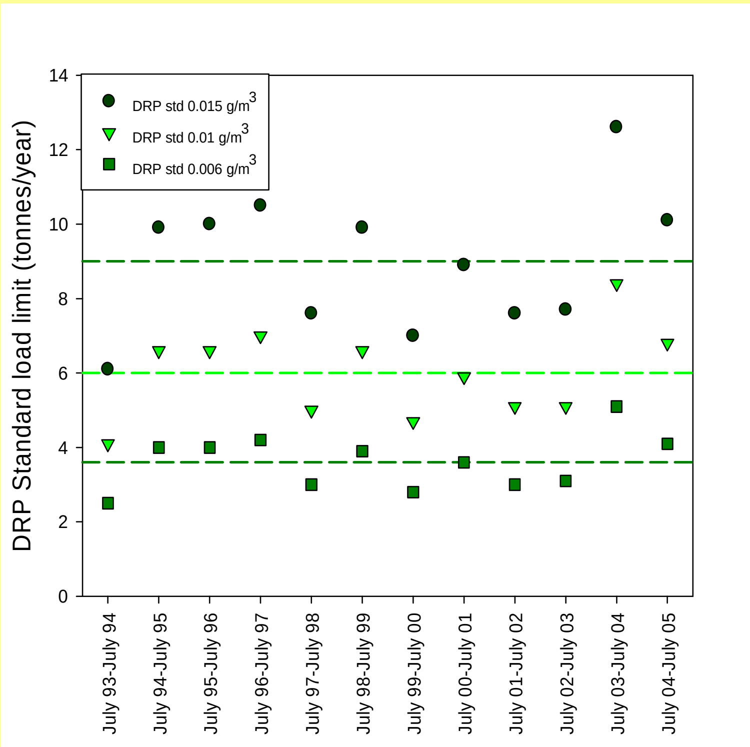


Figure: Comparison of potential Standard load limits for the Mangatainoka at SH2 based on varying concentration standards for DRP between 1993 and 2005. Dashed lines refer to the average Standard load limit relative to concentration standard (ie. Dark green = 0.015 gDRP/m^3, Light green = 0.010 g DRP/m^3 and Green = 0.006 g DRP/m^3).

5.3 Comparing Standard load limits to Measured loads for the Manawatu at Hopelands site

Between 1989 and 2005, the Measured SIN load (the sum of the annual averages for each flow decile category) for the Manawatu at Hopelands State of the Environment (SOE) site had a value of 745 tonnes/year for all flows (Table 12). This load was slightly more than twice the Standard load limit of 358 tonnes SIN/year (Figure 21). After removing the loads associated with the highest flow decile category (when the concentration standard does not apply), the average Measured load became 478 tonnes SIN/year (Table 12). Again, the Measured load is more than twice the Standard load limit of 211 tonnes SIN/year at flows less than the 10th percentile (Figure 21).

For the same period of record, the Measured DRP load at the Manawatu at Hopelands SOE site had an average value of 20.6 tonnes/year for all flows (Table 13). This load was more than two and a half times the Standard load limit of 8.1 tonnes DRP/year (Figure 22). After removing the loads associated with the highest flow decile category, (when the concentration standard does not apply), the average Measured load was 12.8 tonnes DRP/year (Table 13), more than 2.5 times the Standard load limit (Figure 22).

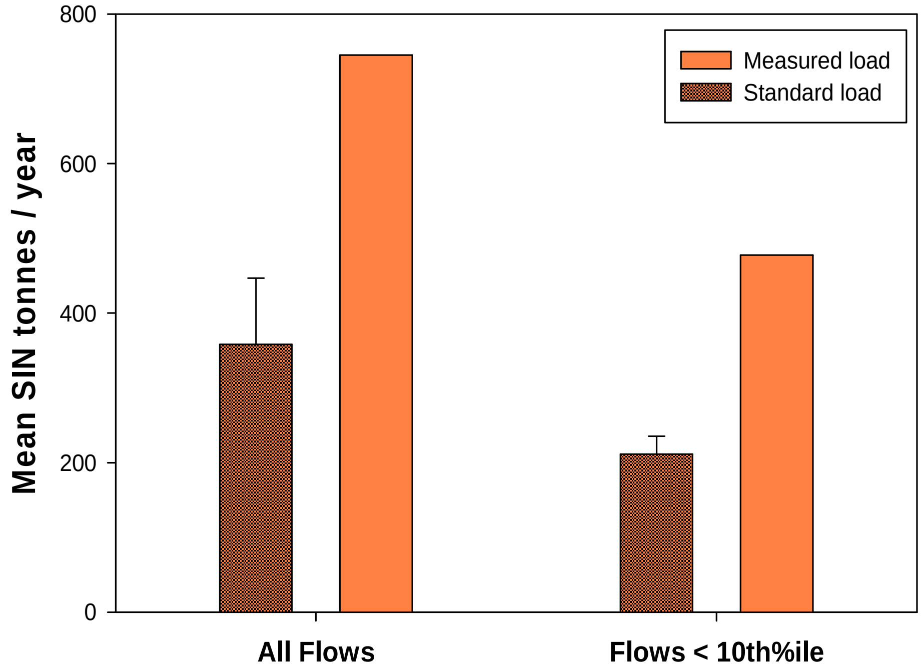


Figure 21: Comparison of Soluble Inorganic Nitrogen (SIN) Standard load limit and Measured load in tonnes/year at the Manawatu at Hopelands SOE site. Measured loads were calculated from grab samples analysed for SIN and continuous flow series data recorded between 1989 and 2005. Bars represent one standard deviation from the mean. Measured loads do not have error bars as they are sums of averages for each percentile of flow.

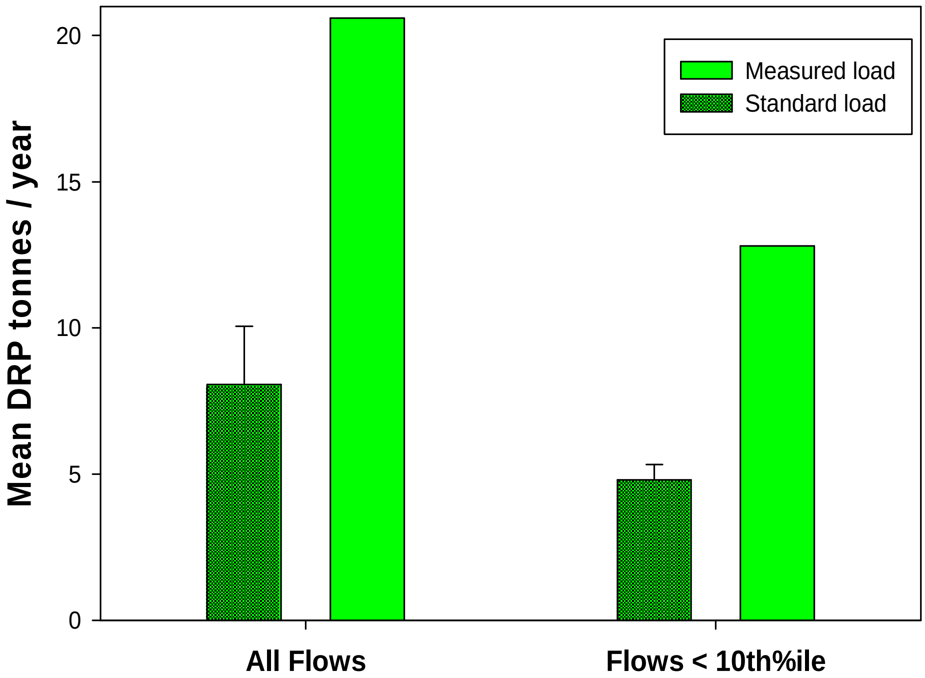


Figure 22: Comparison of Dissolved Reactive Phosphorus (DRP) Standard load limit and Measured load in tonnes/year at the Manawatu at Hopelands SOE site. Measured loads were calculated from grab samples analysed for DRP and continuous flow series data recorded between 1989 and 2005. Bars represent one standard deviation from the mean, Measured loads do not have error bars as they are sums of averages for each percentile of flow.

5.3.1 Comparing the Measured load and Standard load limit for flow deciles in the Manawatu

When the SIN Measured load was compared as a percentage of the Standard load limit for each flow decile category (Table 12 and Figure 23), the Measured load did not drop below the Standard load limit until flows dropped into the 90th percentile category. DRP Measured loads, when compared as a percentage of the Standard load limit for each flow decile category (Table 13 and Figure 24), never dropped below the Standard load limit and in fact increased in the lowest decile category. This suggests the processes driving the inputs of SIN and DRP in the upper Manawatu River at low flows may change from those at higher flows and supports the concepts of Parfitt *et al.* (2007) regarding the remineralisation of dissolved phosphorus from bed-deposited sediments.

Table 12: Comparison of Soluble Inorganic Nitrogen (SIN) Standard load limits and Measured loads recorded in the Manawatu River at Hopelands State of the Environment (SOE) monitoring site between 1989 and 2005. *Note: proposed SIN concentration-based standard used for all calculations is 0.444 g/m^3.*

Manawatu at Hopelands site		Flow percentile category											
	Units	**0-10th**	**10th-20th**	**20th-30th**	**30th-40th**	**40th-50th**	**50th-60th**	**60th-70th**	**70th-80th**	**80th-90th**	**90th-100th**	All flows	Flows less than 10th percentile
Flow[8]	m^3/s	49.496	32.653	24.289	19.106	15.4	12.422	9.9	7.712	5.439	2.005		
Mean Standard Load	**tonnes SIN/year**	**146.7**	**55.7**	**39.3**	**30.1**	**24.0**	**19.4**	**15.5**	**12.3**	**9.2**	**5.7**	**358**	**211.3**
Standard deviation (standard load)	tonnes SIN/year	72	20	10	5.4	4.1	3.9	4.7	2.7	3.2	4.4	89	24
Measured SOE results													
Maximum daily load	kg SIN/day	12345	4992	5446	3498	3020	1965	1565	1200	608	308		
Mean daily load	**kg SIN/day**	**7326**	**3267**	**2856**	**2096**	**1802**	**1258**	**821**	**519**	**339**	**129**		
Standard deviation (Measured load)	kg SIN/day	2833	1021	1221	742	746	495	307	327	170	89		
Median daily load	kg SIN/day	7082	3359	2727	1981	1980	1210	876	480	400	114		
Minimum daily load	kg SIN/day	658	1632	1061	876	410	468	195	72	105	7		
Number of samples		19	14	16	17	27	12	25	17	16	15	178	159
Days per year flow occurrence		36.5	36.5	36.5	36.5	36.5	36.5	36.5	36.5	36.5	36.5		
Maximum Measured load	tonnes SIN/year	450.6	182.2	198.8	127.7	110.2	71.7	57.1	43.8	22.2	11.2	1275.6	825
Mean Measured load	**tonnes SIN/year**	**267.4**	**119.2**	**104.3**	**76.5**	**65.8**	**45.9**	**30.0**	**18.9**	**12.4**	**4.7**	**745**	**478**
Standard deviation (Measured load)	tonnes SIN/year	103	37	45	27	27	18	11	12	6	3	n/a	n/a
Median Measured load	tonnes SIN/year	258.5	122.6	99.6	72.3	72.3	44.2	32.0	17.5	14.6	4.1	737.7	479.2
Minimum Measured load	tonnes SIN/year	24	59.6	38.7	32	15	17	7.1	2.6	3.8	0.3	200.1	176.1
Difference between Standard load and Measured load (Measured load – Standard load)													
Maximum Measured load – Standard load	tonnes SIN/year	303.9	126.5	159.4	97.6	86.2	52.3	41.6	31.5	13	5.5	917.6	613.6
Mean Measured load – Standard load	**tonnes SIN/year**	**120.7**	**63.6**	**64.9**	**46.4**	**41.8**	**26.5**	**14.4**	**6.6**	**3.2**	**-1.0**	**387.1**	**266.4**
Median Measured load – Standard load	tonnes SIN/year	111.8	66.9	60.2	42.2	48.3	24.7	16.5	5.2	5.4	-1.6	379.7	267.8
Minimum Measured load – Standard load	tonnes SIN/year	-122.7	3.9	-0.6	1.9	-9.0	-2.3	-8.4	-9.7	-5.4	-5.5	-157.8	-35.2
Measured load as percentage of Standard load (Measured load/Standard load)													
Maximum Measured load/Standard load	%	307	327	505	424	459	369	368	356	241	197	356	390
Mean Measured load/Standard load	**%**	**182**	**214**	**265**	**254**	**274**	**236**	**193**	**154**	**135**	**82**	**208**	**226**
Median Measured load/Standard load	%	176	220	253	240	301	227	206	142	159	72	206	227
Minimum Measured load/Standard load	%	16	107	98	106	62	88	46	21	42	5	56	83

[8] This is the lowest flow for each decile category, used to partition the Measured load data for each flow percentile bin.

Table 13: Comparison of Dissolved Reactive Phosphorus (DRP) Standard load limits and Measured loads recorded in the Manawatu River at Hopelands State of the Environment (SOE) monitoring site between 1989 and 2005. *Note: proposed DRP concentration-based standard used for all calculations is $0.01g/m^3$.*

Manawatu at Hopelands site		Flow percentile category											
	Units	**0-10th**	**10th-20th**	**20th-30th**	**30th-40th**	**40th-50th**	**50th-60th**	**60th-70th**	**70th-80th**	**80th-90th**	**90th-100th**	All flows	Flows less than 10th percentile
Flow[9]	m^3/s	49.496	32.653	24.289	19.106	15.4	12.422	9.9	7.712	5.439	2.005		
Mean Standard Load	**tonnes DRP/year**	**3.3**	**1.25**	**0.89**	**0.68**	**0.54**	**0.44**	**0.35**	**0.28**	**0.21**	**0.13**	**8.06**	**4.3**
Standard deviation (Standard load)	tonnes DRP/year	1.62	0.50	0.23	0.12	0.09	0.09	0.11	0.06	0.07	0.1	2.0	0.53
Measured SOE results													
Maximum daily load	kg DRP/day	657.3	224.8	134	71.7	62.7	49	47.4	32.5	37.8	39.8		
Mean daily load	**kg DRP/day**	**213.8**	**115.1**	**74**	**45.5**	**36.7**	**26.3**	**21.9**	**12.9**	**9.4**	**9.4**		
Standard deviation (Measured load)	kg DRP/day	140.8	51.7	28.6	12.0	12.0	13.9	12.8	10.2	9.1	9.3		
Median daily load	kg DRP/day	164.2	99.9	69.9	45.9	37.5	25.8	17.4	11.5	6.7	8.2		
Minimum daily load	kg DRP/day	98.1	61.9	23.5	26.9	14.5	2.7	1.7	2.1	1.6	0.4		
Number of samples		19	14	16	17	27	12	24	17	16	15	177	158
Days per year flow occurrence		36.5	36.5	36.5	36.5	36.5	36.5	36.5	36.5	36.5	36.5		
Maximum Measured load	tonnes DRP/year	24	8.2	4.9	2.6	2.3	1.8	1.7	1.2	1.4	1.5	49.5	25.5
Mean Measured load	**tonnes DRP/year**	**7.8**	**4.2**	**2.7**	**1.7**	**1.3**	**1.0**	**0.8**	**0.5**	**0.3**	**0.3**	**21**	**13**
Standard deviation (Measured load)	tonnes DRP/year	5.1	1.9	1.0	0.4	0.4	0.5	0.5	0.4	0.3	0.3	n/a	n/a
Median Measured load	tonnes DRP/year	6.0	3.6	2.5	1.7	1.4	0.9	0.6	0.4	0.2	0.3	17.8	11.8
Minimum Measured load	tonnes DRP/year	3.6	2.3	0.9	1.0	0.5	0.1	0.1	0.1	0.1	0.01	8.5	4.9
Difference between Standard load and Measured load (Measured load – Standard load)													
Maximum Measured load – Standard load	tonnes DRP/year	20.7	7.0	4.0	1.9	1.7	1.3	1.4	0.9	1.2	1.3	41.5	20.8
Mean Measured load – Standard load	**tonnes DRP/year**	**4.5**	**2.9**	**1.8**	**1.0**	**0.8**	**0.5**	**0.4**	**0.2**	**0.1**	**0.2**	**12.6**	**8.1**
Median Measured load – Standard load	tonnes DRP/year	2.7	2.4	1.7	1.0	0.8	0.5	0.3	0.1	0.0	0.2	9.7	7.0
Minimum Measured load – Standard load	tonnes DRP/year	0.3	1.0	0.0	0.3	0.0	-0.3	-0.3	-0.2	-0.1	-0.1	0.5	0.2
Measured load as percentage of Standard load (Measured load/Standard load)													
Maximum Measured load/Standard load	%	727	654	552	386	423	408	495	428	667	1127	614	537
Mean Measured load/Standard load	**%**	**236**	**335**	**305**	**245**	**248**	**219**	**229**	**170**	**166**	**266**	**256**	**269**
Median Measured load/Standard load	%	182	291	288	247	253	215	181	152	119	233	221	248
Minimum Measured load/Standard load	%	108	180	97	145	98	22	18	28	29	11	106	104

9 This is the lowest flow for each decile category, used to partition the Measured load data for each flow percentile bin.

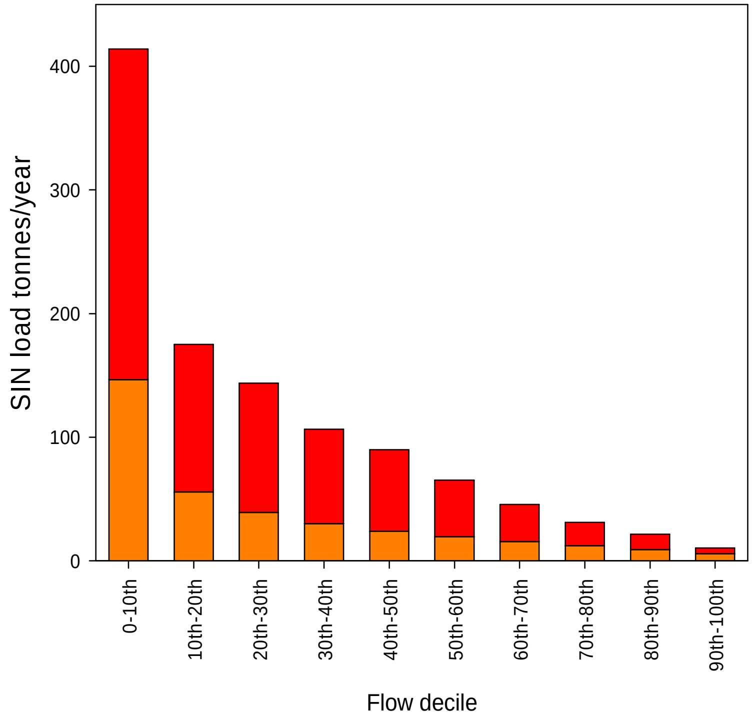


Figure 23: Comparison of Standard load limit (orange bar) (SIN) to Measured load (red bar) in tonnes/year by flow decile category for the upper Manawatu River at Hopelands between 1989 and 2005.

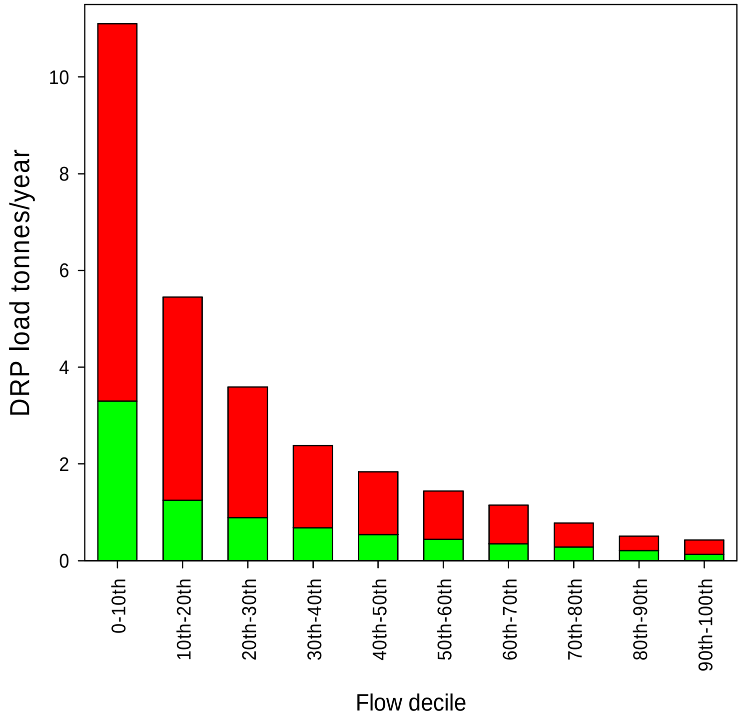


Figure 24: Comparison of Standard load limit (green bar) (DRP) to Measured load (red bar) in tonnes/year by flow decile category for the upper Manawatu River at Hopelands between 1989 and 2005.

5.4 Comparing Standard load limits to Measured loads for the Mangatainoka at SH2 site

Between 1993 and 2005, the Measured SIN load for the Manawatu at Hopelands State of the Environment (SOE) site had an average value of 603 tonnes/year for all flows (Table 14). This load was more than twice the Standard load limit of 266 tonnes SIN/year (Figure 25). After removing the loads associated with the highest flow decile category (when the concentration-based standard does not apply), the average Measured load became 401 tonnes SIN/year (Table 14). Again, the Measured load is approximately 2.5 times the Standard load limit of 166 tonnes SIN/year at flows less than the 10th percentile (Figure 25).

For the same period of record, the Measured DRP load at the Mangatainoka at SH2 SOE site had an average value of 9.3 tonnes/year for all flows (Table 15). This load was approximately 1.5 times the Standard load limit of 6 tonnes DRP/year (Figure 26). After removing the loads associated with the highest flow decile category, (when the concentration standard does not apply), the average Measured load was 4.5 tonnes DRP/year (Table 14), 1.2 times the Standard load limit of 3.7 tonnes/year (Figure 26).

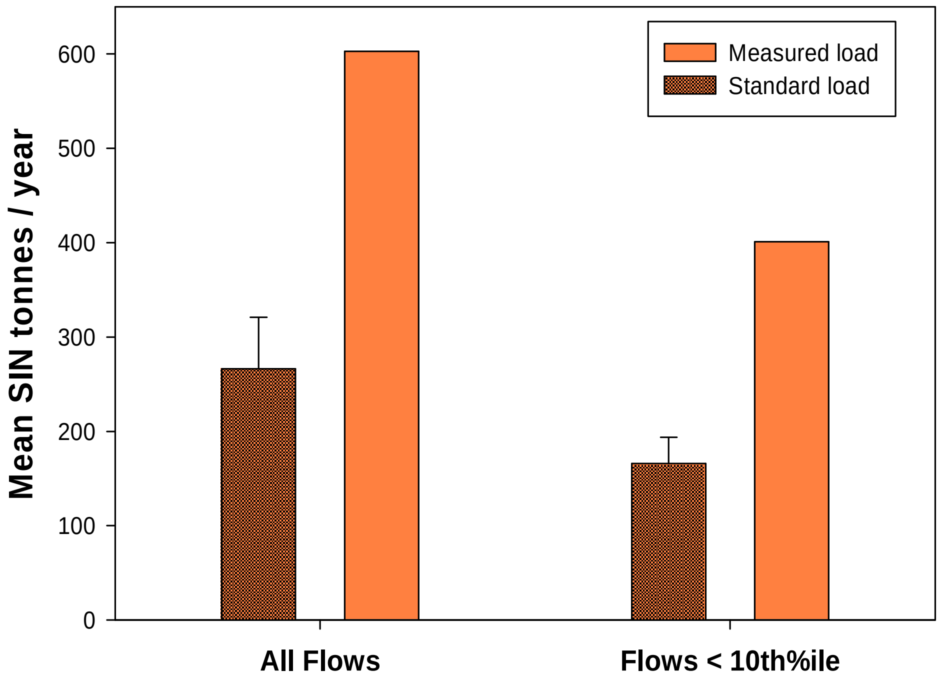


Figure 25: Comparison of Soluble Inorganic Nitrogen (SIN) Standard load limit and Measured load in tonnes/year at the Mangatainoka at SH2 SOE site. Measured loads were calculated from grab samples analysed for SIN and continuous flow series data recorded between 1993 and 2005. Bars represent one standard deviation from the mean. Measured loads do not have error bars as they are sums of averages for each percentile of flow.

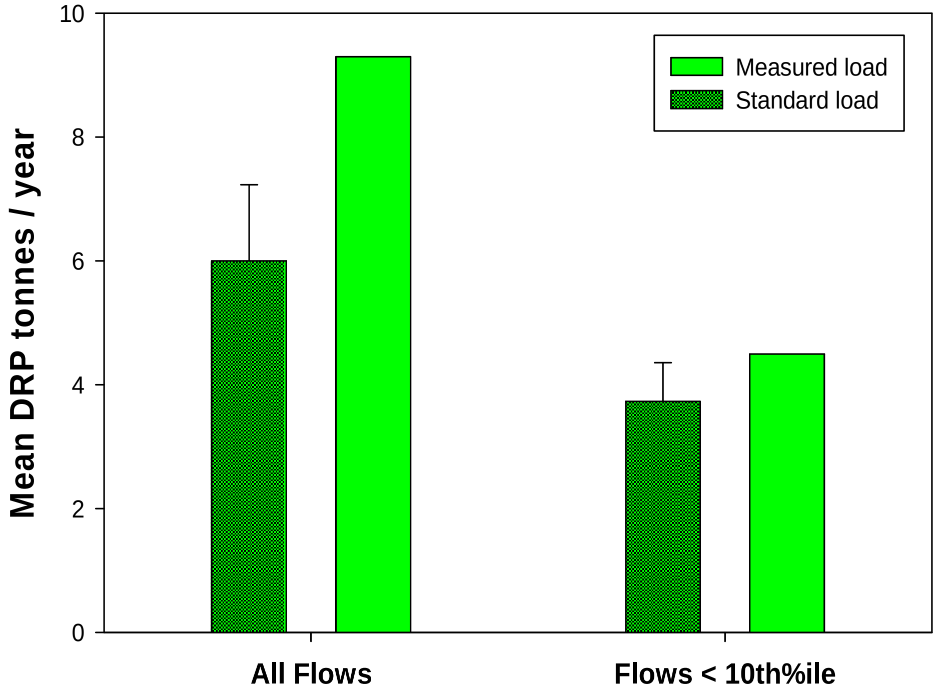


Figure 26: Comparison of Dissolved Reactive Phosphorus (DRP) Standard load limit and Measured load in tonnes/year at the Mangatainoka at SH2 SOE site. Measured loads were calculated from grab samples analysed for DRP and continuous flow series data recorded between 1993 and 2005. Bars represent one standard deviation from the mean. Measured loads do not have error bars as they are sums of averages for each percentile of flow.

5.4.1 Comparing the Measured load and Standard load limit for flow deciles in the Mangatainoka

When the SIN Measured load in the Mangatainoka was compared as a percentage of the Standard load limit for each flow decile category (Table 14 and Figure 27), the Measured load did not drop below the Standard load limit until flows dropped into the 90th percentile category, in a similar pattern to the upper Manawatu. DRP Measured loads, when compared as a percentage of the Standard load limit for each flow decile category (Table 15 and Figure 28), dropped below the Standard load limit for half of the flow decile categories (ie. the 30th-40th, 50th-60th, 70th-80th, 80th-90th and 90th-100th flow decile categories). This suggests the processes driving the inputs of DRP in the Mangatainoka River do not vary with flow as much as in the upper Manawatu River and that DRP loads vary about an average that is close to the Standard load limit over most of the flow series.

Table 14: Comparison of Soluble Inorganic Nitrogen (SIN) Standard load limits and Measured loads recorded in the Mangatainoka River at State Highway 2 Bridge (SH2) State of the Environment (SOE) monitoring site between 1993 and 2005. *Note: proposed SIN concentration-based standard used for all calculations is 0.444 g/m^3.*

Mangatainoka at SH2 site		Flow percentile category											
	Units	**0-10th**	**10th-20th**	**20th-30th**	**30th-40th**	**40th-50th**	**50th-60th**	**60th-70th**	**70th-80th**	**80th-90th**	**90th-100th**	All flows	Flows less than 10th percentile
Flow[10]	m^3/s	40.57	25.3	18	13.48	10.2	7.81	5.89	4.27	2.52	0.23		
Mean Standard Load	**tonnes SIN/year**	**100.5**	**38.94**	**27.6**	**21.18**	**17.2**	**14.6**	**12.6**	**11.7**	**11**	**11**	**266.3**	**165.8**
Standard deviation (Standard load)	tonnes SIN/year	38	14.1	9.2	5.4	3.8	3.2	2.2	2.9	4.1	3.3	54.5	27.8
Measured SOE results													
Maximum daily load	kg SIN/day	13714	5074	3754	2536	2285	1887	1228	949	568	310		
Mean daily load	**kg SIN/day**	**5532**	**3276**	**2017**	**1513**	**1419**	**934**	**728**	**570**	**331**	**196**		
Standard deviation (Measured load)	kg SIN/day	3195	1162	917	691	445	408	296	213	104	72		
Median daily load	kg SIN/day	4868	3299	1944	1247	1400	856	737	617	309	204		
Minimum daily load	kg SIN/day	1624	1718	698	671	464	508	98	166	152	69		
Number of samples		19	14	14	10	13	16	16	17	17	19	155	136
Days per year flow occurrence		36.5	36.5	36.5	36.5	36.5	36.5	36.5	36.5	36.5	36.5		
Maximum Measured load	tonnes SIN/year	500.5	185.2	137	92.5	83.4	68.9	44.8	34.6	20.7	11.3	1179.1	678.5
Mean Measured load	**tonnes SIN/year**	**201.9**	**119.6**	**73.6**	**55.2**	**51.8**	**34.1**	**26.6**	**20.8**	**12.1**	**7.2**	**603**	**401**
Standard deviation (Measured load)	tonnes SIN/year	116.6	42.4	33.5	25.2	16.2	14.9	10.8	7.8	3.8	2.6	n/a	n/a
Median Measured load	tonnes SIN/year	177.7	120.4	71	45.5	51.1	31.2	26.9	22.5	11.3	7.4	565	387.3
Minimum Measured load	tonnes SIN/year	59.3	62.7	25.5	24.5	16.9	18.5	3.6	6.1	5.5	2.5	225.1	165.9
Difference between Standard load and Measured load (Measured load – Standard load)													
Maximum Measured load – Standard load	tonnes SIN/year	400	146.3	109.5	71.4	66.2	54.2	32.2	23	9.7	0.4	912.8	512.7
Mean Measured load – Standard load	**tonnes SIN/year**	**101.4**	**80.6**	**46**	**34**	**34.6**	**19.5**	**13.9**	**9.1**	**1.1**	**-3.8**	**336.5**	**235.1**
Median Measured load – Standard load	tonnes SIN/year	77.2	81.5	43.4	24.3	33.9	16.6	14.3	10.8	0.3	-3.5	298.7	221.5
Minimum Measured load – Standard load	tonnes SIN/year	-41.2	23.8	-2.1	3.3	-0.3	3.9	-9.1	-5.6	-5.5	-8.4	-41.2	0
Measured load as percentage of Standard load (Measured load/Standard load)													
Maximum Measured load/Standard load	%	498	476	497	437	484	470	355	297	188	103	443	409
Mean Measured load/Standard load	**%**	**201**	**307**	**267**	**261**	**301**	**233**	**210**	**178**	**110**	**65**	**226**	**242**
Median Measured load/Standard load	%	177	309	257	215	297	213	213	193	102	68	212	234
Minimum Measured load/Standard load	%	59	161	92	116	98	127	28	52	50	23	85	100

10 This is the lowest flow for each decile category, used to partition the Measured load data for each flow percentile bin.

Table 15: Comparison of Dissolved Reactive Phosphorus (DRP) Standard load limits and Measured loads recorded in the Mangatainoka River at State Highway 2 Bridge (SH2) State of the Environment (SOE) monitoring site between 1993 and 2005. *Note: proposed DRP concentration-based standard used for all calculations is 0.01g/m^3.*

Mangatainoka at SH2 site		Flow percentile category											
	Units	**0-10th**	**10th-20th**	**20th-30th**	**30th-40th**	**40th-50th**	**50th-60th**	**60th-70th**	**70th-80th**	**80th-90th**	**90th-100th**	All flows	Flows less than 10th percentile
Flow[11]	m^3/s	40.57	25.3	18	13.48	10.2	7.81	5.89	4.27	2.52	0.23		
Mean Standard Load	**tonnes DRP/year**	**2.26**	**0.88**	**0.62**	**0.48**	**0.39**	**0.33**	**0.28**	**0.26**	**0.25**	**0.25**	**6.0**	**3.73**
Standard deviation (Standard load)	tonnes DRP/year	0.86	0.32	0.21	0.12	0.09	0.07	0.05	0.06	0.09	0.08	1.23	0.63
Measured SOE results													
Maximum daily load	kg DRP/day	445.5	114.3	205.1	15.7	19.7	12.7	29.3	14.9	8.0	19.5		
Mean daily load	**kg DRP/day**	**131.2**	**43.3**	**32.7**	**10.4**	**10.9**	**6.9**	**8.5**	**3.9**	**2.8**	**3.4**		
Standard deviation (Standard load)	kg DRP/day	114	27	51	4	4	3	8	3	2	5		
Median daily load	kg DRP/day	87.2	44.9	32.7	10.4	10.9	6.9	8.5	3.9	2.8	3.4		
Minimum daily load	kg DRP/day	21.8	5.9	3.8	4.1	6.3	2.3	2.8	1.2	0.7	0.3		
Number of samples		19	13	14	10	13	16	16	17	17	19	154	135
Days per year flow occurrence		36.5	36.5	36.5	36.5	36.5	36.5	36.5	36.5	36.5	36.5		
Maximum Measured load	tonnes DRP/year	16.3	4.2	7.5	0.6	0.7	0.5	1.1	0.5	0.3	0.7	32.3	16.0
Mean Measured load	**tonnes DRP/year**	**4.8**	**1.6**	**1.2**	**0.4**	**0.4**	**0.3**	**0.3**	**0.1**	**0.1**	**0.1**	**9.3**	**4.5**
Standard deviation (Standard load)	tonnes DRP/year	4.2	1.0	1.8	0.1	0.1	0.1	0.3	0.1	0.1	0.2	n/a	n/a
Median Measured load	tonnes DRP/year	3.2	1.6	0.7	0.4	0.4	0.2	0.2	0.1	0.1	0.1	6.9	3.8
Minimum Measured load	tonnes DRP/year	0.8	0.2	0.1	0.1	0.2	0.1	0.1	0	0	0	1.8	1.0
Difference between Standard load and Measured load (Measured load – Standard load)													
Maximum Measured load – Standard load	tonnes DRP/year	14	3.3	6.9	0.1	0.3	0.1	0.8	0.3	0	0.5	26.3	12.3
Mean Measured load – Standard load	**tonnes DRP/year**	**2.5**	**0.7**	**0.6**	**-0.1**	**0**	**-0.1**	**0**	**-0.1**	**-0.1**	**-0.1**	**3.3**	**0.7**
Median Measured load – Standard load	tonnes DRP/year	0.9	0.8	0.1	-0.1	0	-0.1	-0.1	-0.2	-0.2	-0.2	0.9	0
Minimum Measured load – Standard load	tonnes DRP/year	-1.5	-0.7	-0.5	-0.3	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-4.2	-2.7
Measured load as percentage of Standard load (Measured load/Standard load)													
Maximum Measured load/Standard load	%	718	476	1205	120	186	140	376	207	118	288	538	429
Mean Measured load/Standard load	**%**	**212**	**180**	**192**	**80**	**103**	**76**	**109**	**55**	**41**	**50**	**155**	**120**
Median Measured load/Standard load	%	141	187	109	76	97	72	75	36	33	30	116	101
Minimum Measured load/Standard load	%	35	25	23	31	59	25	36	16	11	4	30	27

[11] This is the lowest flow for each decile category, used to partition the Measured load data for each flow percentile bin.

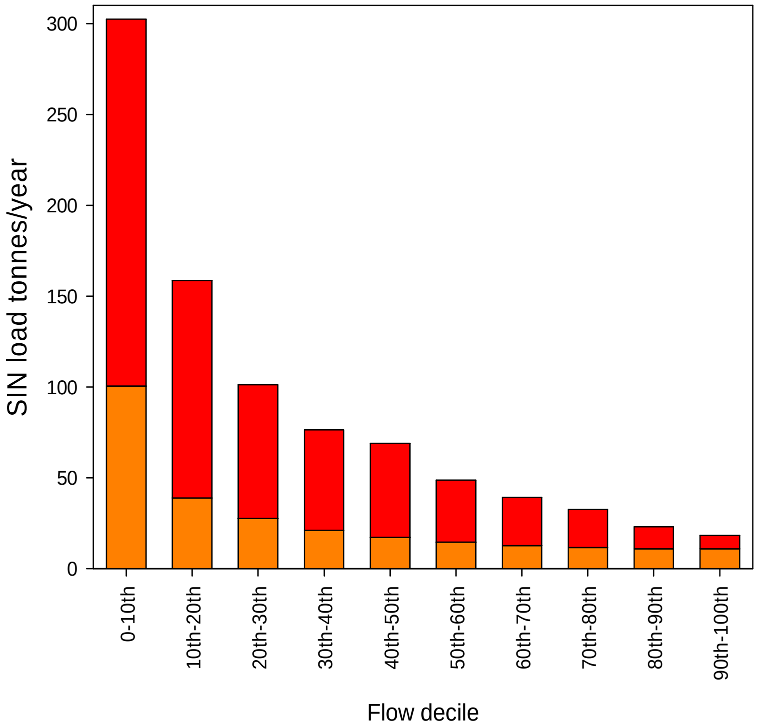


Figure 27: Comparison of Standard load limit (orange bar) (SIN) to Measured load (red bar) in tonnes/year by flow decile category for the Mangatainoka River at SH2 between 1993 and 2005.

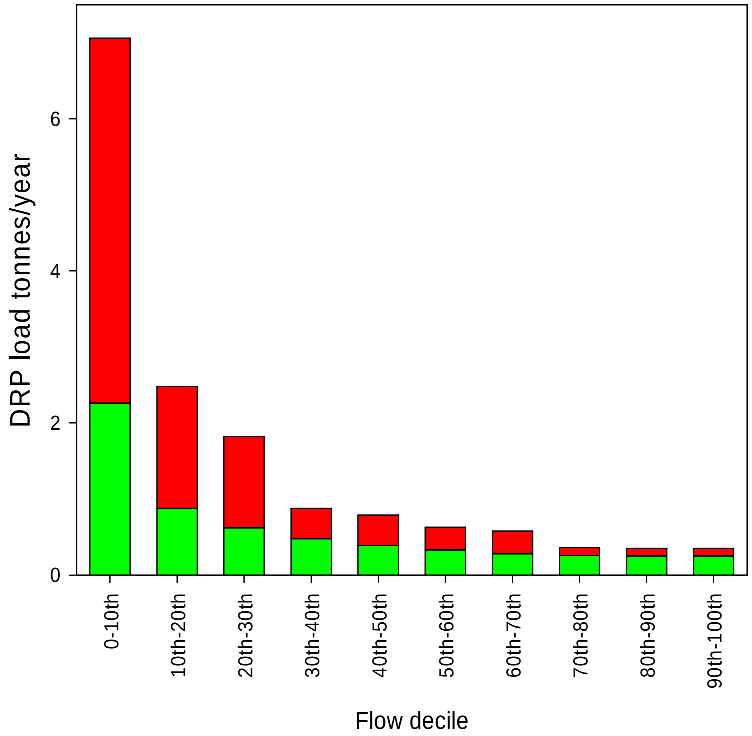


Figure 28: Comparison of Standard load limit (green bar) (DRP) to Measured load (red bar) in tonnes/year by flow decile category for the Mangatainoka River at SH2 between 1993 and 2005.

Summary of Manawatu and Mangatainoka Standard and Measured load results

- In the Manawatu at Hopelands the annual Standard load (for both SIN and DRP) varied from 45% below to 54% above the average Standard load across all years, depending on the variation in the annual flow for each year. The annual variation above and below the average Standard load (across all years) was less in the Mangatainoka River, varying between 32% below and 41% above the average Standard load from year to year.

- In the Manawatu River at Hopelands, 41% of the average Standard load (for both SIN and DRP) occurred at flows greater than the 10^{th} percentile of exceedence (the highest 10% of flows) and only 17% of the standard load occurred at flows less than median, with 2% occurring within the 90^{th} percentile (lowest flow) category. In the Mangatainoka at SH2 38% of the Standard load occurred at the highest flows, 23% of the Standard load occurred at flows less than median and 4% occurred at the lowest flows. Changes in the Standard load between these sites reflected the differences in flow regime of the two study catchments.

- For every 0.001 g/m^3 increase in the concentration-based water quality standard for either SIN or DRP in the Manawatu at Hopelands, 0.9 tonnes/year was added to the Standard load. In the Mangatainoka the same concentration increase resulted in a Standard load increase of 0.6 tonnes/year.

- The Measured load of SIN in the Manawatu at Hopelands was more than twice the Standard load over all flows and at flows less than the 10^{th} decile. Measured DRP load was two and a half times the Standard load for both flow scenarios.

- In the Mangatainoka at SH2, the Measured SIN load was twice the Standard load under both flow scenarios; however, the Measured DRP load was only 150% of the Standard load at all flows. When the highest flow decile loads were removed the Measured DRP load was very near the Standard load.

- When the Measured load was compared to the Standard load within each flow decile bin, SIN and DRP in the Manawatu at Hopelands changed dramatically at low flows. SIN decreased below the Standard load and DRP increased as flows dropped.

- In the Mangatainoka River when Measured loads were compared to Standard loads for each flow decile bin, SIN exhibited a similar pattern to the Manawatu at Hopelands but DRP behaved completely differently, varying both above and below the Standard load within 50% of the decile bins.

6. Calculating the relative inputs of NPS and PS nutrients

6.1 Relative contributions of NPS and PS nutrients to Measured loads

Ledein *et al.* (2007) used 'summer' water quality and flow data from October to May between 2000 and 2003 to trial a range of methods for estimating annual loads of N and P in waterways (the Manawatu above Hopelands case study from Ledein *et al.,* 2007 is appended). Although limited by short time-frames and localised data sets, the key recommendation from Ledein *et al.* (2007) was the requirement for the management of both PS and NPS inputs to reduce total catchment nutrient loads.

From a policy perspective, the One Plan has adopted an output-based model (Overseer®) to manage NPS nutrient contributions to water quality, rather than input-based restrictions on nutrient application to farms.

To link NPS nutrient *losses* directly to water quality outcomes in tonnes of nutrient per year, Clothier *et al.* (2007) determined nutrient export coefficients, based on modelled farm outputs using Overseer® nutrient budgeting, specified for local conditions. Sheep and beef and dairy farms were both modelled, the aims being to determine the proportional NPS nutrient losses from different land uses, and to identify numerical loss targets that could be achieved using best farming practices.

Linking the Clothier *et al.,* (2007) project to the Framework for Managing NPS and PS Nutrients Project (this study) were three key estimates of nutrient enrichment state:

1. the annual average Standard load limit calculated from concentration-based nutrient standards;
2. an accurate estimate of the annual average Measured nutrient load; and
3. the proportion of the Measured nutrient load attributable to NPS.

Once steps 1 and 2 above were completed, determining the relative NPS and PS nutrient contributions to the Measured load required an accurate estimate of PS contributions of N and P on the same annual scale as the NPS contributions, the theory being that the Measured load minus the point source load should approximate the NPS load. Again, separating the data by flow decile category provided the means to examine relative contributions of nutrients on different input scales (ie. daily PS inputs vs. annual NPS inputs). This was an important component of the framework as the relative inputs from various sources and nutrient transfer mechanisms can change markedly with flow.

6.1.1 Assumptions and limitations of determining NPS and PS nutrient contributions

Attenuation, assimilation, remobilisation or storage of PS nutrient inputs within the river system were not factored into the calculations, nor were time or flow lags between discharge points and monitoring sites, potentially underestimating NPS inputs and overestimating PS discharges. To clarify, the Measured load at the State of the Environment monitoring site may be lower than the load discharged to the river from PS due to in-river attenuation processes. The methods which follow are limited by the assumption that no in-stream attenuation occurred between discharge site and SOE measurement site.

The scope of this report also does not extend to identifying which factors contributed to the total NPS inputs, including the potential for natural nutrient inputs from bed rock. For more information on relative NPS inputs from various sources see Clothier *et al.,* 2007.

No calculation of landscape attenuation, remobilisation, or storage of nutrients has been included in this report. It is therefore assumed that the actual exports on a per hectare basis from the source of the nutrient are higher than the NPS loads calculated from data recorded in the river. The speciation of nitrogen and phosphorus exported from farming systems was also not considered. Only soluble (and thereby immediately bio-available) forms of nitrogen and phosphorus have been analysed. The lag time of nutrient transport between landscape and waterway will vary considerably for each catchment; this variation may be reduced by the calculation of loads for different flows over the longest record available, averaged to annual figures.

6.2 Calculating PS inputs

The estimation of PS inputs was undertaken in a similar way to the calculation of the Measured load from the State of the Environment data by comparing the Measured loads upstream and downstream of discharges. Since July 2007, Horizons has undertaken water quality monitoring upstream and downstream of major PS discharges on the same day as the State of the Environment sample collection to accurately determine PS contributions to Measured loads at SOE sites, on the same day and under the same flow conditions. This approach to monitoring was only initiated in July 2007 and thus not enough data was collected at the time of writing to contribute to the PS load calculations used within this report. In future, Measured PS and SOE load calculations should benefit from a consistent monitoring approach.

Dairy shed effluent discharges to water are not monitored for compliance in the same manner as other point source discharges in that few upstream and downstream samples have been collected for each discharge. To examine the cumulative impact of dairy effluent discharges to water and to determine whether these discharges contribute a significant proportion of nitrogen and phosphorus to Measured loads, an estimate of nutrient loads from these discharges was required. The methods used to estimate these loads for the upper Manawatu and Mangatainoka catchments are explained below.

6.2.1 Calculating a load for dairy shed effluent discharges to water in the upper Manawatu

In the upper Manawatu study catchment there were 58 consented dairy shed effluent discharges to water in 1993 (Figure 29). This reduced to a total of seven in 2006, largely as a result of policy-driven changes through the rules in the Manawatu Catchment Water Quality Regional Plan (1999) and the Regional Land and Water Plan (2003) (McArthur & Clark, 2007).

To estimate the soluble nitrogen and phosphorus loads from dairy effluent discharges to water, the number of discharge consents and the maximum daily discharge volume were used. These loads should be used with caution due to the potential variation in daily discharge volumes on an annual timescale, and the possible difference in actual volume of discharged effluent from the maximum daily volumes documented within consents.

The cumulative load was determined by summing the maximum consented discharge volume for all dairy effluent consents in the study catchment (Figure 30) and multiplying this volume by typical dairy shed effluent concentrations of soluble nitrogen (110 g SIN/m^3) and phosphorus (20 g DRP/m^3) (Hickey *et al.,* 1989; Bolan, 2004). This follows the same method used by McArthur & Clark (2007) to examine daily nutrient loads from dairy effluent discharge to water in the Manawatu catchment. The estimated maximum daily loads for discharges upstream of Hopelands were then converted to annual nutrient loads (Figure 31 and Figure 32) for comparison with Measured loads.

Dairy effluent loads upper Manawatu

The number of dairy effluent discharge consents (Figure 29), and thereby volume (Figure 30) and load estimates, peaked at 16.2 tonnes SIN/year and 2.9 tonnes DRP/year in 1998. By 2006 these estimates reduced to 2.1 tonnes SIN/year and 0.4 tonnes DRP/year (Figure 31 and Figure 32), reflecting the considerable decrease in dairy effluent discharges to water by this time.

Accurate dairy discharge consent information was only available from 1993 as discharge permits issued under the Resource Management Act (1991) were only initiated at this time. To compare this with the same timescale used to calculate the Measured or Standard load limits for the upper Manawatu (1989–2005), it was assumed that the number and volume of dairy effluent discharges to water was constant from 1989 to 1993. Using this approach the average annual nutrient load from dairy shed effluent between 1989 and 2005 was calculated to be 12.3 tonnes SIN/year and 2.2 tonnes DRP/year.

Averaging the loads over this timeframe does not accurately portray the annual input from dairy discharges to water, but does allow for comparisons with long-term Measured loads in the river over the same time period, and should only be used for this purpose.

As a proportion of the SIN load at Hopelands, the estimated dairy effluent load of 12.3 tonnes/year was 1.7% of the Measured SIN load (745 tonnes/year Table 12). As a proportion of the DRP load at Hopelands, the estimated dairy effluent load of 2.2 tonnes/year was 10% of the Measured DRP load (21 tonnes/year Table 13).

6.2.2 Calculating a load for dairy shed effluent discharges to water in the Mangatainoka

In the Mangatainoka study catchment there were 39 consented dairy shed effluent discharges to water in 1993 (Figure 33). This reduced to a total of five in 2006 for the same reasons outlined above for the upper Manawatu catchment. Using the same calculation methods, estimates of dairy effluent discharge load to water were calculated from the maximum consented volumes shown in Figure 34.

The number of dairy effluent discharge consents, and thereby volume and load estimates, peaked at 18.4 tonnes SIN/year and 3.4 tonnes DRP/year in 1998. By 2005 these estimates reduced to 2.8 tonnes SIN/year and 0.5 tonnes DRP/year, reflecting the considerable decrease in dairy effluent discharges to water by this time (Figure 35 and Figure 36).

The time period for the estimation of nutrient loads from dairy effluent discharges was consistent with the timescale used to calculate the Measured and Standard load limits for the Mangatainoka, except for the last year of record. Again the loads were averaged over the 1993 to 2005 period for comparison with Measured nutrient loads in the Mangatainoka catchment.

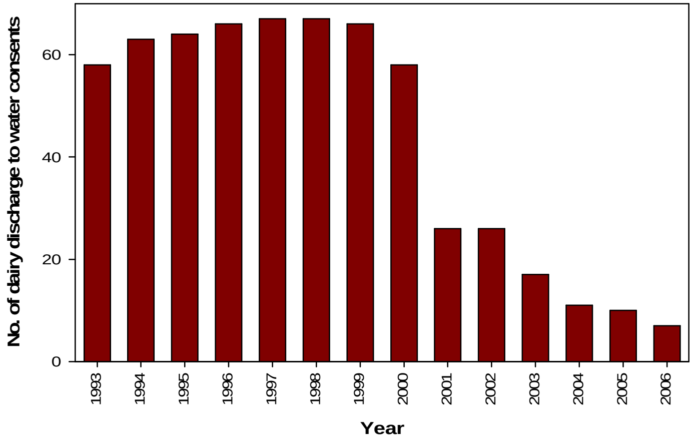
Dairy effluent loads Mangatainoka

The average annual nutrient load from dairy shed effluent between 1993 and 2005 was 12.4 tonnes SIN/year and 2.3 tonnes DRP/year. As a proportion of the SIN load in the Mangatainoka River at SH2, the estimated dairy effluent load of 12.4 tonnes/year was 2.1% of the Measured SIN load (603 tonnes/year Table 14). As a proportion of the DRP load at the SH2 site, the estimated dairy effluent load of 2.3 tonnes/year was 25% of the Measured DRP load (9.3 tonnes/year Table 15).

The larger estimated dairy effluent contribution to Measured loads of soluble nitrogen and phosphorus in the Mangatainoka catchment, when compared with the Manawatu above Hopelands catchment, reflects the greater degree of intensification of dairying in the Mangatainoka. The average discharge volume in the Mangatainoka between 1993 and 2006 was 293m^3/day, whereas in the Manawatu upstream of Hopelands the average discharge volume over the same time period was only 274 m^3/day. The larger nutrient loads and dairy effluent discharge volumes may be a result of the greater proportion of the catchment in dairying land usage in the Mangatainoka. According to Clark & Roygard (2008), 27% of the total catchment area of the Mangatainoka River is in dairying, compared to only 16.2% of the total area of the upper Manawatu catchment upstream of the Hopelands monitoring site.

6.2.3 Dairy effluent: a NPS contributor to nutrient loads

Because of the potential for inaccuracies in the estimated dairy effluent discharges loads, and the significant reduction in the number of consents directly discharging to water since 2000, dairy effluent was treated as a NPS contribution for the remainder of the analyses in this report.



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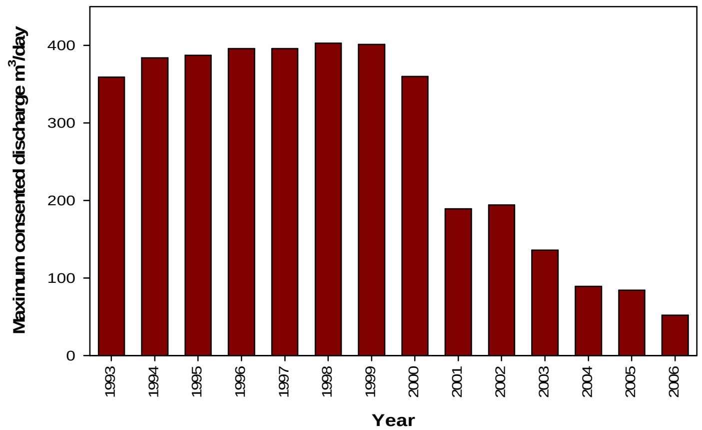

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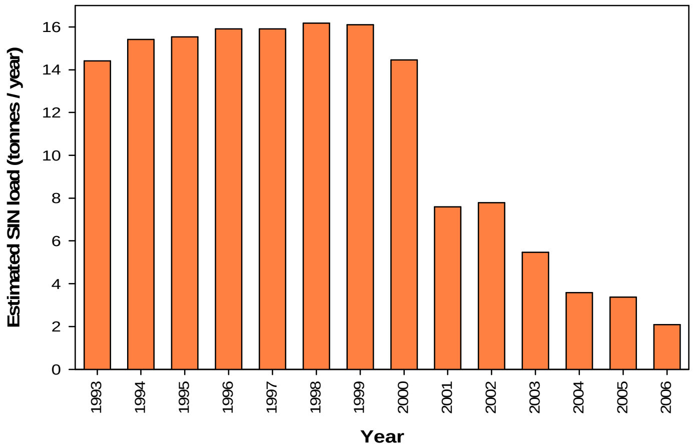

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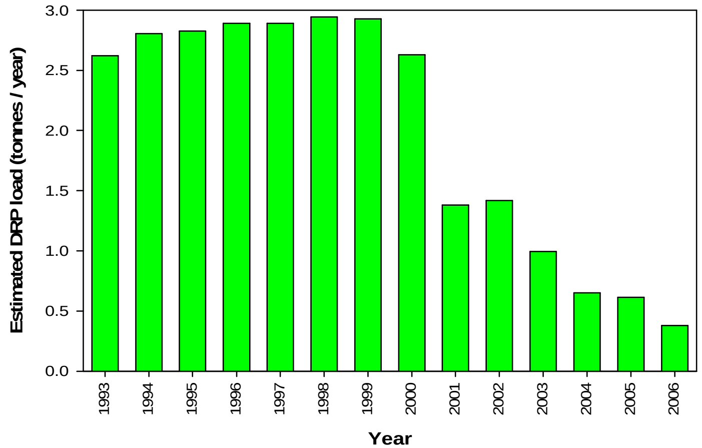

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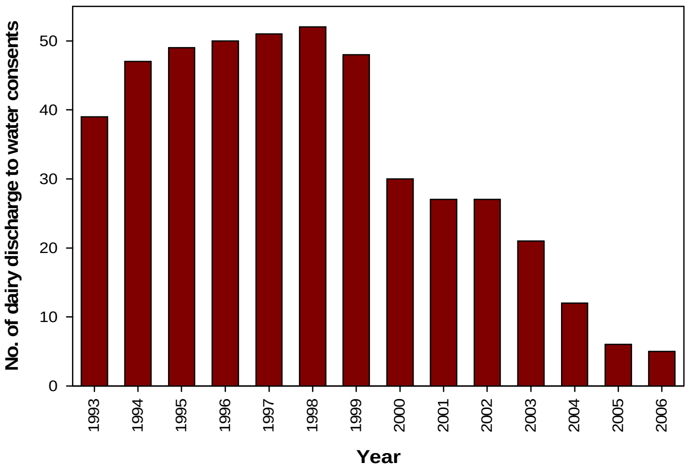
Figure 29: Number of consented dairy effluent discharges to water upstream of the Manawatu at Hopelands SOE monitoring site between 1993 and 2006.

Figure 30: Sum of maximum volume of consented dairy effluent discharges to water (m^3/day) upstream of the Manawatu at Hopelands SOE monitoring site between 1993 and 2006.

Figure 31: Estimated maximum loads of Soluble Inorganic Nitrogen (SIN) from consented dairy effluent discharges to water upstream of the Manawatu at Hopelands SOE monitoring site between 1993 and 2006.

Figure 32: Estimated maximum loads of Dissolved Reactive Phosphorus (DRP) from consented dairy effluent discharges to water upstream of the Manawatu at Hopelands SOE monitoring site between 1993 and 2006.



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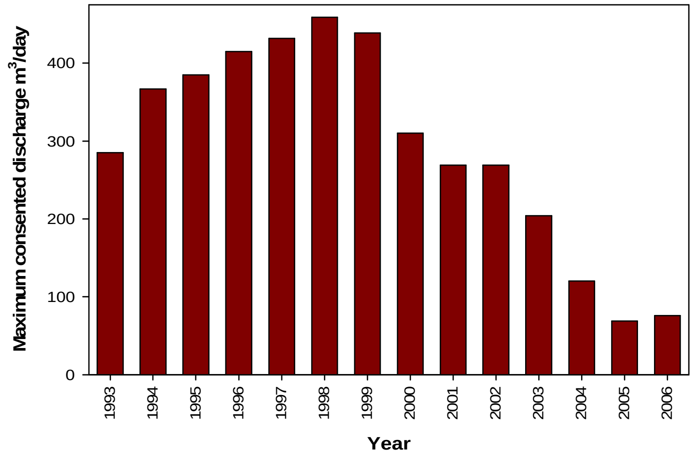

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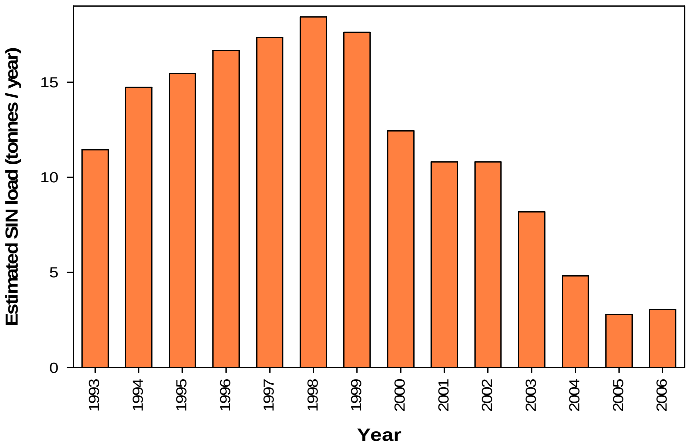

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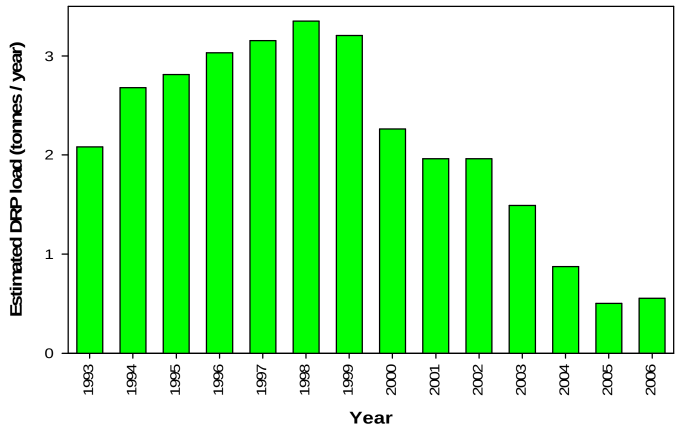

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Figure 33: Number of consented dairy effluent discharges to water in the Mangatainoka River catchment between 1993 and 2006.

Figure 34: Sum of maximum volume of consented dairy effluent discharges to water (m^3/day) in the Mangatainoka River catchment between 1993 and 2006. *(Note: increase in consented volume over the catchment but decrease in number of consents).*

Figure 35: Estimated maximum loads of Soluble Inorganic Nitrogen (SIN) from consented dairy effluent discharges to water in the Mangatainoka River catchment between 1993 and 2006.

Figure 36: Estimated maximum loads of Dissolved Reactive Phosphorus (DRP) from consented dairy effluent discharges to water in the Mangatainoka River catchment between 1993 and 2006.

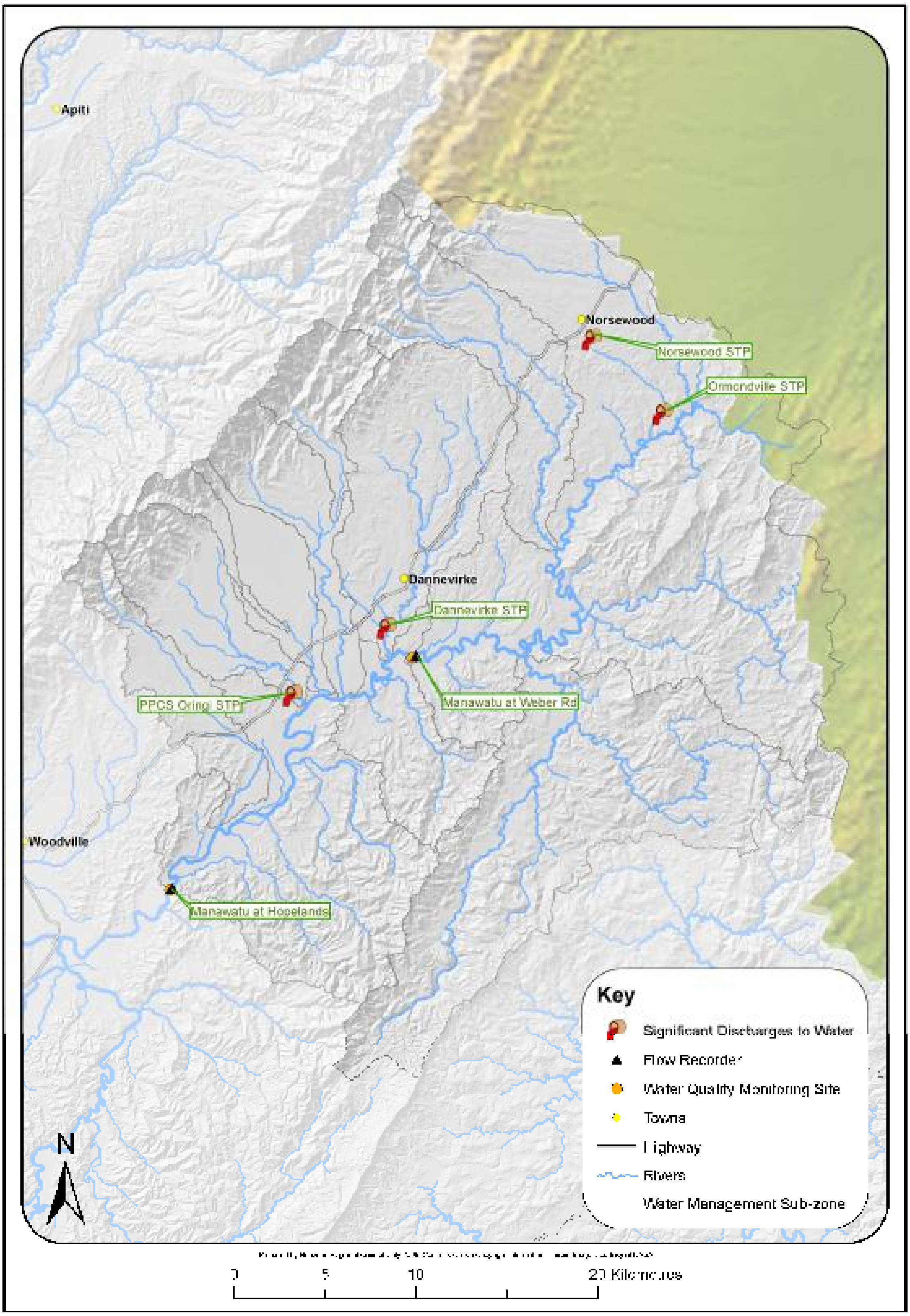
6.3 Significant PS discharges in the upper Manawatu

The upper Manawatu catchment contains several PS discharges to water with the potential to enrich nutrient status within tributaries and the mainstem of the Manawatu (Map 15). McArthur & Clark (2007) give a detailed account of PS discharges throughout the Manawatu-Wanganui Region, including the location of discharges and their receiving waters.

Consistent with the descriptions used by McArthur & Clark (2007) and for the purposes of this report, all domestic Sewage Treatment Plant (STP) discharges were labelled according to the location of the effluent. For example, Norsewood STP refers to the treated domestic sewage effluent discharged from the township of Norsewood and PPCS Oringi STP refers to the treated sewage effluent discharged from the PPCS Oringi plant. Industrial discharges were named after the companies which hold the permits for discharge and sometimes included a location if a company held more than one discharge permit in the Region (ie. PPCS Oringi and PPCS Shannon).

With respect to PS nutrient loads, all discharges other than Dannevirke STP were considered to contribute minor loads to the upper Manawatu catchment. This is consistent with the findings of Ledein *et al.* (2007) and McArthur & Clark (2007). Roygard *et al.* (2006) provide further information on the changes in concentration of soluble nitrogen and phosphorus upstream and downstream of Dannevirke STP, Norsewood STP and PPCS Oringi STP discharges. These discharges are subject to varying levels of treatment prior to discharge and have been carefully monitored under the discharge monitoring programme since July 2007. Any nutrient load from these sources has been encompassed within the NPS component of the Measured load, in the same manner as dairy effluent discharges to land and water.

Nutrient inputs from the PPCS Oringi abattoir discharge (a land treatment system on farmland adjacent to the Manawatu River at Oringi), found to contribute to in-river nutrient loads by Ledein *et al.,* (2007), has been treated as a NPS contribution in this report. Although this discharge is no longer operating as result of the plant’s closure in early 2008, the nutrient loads have contributed to the Measured loads determined over the 1989 to 2005 analysis period, and must therefore be considered within the scope of this report. Ledein *et al.* (2007) estimated an average phosphorus load of 3.5 tonnes DRP/year was contributed from this site but the site made only a minor SIN contribution.



Map 15: Map of the upper Manawatu River Water Management Zone and Sub-zones upstream of the Hopelands SOE monitoring site showing flow, water quality monitoring and significant discharge consent monitoring sites.

6.3.1 Calculating a nutrient load from Dannevirke STP

The major PS discharge upstream of Hopelands is the Dannevirke STP discharge into the Mangatera Stream, a tributary of the Manawatu River arising in the South Eastern Ruahine Ranges. Two methods were used to estimate the nutrient load inputs from this discharge.

Flow-stratified PS load estimation method

The upstream load minus the downstream load was calculated from concentration data and estimated flow in the Mangatera Stream using the flow-stratified method described below. Like the Measured load method, these PS loads were sorted by flow decile bins for the Manawatu at Hopelands percentile flow series, for the time of sample collection.

Because there is no flow recorder in the Mangatera Stream, flows used to calculate PS loads from concentration data were estimated using a relationship between the Manawatu at Weber Road flow recorder and the Mangatera Stream. The simplified flow relationship was: *Mangatera Stream flow was equal to the Manawatu at Weber Road flow divided by ten*. Further examination of the flow relationship by Watson (2007) showed a different relationship of: *Mangatera Stream flow equals Manawatu at Weber Road flow divided by 8.5 with an* r^2 *of 0.91*. PS nutrient loads from Dannevirke STP using the flow-stratified method may not have accurately reflected the soluble nitrogen and phosphorus loads to the stream.

The data used to generate these load estimates was generated from compliance monitoring records and was not necessarily collected on the same day or at the same flow as the SOE monitoring data for the Manawatu at Hopelands site. Compliance data was used from the period July 1997 to April 2004 with a total of 30 upstream and downstream samples. No samples were available for the 0-10 and 10-20 percentile categories so loads for these bins were estimated to be the same as the 20-30 percentile bin.

Using the flow-stratified method, the annual average PS nutrient load from Dannevirke STP was estimated to be 17.1 tonnes SIN/year (Table 16) and 2.6 tonnes DRP/year at all flows (Table 17). When compared to the average Measured load, Dannevirke STP contributed 2.3% of the Measured SIN load and 12.4% of the Measured DRP load. For flows less than the 10th percentile, Dannevirke STP contributions were 15.1 tonnes SIN/year and 2.3 tonnes DRP/year, making up 3.2% and 17.7% of the Measured SIN and DRP respectively.

The major advantage of using the flow-stratified method is the ability to categorise any variation in the relative contribution of SIN and DRP from point and non-point sources over different flow categories. Table 18 shows the relative PS and NPS SIN contributions to the annual Measured load. For all flows less than the 50th percentile category (less than median flow), point sources contributed 37% of the Measured SIN load at these flows and non-point sources contributed only 14.4%. Table 19 shows the contributions of DRP from point sources at flows less than the 50th percentile made up 41% of the Measured load at these flows and NPS contributed only 9.6%.

However, caution should be applied when using this method to determine loads from point sources, particularly at low flows. Instream assimilation of either soluble nitrogen or phosphorus can occur within the mixing zone between the point of discharge and the sampling location by biological and/or chemical processes. Use of the flow-stratified method assumes no time or flow lag, or assimilation of nutrients between the discharge point, the sampling point or the flow monitoring site at Hopelands when PS loads are compared to the Measured load. Further investigation of the influence of travel times and instream biological or chemical assimilation of nutrients under various flow scenarios is warranted to better understand these relationships.

Table 16: Estimation of Point Source (PS) Soluble Inorganic Nitrogen (SIN) loads from the Dannevirke Sewage Treatment Plant (STP) discharge to the Mangatera Stream calculated using the flow-stratified method. *Note: figures in italics are estimated from data in other flow percentiles.*

Dannevirke STP PS SIN load												All flows	Flows less than 10th percentile
River Flow Percentile		*0-10*	*10-20*	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100		
Maximum daily load	kg SIN/day	*94*	*94*	94	167	49	98	61	18	59	39		
Mean daily load	**kg SIN/day**	***55***	***55***	**55**	**97**	**35**	**53**	**61**	**11**	**35**	**14**		
Median daily load	kg SIN/day	*41*	*41*	41	97	35	47	61	13	37	8		
Minimum daily load	kg SIN/day	*30*	*30*	30	26	19	14	61	0	7	3		
Number of samples		***0***	***0***	3	2	5	3	1	4	4	8	30	30
Days per year flow occurrence		*36.5*	*36.5*	36.5	36.5	36.5	36.5	36.5	36.5	36.5	36.5		
Maximum annual PS load	tonnes SIN/year	*3.4*	*3.4*	3.4	6.1	1.8	3.6	2.2	0.7	2.2	1.4	28.2	24.8
Mean annual PS load	**tonnes SIN/year**	***2.0***	***2.0***	**2.0**	**3.5**	**1.3**	**1.9**	**2.2**	**0.4**	**1.3**	**0.5**	**17.1**	**15.1**
Median annual PS load	tonnes SIN/year	*1.5*	*1.5*	1.5	3.5	1.3	1.7	2.2	0.5	1.4	0.3	15.4	13.9
Minimum annual PS load	tonnes SIN/year	*1.1*	*1.1*	1.1	1.0	0.7	0.5	2.2	0.0	0.2	0.1	8.0	6.9

Table 17: Estimation of Point Source (PS) Dissolved Reactive Phosphorus (DRP) loads from the Dannevirke Sewage Treatment Plant (STP) discharge to the Mangatera Stream calculated using the flow-stratified method. *Note: figures in italics are estimated from data in other flow percentiles.*

Dannevirke STP PS DRP load												All flows	Flows less than 10th percentile
River Flow Percentile		*0-10*	*10-20*	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100		
Maximum daily load	kg DRP/day	*10.9*	*10.9*	10.9	15.8	7.1	7.7	7.3	8.4	5.6	8.8		
Mean daily load	**kg DRP/day**	***8.0***	***8.0***	**8.0**	**11.6**	**5.6**	**4.9**	**7.3**	**5.4**	**4.9**	**6.2**		
Median daily load	kg DRP/day	*7.7*	*7.7*	7.7	11.6	6.0	6.4	7.3	5.0	4.9	6.0		
Minimum daily load	kg DRP/day	*5.5*	*5.5*	5.5	7.4	2.9	0.6	7.3	3.3	4.2	4.4		
Number of samples		***0***	***0***	3	2	5	3	1	4	4	8	30	30
Days per year flow occurrence		*36.5*	*36.5*	36.5	36.5	36.5	36.5	36.5	36.5	36.5	36.5		
Maximum annual PS load	tonnes DRP/year	*0.40*	*0.40*	0.40	0.58	0.26	0.28	0.27	0.31	0.20	0.32	3.4	3.0
Mean annual PS load	**tonnes DRP/year**	***0.29***	***0.29***	**0.29**	**0.42**	**0.21**	**0.18**	**0.27**	**0.20**	**0.18**	**0.22**	**2.6**	**2.3**
Median annual PS load	tonnes DRP/year	*0.28*	*0.28*	0.28	0.42	0.22	0.24	0.27	0.18	0.18	0.22	2.6	2.3
Minimum annual PS load	tonnes DRP/year	*0.20*	*0.20*	0.20	0.27	0.11	0.02	0.27	0.12	0.15	0.16	1.7	1.5

Table 18: Relative contributions of point source (PS) and non-point sources (NPS) to Soluble Inorganic Nitrogen (SIN) loads calculated using the flow-stratified method for the Manawatu at Hopelands monitoring site. *Note: figures in italics are estimated from data in other flow percentiles.*

	Units	**0-10th**	**10th-20th**	**20th-30th**	**30th-40th**	**40th-50th**	**50th-60th**	**60th-70th**	**70th-80th**	**80th-90th**	**90th-100th**	All flows	Flows less than 10th %ile	Flows less than 50th %ile
Flow	m^3/s	49.5	32.65	24.29	19.11	15.4	12.42	9.9	7.71	5.44	2.01			
Mean Standard load	tonnes SIN/year	146.7	55.7	39.3	30.1	24	19.4	15.5	12.3	9.2	5.7	358	211.3	62.2
Measured load	tonnes SIN/year	267.4	119.2	104.3	76.5	65.8	45.9	30	18.9	12.4	4.7	745	478	111.9
PS Load	tonnes SIN/year	2.0	2.0	2.0	3.5	1.3	1.9	2.2	0.4	1.3	0.5	17.1	15.1	6.3
NPS Load	tonnes SIN/year	265.4	117.2	102.3	73	64.5	44	27.8	18.5	11.1	4.2	727.9	462.9	105.6
Measured load > Standard	tonnes SIN/year	120.7	63.5	65	46.4	41.8	26.5	14.5	6.6	3.2	-1	387	266.7	49.7
% Standard load per flow bin		41	16	11	8	7	5	4	3	3	2	100	59	17
% Measured load per flow bin		35.9	16	14	10.3	8.8	6.2	4	2.5	1.7	0.6	100	64.1	15
% PS load per flow bin		11.7	11.7	11.7	20.6	7.4	11.3	13.0	2.4	7.5	2.9	100	88.3	37
% NPS load per flow bin		36.5	16.1	14.1	10	8.9	6	3.8	2.5	1.5	0.6	100	63.5	14.4

Table 19: Relative contributions of point source (PS) and non-point sources (NPS) to Dissolved Reactive Phosphorus (DRP) loads calculated using the flow-stratified method for the Manawatu at Hopelands monitoring site. *Note: figures in italics are estimated from data in other flow percentiles.*

	Units	**0-10th**	**10th-20th**	**20th-30th**	**30th-40th**	**40th-50th**	**50th-60th**	**60th-70th**	**70th-80th**	**80th-90th**	**90th-100th**	All flows	Flows less than 10th %ile	Flows less than 50th %ile
Flow	m^3/s	49.5	32.65	24.29	19.11	15.4	12.42	9.9	7.71	5.44	2.01			
Mean Standard load	tonnes DRP/year	3.3	1.3	0.9	0.7	0.5	0.4	0.3	0.3	0.2	0.1	8.1	4.8	1.4
Measured load	tonnes DRP/year	7.8	4.2	2.7	1.7	1.3	1.0	0.8	0.5	0.3	0.3	21	13	2.9
PS Load	tonnes DRP/year	0.3	0.3	0.3	0.4	0.2	0.2	0.3	0.2	0.2	0.2	2.6	2.3	1.0
NPS Load	tonnes DRP/year	7.5	3.9	2.4	1.3	1.1	0.8	0.5	0.3	0.1	0.1	18.4	10.7	1.9
Measured load > Standard	tonnes DRP/year	4.5	2.9	1.8	1	0.8	0.6	0.5	0.2	0.1	0.2	12.9	8.2	1.5
% Standard load per flow bin		41	16	11	8	7	5	4	3	3	2	100	59	17
% Measured load per flow bin		37.1	20	12.9	8.1	6.2	4.8	3.8	2.4	1.4	1.4	100	62.9	13.8
% PS load per flow bin		11.5	11.5	11.5	16.6	8.0	7.0	10.4	7.7	7.0	8.8	100	88.5	41
% NPS load per flow bin		40.8	21.2	13	7.1	6	4.3	2.7	1.6	0.5	0.5	100	59.2	9.6

Effluent PS load estimation method

Because of the potential for considerable error in the flow-stratified method, introduced by estimating the flow in the Mangatera Stream and the low or absent representation of samples for some flow decile bins, alternative PS load estimation methods were investigated.

In the absence of accurate, long-term monitoring data for many PS discharges, load estimates for a range of PS inputs are only comparable when a consistent estimation method is used. McArthur & Clark (2007), in a study of PS nutrient loads at low flows, used estimates based on the average concentration of soluble nitrogen and phosphorus in effluent discharges multiplied by the average effluent discharge volume. This method assumes that average effluent discharges are relatively constant in nutrient concentration and discharge volume over time.

The effluent nutrient concentrations and daily discharge volumes used to estimate loadings are summarized below (Table 20). Fifty-five SIN and 61 DRP effluent concentration observations from compliance monitoring of effluent from Dannevirke STP, between December 1989 and June 2008, were used in a matrix with daily effluent volume data from between November 2004 and June 2007 (Table 21). A comparison of annual nutrient load from Dannevirke STP shows the annual average SIN load was 16 tonnes/year and the annual average DRP load was 4.2 tonnes/year. When compared to the average Measured load, Dannevirke STP contributed 2.1% of the Measured SIN load and 20% of the Measured DRP load.

Using an estimation of soluble nutrient load from the Dannevirke STP, based on effluent discharge volume and nutrient concentration, produced an annual load slightly lower than the upstream minus downstream load calculation with respect to SIN, but a higher load with respect to DRP. For the purposes of this report, loads calculated from effluent concentration and volume are preferred and used throughout the remainder of this report, because the data requirements of this method are consistent with the availability and quality of historical compliance monitoring data. Advances in monitoring of discharges throughout the Region may necessitate the use of flow-stratified calculation methods to estimate PS nutrient loads in future.

Table 20: Summary of Soluble Inorganic Nitrogen (SIN) and Dissolved Reactive Phosphorus (DRP) phosphorus concentrations and daily effluent volumes discharged from the Dannevirke Sewage Treatment Plant (STP) to the Mangatera Stream.

Summary statistic	SIN conc. g/m^3	DRP conc. g/m^3	Effluent volume m^3/day
Maximum	27.8	7.8	4550
Mean	15	3.9	2953
Standard deviation	6.8	1.5	989
Median	15.6	3.7	3016
Minimum	1.8	0.5	72
Count	55	61	949

Table 21: Annual loads of Soluble Inorganic Nitrogen (SIN) and Dissolved Reactive Phosphorus (DRP) in tonnes per year discharged from the Dannevirke Sewage Treatment Plant (STP) to the Mangatera Stream.

SIN load (tonnes/year)			
Effluent conc.	Effluent volume		
	Mean	Median	Maximum
Maximum	30	31	46
Mean	**16**	17	25
Median	17	17	26
Minimum	2	2	3
DRP load (tonnes/year)			
Effluent conc.	Effluent volume		
	Mean	Median	Maximum
Maximum	8.4	8.7	13.0
Mean	**4.2**	4.3	6.5
Median	4.0	4.1	6.1
Minimum	0.5	0.5	0.8

6.3.2 Calculating NPS nutrient loads to the upper Manawatu catchment

Non-Point Source loads to the catchment upstream of the Manawatu at Hopelands monitoring site were estimated by subtracting the annual PS load, estimated using the 'effluent PS load' method (Table 21), from the Measured load. Removal of the PS load from the Measured load provides a NPS estimate of 729 tonnes SIN/year and 16.8 tonnes DRP/year over all flow conditions (Figure 37). This equates to a proportional NPS contribution of 97.9% to the Measured SIN load and 80% of the Measured DRP load.

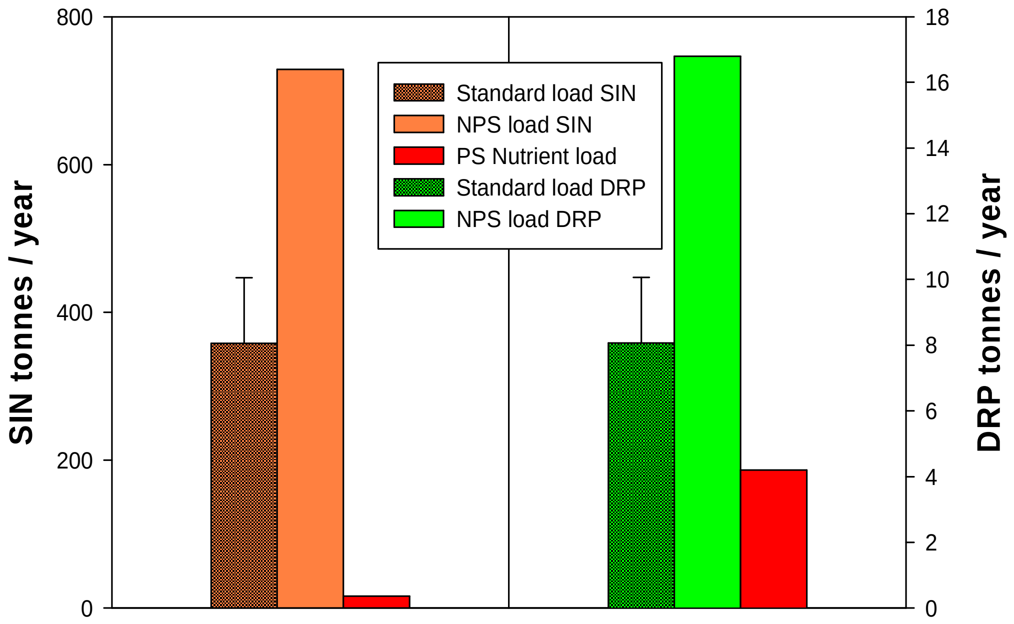


Figure 37: Annual SIN load (tonnes/year) attributable to Point Source (PS: Dannevirke STP) and Non-Point Sources (NPS) of nutrient in the upper Manawatu catchment upstream of the Hopelands monitoring site.

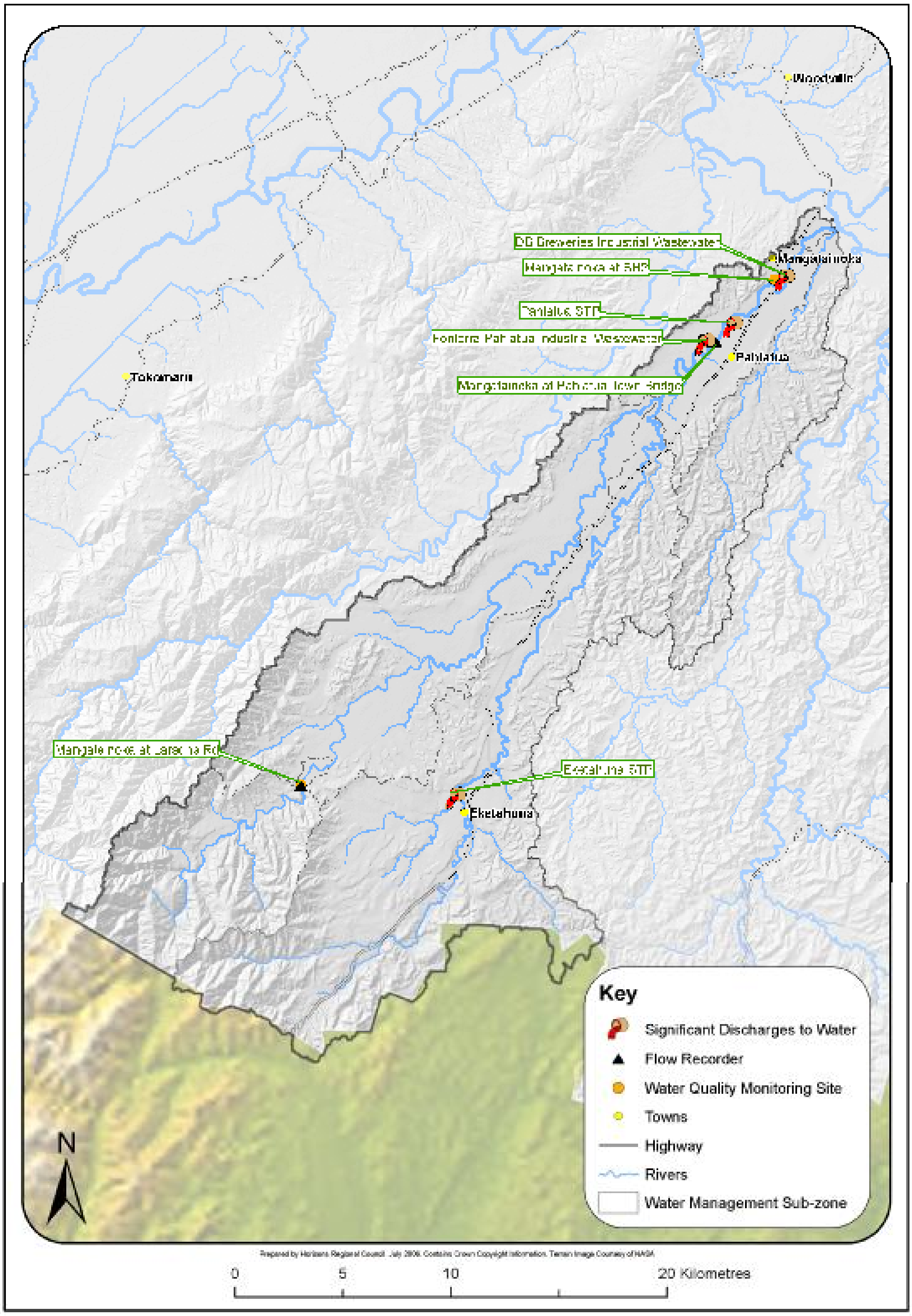
As shown in Figure 37, NPS enrichment is the major cause of high Measured nutrient loads in the upper Manawatu catchment. However, PS loads from Dannevirke STP make a far greater contribution to Measured loads of soluble phosphorus than nitrogen, on an annual basis.

6.4 Significant PS discharges in the Mangatainoka

Like the upper Manawatu, the Mangatainoka catchment is subject to several PS discharges to water with the potential to enrich the nutrient status within the Makakahi and Mangatainoka Rivers (Map 16).

There are four main discharges in the Mangatainoka catchment (McArthur & Clark, 2007): Eketahuna STP discharges to the Makakahi River, a tributary of the Mangatainoka arising in the North Eastern Tararua Ranges; Fonterra Pahiatua discharges dairy processing condensate just upstream of the Mangatainoka at Pahiatua at Town Bridge flow site; Pahiatua STP discharges 3.5 km upstream of the Mangatainoka at SH2 monitoring site; and DB Breweries discharges immediately downstream of the Mangatainoka at SH2 site.

The Fonterra Pahiatua condensate discharge does not contribute any significant nutrient load to the Mangatainoka River (McArthur & Clark, 2007) and therefore is not within the scope of this report. Because of the location of the DB Breweries discharge downstream of the SOE monitoring site on the Mangatainoka, all Measured load calculations within this report are an underestimate of soluble nutrients loads as they do not account for contributions from the DB discharge. Using the daily load estimates from McArthur & Clark (2007), annual load estimates for DB Breweries discharge downstream of the SH2 monitoring site are 0.10 tonnes SIN/year and 5.55 tonnes DRP/year on average. Following the recent change to non-phosphorus based detergents within the DB Breweries plant, phosphorus concentrations are expected to decrease significantly, however, data was not available at the time of writing to confirm the magnitude of the phosphorus reduction.



Map 16: Map of the Mangatainoka River Water Management Zone and Sub-zones showing flow, water quality monitoring and discharge consent monitoring sites.

6.4.1 Calculating a nutrient load from Eketahuna and Pahiatua STPs

Due to the quality and availability of historical compliance data, only the effluent load method was used to estimate nitrogen and phosphorus contributions from Eketahuna and Pahiatua STP discharges. Again, the major assumption underlying this method was that effluent discharges were, on average, relatively constant in nutrient concentration and discharge volume.

Accurate discharge volumes for Eketahuna STP and Pahiatua STP were unable to be applied in the calculations because of persistent malfunctions in the outflow meters fitted by the Consent Holder (Good Earth Matters, AEE for Pahiatua and Eketahuna STP Resource Consent Applications, 2005). Estimates of the average effluent volume determined by McArthur & Clark (2007) have been used for load calculations in this report. Additionally, nutrient loads from the Imhoff Tank discharge that is used to partially treat sewage from a small proportion of the domiciles in the Eketahuna Township have not been added to the final loads because of the small volumes discharged. Any input from this source is included within the NPS proportion of the Measured load.

The effluent nutrient concentrations and average discharge volumes used to estimate loads are summarised below (Table 22). Seventy-two effluent concentration observations from compliance monitoring of Eketahuna STP and sixty observations from monitoring of Pahiatua STP, collected between August 1989 and June 2008, were used with the estimated average discharge volumes to calculate SIN and DRP loads for Eketahuna and Pahiatua STP discharges (Table 23).

A comparison of annual nutrient load from Eketahuna STP shows the annual average SIN load was 0.42 tonnes/year and the annual average DRP load was 0.17 tonnes/year. When compared to the average Measured load, Eketahuna STP contributed only 0.07% of the Measured SIN load and 0.2% of the Measured DRP load. These nutrient loads should therefore be considered as only having a minor impact on the Measured SIN and DRP loads at the Mangatainoka at SH2 monitoring site and therefore were considered as part of the NPS contribution for the remainder of this report. Although not within the scope of this report, the effect of this effluent on the Makakahi River at the point of discharge should be considered against the concentration-based water quality standards for any separate consent processes and any effects arising from such a consideration should not be discounted.

Pahiatua STP had an annual average SIN load of 3.39 tonnes SIN/year and 1.47 tonnes DRP/year. The proportional contributions of these loads to the Measured load in the Mangatainoka at SH2 were 0.6% for SIN and 15.8% for DRP. Similar to the upper Manawatu case study, and consistent with the findings of McArthur & Clark (2007), the contribution of soluble phosphorus from PS inputs to Measured loads is far greater than for nitrogen. As McArthur & Clark (2007) found, the phosphorus load from the Pahiatua STP has the potential to exceed the proposed standards for DRP in the Mangatainoka River at flows less than half median.

If we assumed all nutrient added to the river from the Eketahuna STP discharge travelled downstream approximately 35 km to the Mangatainoka at

SH2 monitoring site, without any change to the total load along the way, the combined contribution of Eketahuna and Pahiatua STP discharges (Table 23) would still only account for 0.6% of the Measured SIN load and 15.5% of the DRP load.

Table 22: Summary of Soluble Inorganic Nitrogen (SIN) and Dissolved Reactive Phosphorus (DRP) phosphorus concentrations and estimated average effluent volume discharged from the Eketahuna and Pahiatua Sewage Treatment Plants (STP) to the Makakahi and Mangatainoka Rivers.

Eketahuna STP			
Summary statistic	**SIN conc. g/m^3**	**DRP conc. g/m^3**	**Effluent volume m^3/day**
Maximum	11.1	4.3	300
Mean	3.9	1.5	
Standard deviation	2.1	1.1	
Median	3.7	1.4	
Minimum	0.7	0.1	
Count	72	72	
Pahiatua STP			
Summary statistic	**SIN conc. g/m^3**	**DRP conc. g/m^3**	**Effluent volume m^3/day**
Maximum	23.1	6.9	1020
Mean	9.1	3.9	
Standard deviation	6.2	1.4	
Median	8.3	3.8	
Minimum	0.01	0.24	
Count	60	60	

Table 23: Annual loads of Soluble Inorganic Nitrogen (SIN) and Dissolved Reactive Phosphorus (DRP) in tonnes per year discharged from the Eketahuna and Pahiatua Sewage Treatment Plants (STP) to the Makakahi and Mangatainoka Rivers.

Eketahuna STP		
Effluent conc.	SIN (tonnes/year)	DRP (tonnes/year)
Maximum	1.21	0.47
Mean	**0.42**	**0.17**
Median	0.40	0.15
Minimum	0.07	0.01
Pahiatua STP		
Effluent conc.	SIN (tonnes/year)	DRP (tonnes/year)
Maximum	8.58	2.57
Mean	**3.39**	**1.47**
Median	3.09	1.41
Minimum	0.004	0.09
Combined load		
Effluent conc.	SIN (tonnes/year)	DRP (tonnes/year)
Maximum	9.79	3.04
Mean	**3.82**	**1.63**
Median	3.49	1.56
Minimum	0.08	0.10

6.4.2 Calculating NPS nutrient loads to the upper Mangatainoka catchment

Non-Point Source (NPS) loads to the Mangatainoka catchment upstream of the SH2 monitoring site were estimated by subtracting the annual PS load from the Pahiatua STP discharge Measured load. Removal of the PS load from the Measured load provides a NPS estimate of 600 tonnes SIN/year and 7.83 tonnes DRP/year over all flow conditions (Figure 38). This equates to a proportional NPS contribution of 99.4% to the Measured SIN load and 84.2% of the Measured DRP load.

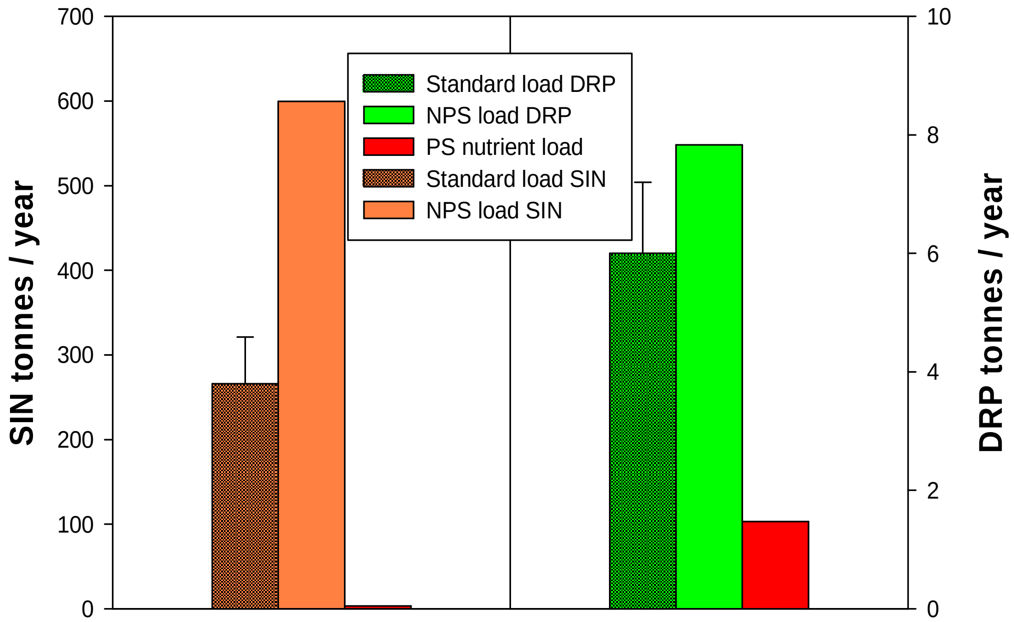


Figure 38: Annual SIN load (tonnes/year) attributable to Point Source (PS: Pahiatua STP) and Non-Point Sources (NPS) of nutrient in the Mangatainoka catchment upstream of the State Highway 2 monitoring site.

As shown in Figure 38, NPS enrichment is the major cause of high Measured nutrient loads in the Mangatainoka catchment. However, PS loads from Pahiatua STP make a greater contribution to Measured loads of soluble phosphorus than nitrogen, on an annual basis. Point sources in the Mangatainoka catchment make a smaller contribution to Measured loads of SIN and DRP than in the upper Manawatu catchment.

Summary of Manawatu and Mangatainoka PS and NPS nutrient load results

- Direct dairy effluent discharges to water reduced significantly between 1989 and 2003. Due to the change in effluent disposal from water discharge to land discharge during the period of analysis, dairy effluent discharges were considered NPS loads.

- In the upper Manawatu catchment upstream of Hopelands, estimated dairy effluent loads made up 1.7% of the Measured SIN load on average and 10% of the Measured DRP load, whereas in the Mangatainoka catchment, estimated dairy effluent loads made up 2.1% of the Measured SIN load and 25% of the Measured DRP load.

- Dannevirke STP was the major point source contributor of nutrients to the upper Manawatu catchment. All other PS contributions were considered within NPS loads.

- Two methods were used to estimate annual nutrient loads from Dannevirke STP. The ‘flow stratified load method’ estimated the SIN load to be 17.1 tonnes/year and the DRP load to be 2.6 tonnes/year making up 2.4% and 10% of the Measured SIN and DRP at Hopelands respectively.

- The ‘effluent PS load’ method of estimating nutrient contribution from Dannevirke STP determined an annual SIN load of 16 tonnes/year and 4.2 tonnes/year of DRP, making up 2.1% and 20% of the Measured loads at Hopelands.

- Pahiatua STP was the major point source contributor of nutrients to the Mangatainoka River upstream of the SH2 monitoring site; all other discharges were considered as NPS nutrient components of the Measured load. DB Breweries discharge contributed a significant amount of DRP downstream of the SOE monitoring site over the period of record, which was not accounted for in the monitoring data used for this report.

- Using the ‘effluent PS load’ method, Pahiatua STP was estimated to contribute a SIN load of 3.39 tonnes/year and 1.47 tonnes of DRP/year. These point source loads made up 0.6% of the Measured annual SIN load and 15.9% of the Measured DRP load.

- In the Mangatainoka catchment PS made a smaller contribution to Measured SIN and DRP loads than in the upper Manawatu catchment.

- To estimate the NPS contribution the PS load was subtracted from the Measured load for each nutrient. In the upper Manawatu the estimated NPS SIN load was 729 tonnes/year, 97.9% of the annual Measured load. The NPS contribution to DRP was 16.8 tonnes/year or 80% of the annual Measured load.

- In the Mangatainoka catchment the NPS SIN load was estimated as 600 tonnes/year, or 99.4% of the Measured SIN load, whereas the NPS DRP contribution was 7.8 tonnes/year, or 84.2% of the Measured load.

7. NPS Target loads to achieve water quality standards

7.1 Introduction

Ideally, to achieve a concentration-based river nutrient standard, the sum of the inputs from NPS and PS need to be managed to reduce the annual Measured load to less than the Standard load limit for both SIN and DRP. There are a number of ways to achieve such a management regime but management of PS and NPS will require separate mechanisms. For example, *annual* NPS Target loads will be applicable to managing nutrient losses from farming systems and *daily* flow-based load limits to manage nutrient inputs from PS discharges.

One possible approach to managing PS inputs within Standard load limits could be to measure upstream water quality immediately prior to an intended discharge of wastewater, to determine whether any PS load could be added to the river given the current upstream nutrient load. A discharge volume of a known concentration could then be allowed if it were likely to remain within the Standard load limit under the prevailing flow conditions at the time of discharge. However, this approach would provide little certainty for consent holders and would provide a number of technical challenges, especially in relation to procuring accurate and timely results from water quality analyses. Because of these difficulties, such an approach is not recommended.

A recommended method for developing policy, to meet the objective of achieving water quality within the Proposed One Plan nutrient standards, is to establish Standard SIN and DRP load limits for each flow decile category using the methods outlined in the chapters above. The SIN or DRP Standard load limit for a particular flow decile could then be apportioned between point and non-point source contributors.

In deciding how to apportion the NPS and PS contributions of SIN and DRP for each flow decile category, consideration must be given to the mechanisms currently available to reduce the present level of nutrient load from both sources.

7.2 Managing PS nutrient loads to meet Standard load limits for flow deciles on a daily basis

There is likely to be variation in river flow over the course of any 24-hour period. Such flow variations could potentially change the decile category within which the flow occurs and thereby the Standard load limits applying over a 24-hour period. However, a pragmatic approach to the daily management of PS nutrient inputs in relation to flow decile could include applying a daily Standard load limit based on one of two options to determine the 'flow decile for the day'.

The first and simplest option is to set a condition which states that the Standard load limit for the day, derived from the flow decile for that 24 hour period, will be determined based on the decile of flow at 8 am on the day of the discharge. The second more complex option would determine the predicted average flow and flow decile for the day, based on flow forecasting techniques. These techniques are currently used for flood forecasting purposes throughout the Region and could potentially be refined for low flow conditions.

Currently there are several challenges in implementing a flow-related regime of this kind for water quality management. One major challenge is that the management of many domestic sewage effluent plants (and some industrial wastewater discharges) is not of a technological standard high enough to produce effluent of a consistent contaminant concentration, or to accurately control the discharge volumes and loads to meet a daily nutrient load limit. Many community sewage effluent plants are affected by variable trade waste inputs and stormwater inflow and infiltration that potentially influence contaminant loads, treatment efficacy, discharge volume and effluent storage potential.

At present, the active management of many discharges is typically limited to reducing discharge volumes at a specified flow, usually low flows, which are somewhat easier to predict and prepare for. However, there are currently a small number of industrial wastewater discharges that discharge within flow-related loading regimes and this is an accepted way of meeting receiving water quality standards under varying flow regimes.

Adopting a daily discharge load limit will require active management of discharges on an ongoing daily basis, accurate profiling of variations in contaminant concentrations, and precise measurement of discharge volumes.

7.3 Managing NPS nutrient loads to meet annual Standard load limits

To reduce NPS contributions to Measured river nutrient loads, consideration must be given to the mechanisms of NPS input. Non-point sources can range from natural inputs from rock types and wetlands, to land treatment and/or disposal systems for wastewater, stormwater and urban run-off, and diffuse outputs from various production systems.

7.3.1 Best Management Practices (BMP) for P reduction

Reductions in diffuse nutrient loads to rivers from agricultural systems may be achievable by implementing best practices on-farm. With regard to phosphorus, Parfitt *et al.* (2007) made a number of estimates, based on current knowledge, of the potential reduction in dissolved phosphorus load resulting from changes to agricultural systems and point source inputs in the upper Manawatu catchment (Table 24). Parfitt *et al.* (2007) estimated a total dissolved phosphorus load of 35 tonnes/year, of which 21 tonnes was DRP (with the remaining 14 tonnes being Dissolved Organic Phosphorus (DOP)).

Assuming all potential BMPs were implemented to the proportions described in Parfitt *et al* (2007), the estimate of total net reduction in annual loads of dissolved phosphorus from all sources in the upper Manawatu was 16 tonnes/year. This resulted in a projected dissolved phosphorus load of 19 tonnes/year passing the Hopelands monitoring site in fifteen years time, once BMPs had had a chance to be effectively implemented (Parfitt *et al.,* 2007).

If we also assume that the ratio of DRP to DOP remains roughly the same as the current ratio (2:1) (*R. Parfitt pers. comm. 8/8/08.)* regardless of any influence from the different mechanisms of BMP reduction, we can estimate the contribution of DRP to the projected dissolved phosphorus load. Given these assumptions, the estimated DRP load was approximately 12.5 tonnes/year if all BMPs were implemented as described in Table 24 and there were no significant changes to land use in the upper Manawatu catchment. This would mean a potential 40% reduction of the current DRP load (21 tonnes/year).

However, without measurements of DOP these figures remain only estimates. Routine monitoring of DOP and DRP ratios at sites affected by high phosphorus loads (such as the Manawatu at Weber Road, Manawatu at Hopelands and Mangatainoka at SH2 sites) has recently been implemented under the State of the Environment water quality monitoring programme. Results from this monitoring may better inform us of the potential gains to be made in BMP of phosphorus inputs from PS and NPS.

Table 24: Reductions in dissolved phosphorus load achievable through Best Management Practices (BMP) in the upper Manawatu catchment (source: Parfitt *et al.,* 2007).

BMP	Percentage implementation	Dissolved P load reduction
Dannevirke STP:		
Chemical coagulation/precipitation or partial removal of discharge	-	4 - 5 tonnes/year
Fertiliser Use:		
Soil P storage and Olsen-P levels	-	Soil type, Olsen-P and weather dependent - potentially zero net change across catchment
Use of Reactive Phosphate Rock (RPR) fertilisers	-	Potential 50% reduction in losses from soluble fertilizers but dependent on weather, soil and application accuracy
Dairy:		
Stock exclusion from waterways	10%	1 tonne/year
Removing farm races linked to streams	50%	1 tonne/year
Deferred and low rate effluent irrigation technologies	100%	2 tonnes/year
Sheep and Beef:		
Planting steep slopes	-	4 tonnes/year (?)[12]
Riparian fencing and planting on larger rivers	-	
Hill Country Land Management (SLUI):		
Eroded hill country sediment reduction and reduced remobilisation from bed sediments	10% of priority farms	4 tonnes/year

[12] Parfitt *et al.,* (2007) recognise this estimate included a high degree of uncertainty, requiring further investigation.

7.3.2 Best Management Practices (BMP) for N and P reduction

This section outlines best management practice nutrient management scenarios that should be *theoretically* possible if implemented across all dairying and sheep and beef farming and applied to all point source discharges. Section 7.5 below outlines nutrient management scenarios proposed under Rule 13-1 of the One Plan.

Clothier *et al.* (2007) were commissioned by Horizons to develop a method linking land use contaminant losses and measured water quality. Clothier *et al.* (2007) also developed a framework for setting acceptable and realistic farm nutrient loss targets which could be endorsed by Horizons to achieve water quality objectives proposed in the One Plan. The following sections investigate three scenarios used in the development of these methods.

Scenarios for modeling nutrient reductions under BMP in the upper Manawatu and Mangatainoka Rivers

Scenario 0: The 'no change' current state scenario. Measured annual nutrient loads, as calculated in previous chapters.

Scenario 1: The one-third NPS reduction and 'no change' PS scenario. Percentage of annual PS and NPS nutrient contributions to Measured loads after a one-third improvement in NPS loads across all farms (both dairy and sheep and beef sectors): the NPS target load.

Scenario 2: The combined BMP NPS and PS scenario. BMP implemented on all farms (NPS target load) and removal of PS discharges at flows when the Standard load limit is still exceeded by NPS to remain within the Standard load limit across all flow deciles, except the highest 10% of flows when the concentration standard does not apply.

The scenarios tested by Clothier *et al.,* (2007) assume a one-third reduction in nitrogen and phosphorus loads. The main findings from the Clothier *et al.* (2007) report with regards to nitrogen reduction are included below for context:

"*Improvements in dairy farm operations, through the adoption of Best Management Practices could reduce farm losses by up to one third. If the mitigation options were successful, and if they were capable of application across the whole farm, the loss of N could potentially be reduced to around 21 kg-N^{-1}ha^{-1} year^{-1}. For the sub-catchment of Hopelands, if such a reduction in NPS pollution could be achieved through the adoption of best management practices, this would translate into a reduction in the N loading of the river of 72,545 kg-N^{-1} year^{-1}, and improvement of around 18.3%."*

When comparing the findings of Clothier *et al.* (2007) to the Measured nitrogen load determined in the previous chapters of this report there is a discrepancy between the percentage improvement in water quality that may result from the implementation of BMP quoted by Clothier *et al.* (2007) and the figures determined above. This is because the figures quoted by Clothier *et al.* (2007) apply only to the catchment area between the Hopelands and

Weber Road monitoring sites, not the entire upper Manawatu above Hopelands as used for this report.

Clothier *et al.* (2007) did not provide a clear numerical estimate of the quantities of DRP reduction through best practice implementation because the nutrient loss modelling outputs from Overseer® apply a risk-based assessment of dissolved phosphorus loss (ranging from low to extreme risk) rather than a numerical loss figure. When compared to the projected phosphorus reduction of 40% estimated from the results of Parfitt *et al.* (2007) above, it would seem that applying the same one-third reduction scenario for phosphorus would not be unrealistic, if BMP were implemented. For the purposes of this report and the scenarios modelled by Clothier *et al.* (2007) a one-third improvement in both phosphorus and nitrogen has been applied.

Clothier *et al.* (2007) did however, caution the application of a one-third reduction in nutrient losses across all farms because the achievable reduction is affected by the proportionate differences between dairying and sheep and beef land use within the upper Manawatu catchment. They stated:

"Because dairying and sheep/beef each contribute about one-half of the total loading of nitrogen in the river at Hopelands, a one-third improvement in either will only translate to an improvement of about half of that improvement in the river. Of course, if both farm types were able successfully to improve practices to reduce losses by one-third, there would be a one-third improvement in the river, according to this linear transfer-function approach. We add that the range of mitigation and optimisation measures available to reduce N loss under sheep/beef grazing is less than that possible in the dairy sector."

7.3.3 Testing the BMP nutrient scenarios in the upper Manawatu catchment

Effects of nitrogen reduction on Measured loads

The Measured SIN load in the Manawatu River at Hopelands is predicted to reduce from 745 tonnes per year under the current situation (Scenario 0) to 502 tonnes per year with a one-third improvement in water quality as a result of reduced nitrogen losses from all NPS (both dairying and sheep and beef farms) (Scenario 1) (Figure 39). If PS discharges were required to be removed from the river when the load for that flow decile category already meets or exceeds the Standard load limit for SIN as a result of NPS inputs, reducing the total PS load input with the exception of the 10th percentile flows (Scenario 2), the predicted Measured load would further reduce to 494 tonnes per year. This 'best case scenario' reduction in nitrogen load would still account for 138% of the SIN Standard load limit for Hopelands of 358 tonnes/year.

A predicted one-third improvement in NPS inputs changes the proportional contribution of PS inputs to the Measured load at all flows. Under Scenario 0, PS contributes 2% of the Measured SIN load, 3% of the predicted SIN load under Scenario 1, and 2% of the predicted SIN load for Scenario 2 (Figure 40). To endeavor to remain below the SIN Standard load limit, BMP for PS loads would require cessation of nitrogen discharge between the 70th and 20th flow percentiles (Figure 42). Under Scenario 2 the three lowest of the flow decile categories would be able to receive increased PS SIN loads to an annual load of 6.4 tonnes/year. This is a significant reduction compared to the current PS SIN load of 16.1 tonnes/year across all flows and 14.5 tonnes/year at flows less than the 10th percentile.

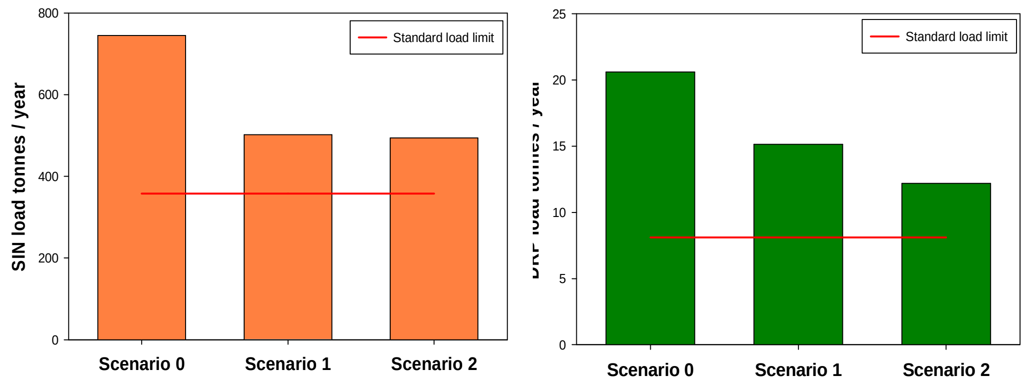


Figure 39: Predicted changes in annual Soluble Inorganic Nitrogen (SIN) and Dissolved Reactive Phosphorus (DRP) loads in the Manawatu River at Hopelands as a result of three nutrient management scenarios.

Effects of phosphorus reduction on Measured loads

The Measured DRP load in the Manawatu River at Hopelands is predicted to reduce from 21 tonnes/year under the current situation (Scenario 0) to 15 tonnes/year with a one-third improvement in water quality as a result of reduced phosphorus losses from all NPS (both dairying and sheep and beef farms) (Scenario 1) (Figure 39).

Scenario 2 requires PS discharges to be removed from the river when the load for that flow decile category already meets or exceeds the Standard load limit as a result of NPS inputs (with the exception of the top 10th percentile of flows) or to discharge a lesser volume and reduce the PS load input to within the Standard load limit for each flow decile. Under Scenario 2, the predicted Measured load would further reduce to 12 tonnes/year. This ‘best case scenario’ reduction in dissolved phosphorus load would still account for 150% of the DRP Standard load limit for Hopelands (8.1 tonnes/year).

Adopting best management practices for NPS and PS inputs changes the proportional contribution of inputs to the Measured load at all flows. Under Scenario 0, PS contributes 21% of the Measured DRP load, 29% of the predicted DRP load under Scenario 1, and 10% of the predicted DRP load for Scenario 2 (Figure 41). To endeavor to comply with the DRP Standard load limit, BMP for PS loads would require complete cessation of dissolved phosphorus discharge between the 50th and 10th flow percentiles and reduced loads for all other categories, except the highest flow decile (Figure 43). The five lowest of the flow decile categories would be able to receive reduced PS discharges to a combined load of 0.8 tonnes/year. This is a significant reduction compared to the current PS DRP load of 4.3 tonnes/year across all flows and 3.9 tonnes/year for flows less than the 10th percentile.

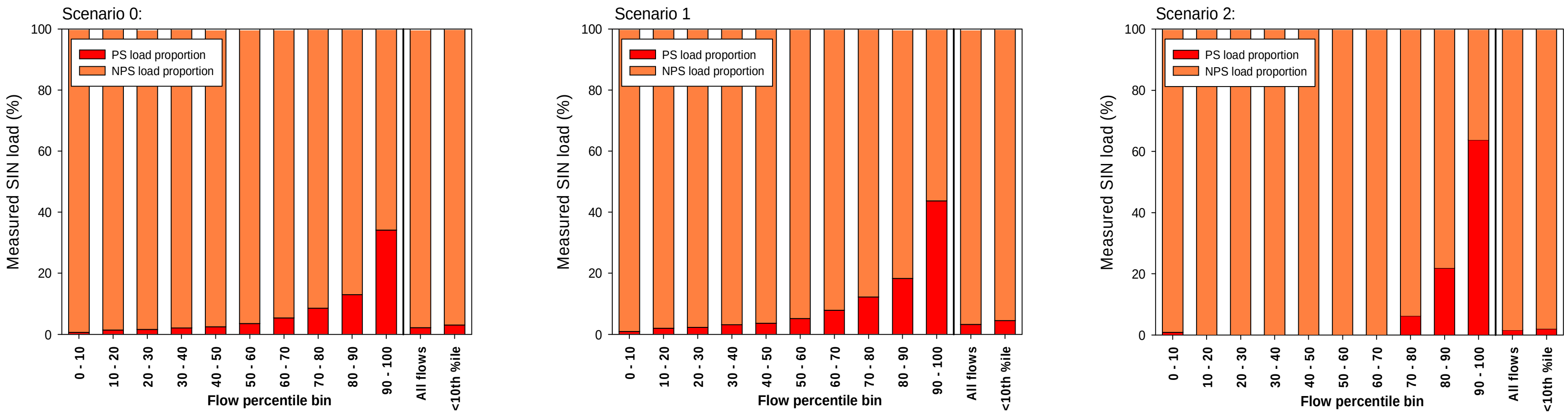


Figure 40: Actual and projected percentage contributions of Soluble Inorganic Nitrogen (SIN) from Non-Point Source (NPS) and Point Source (PS) inputs to the annual Measured load in the Manawatu River at Hopelands under three nutrient management scenarios.

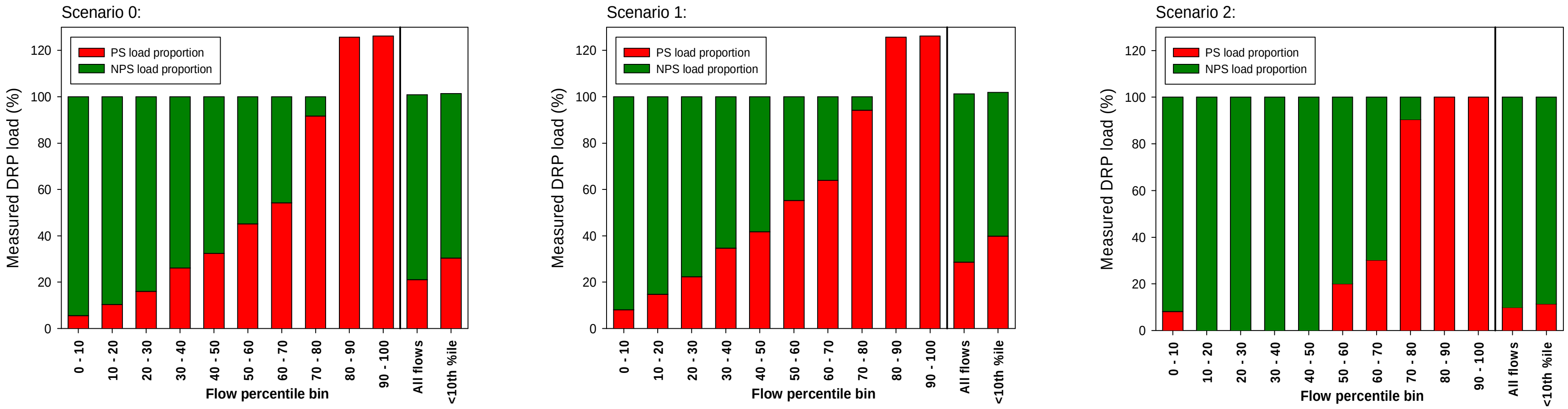


Figure 41: Actual and projected percentage contributions of Dissolved Reactive Phosphorus (DRP) from Non-Point Source (NPS) and Point Source (PS) inputs to the annual Measured load in the Manawatu River at Hopelands under three nutrient management scenarios.

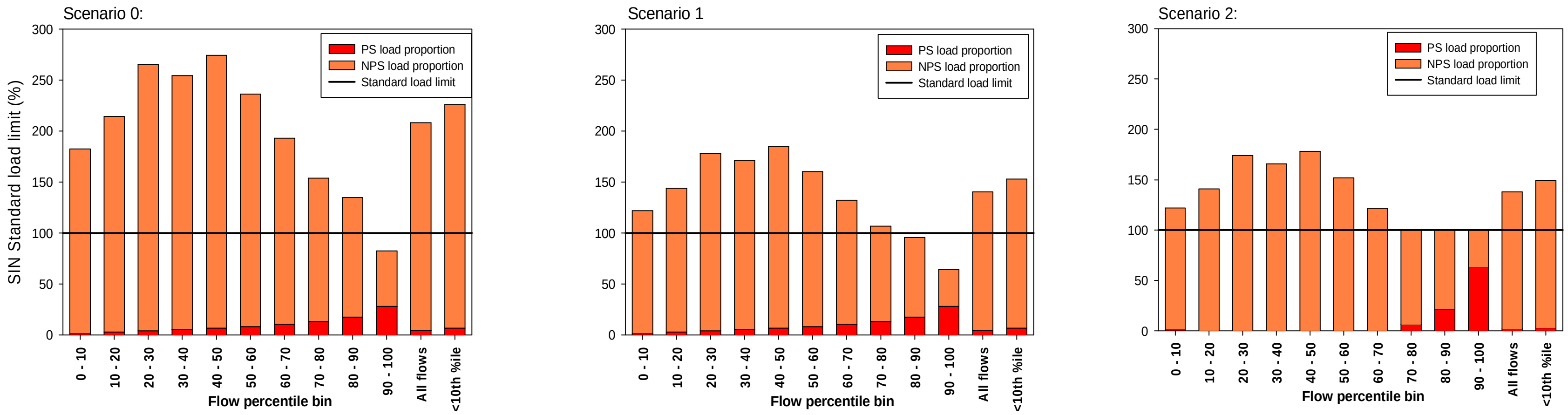


Figure 42: Actual and projected percentage contributions of Soluble Inorganic Nitrogen (SIN) from Non-Point Source (NPS) and Point Source (PS) inputs to the annual Standard load limit for the Manawatu River at Hopelands under three nutrient management scenarios.

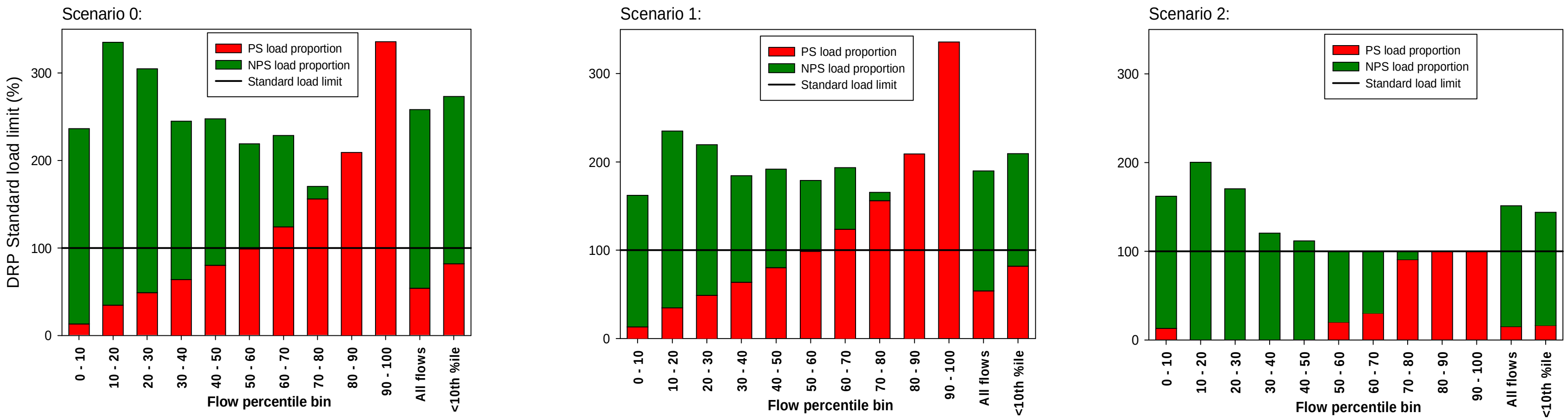


Figure 43: Actual and projected percentage contributions of Dissolved Reactive Phosphorus (DRP) from Non-Point Source (NPS) and Point Source (PS) inputs to the annual Standard load limit for the Manawatu River at Hopelands under three nutrient management scenarios.

7.3.4 Testing the BMP nutrient scenarios in the Mangatainoka catchment

Effects of nitrogen reduction on Measured loads

The Measured SIN load in the Mangatainoka River at SH2 is predicted to reduce from 603 tonnes/year under the current situation (Scenario 0) to 403 tonnes/year with a one-third improvement in water quality as a result of reduced nitrogen losses from all NPS (both dairying and sheep and beef farms) (Scenario 1) (Figure 44). If PS discharges were required to be removed from the river when the load for that flow decile category already meets or exceeds the Standard load limit as a result of NPS inputs, or were required to discharge a lesser volume and thereby reduce the PS load input with the exception of the top 10th percentile of flows (Scenario 2), the predicted Measured load would increase slightly to 410 tonnes/year. The Scenario 2 reduction in nitrogen load would still account for 154% of the SIN Standard load limit for the Mangatainoka at SH2 of 266 tonnes/year.

Changes in the BMP of NPS and PS nutrient loads also changes the proportional contribution of PS inputs to the Measured load at all flows. Under Scenario 0, PS contributes 1% of the Measured SIN load, 1% of the predicted SIN load under Scenario 1, and 2% of the predicted SIN load for Scenario 2 (Figure 45). To endeavor to be within the SIN Standard load limit, BMP for PS loads would require cessation of nitrogen discharge at flows above the 80th percentile except the top 10th percentile flows (Figure 47). Under Scenario 2 the two lowest of the flow decile categories would be able to receive increased PS discharges to a combined load of 9.9 tonnes/year. Unlike the Scenario 2 situation for the upper Manawatu catchment, this is a significant increase when compared to the current PS SIN load of 3.4 tonnes/year at all flows and 3 tonnes per year at flows below the 10th percentile in the Mangatainoka River.

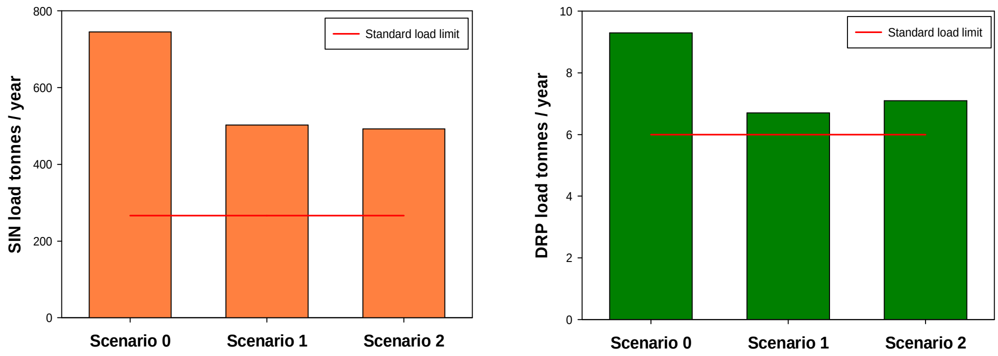


Figure 44: Predicted changes in annual Soluble Inorganic Nitrogen (SIN) and Dissolved Reactive Phosphorus (DRP) loads in the Mangatainoka River at SH2 as a result of three nutrient management scenarios.

Effects of phosphorus reduction on Measured loads

The Measured DRP load in the Mangatainoka River at SH2 is predicted to reduce from 9.3 tonnes/year under the current situation (Scenario 0) to 6.7 tonnes/year with a one-third improvement in water quality as a result of reduced phosphorus losses from all NPS (both dairying and sheep and beef farms) (Scenario 1) (Figure 44). If PS discharges were required to be removed from the river when the load for that flow decile category already meets or exceeds the Standard load limit (with the exception of the top 10^{th} percentile of flows), or were given the flexibility to discharge increased volumes depending on the flow decile and the current NPS DRP load (Scenario 2), the predicted Measured load would increase to 7.1 tonnes/year.

Changing the management regimes of PS and NPS nutrient inputs also changes their relative contributions to the Measured load. Under Scenario 0, PS contributes 16% of the Measured DRP load, 22% of the predicted DRP load under Scenario 1, and 27% of the predicted DRP load for Scenario 2 (Figure 46). To remain within the DRP Standard load limit, BMP for PS loads would require cessation of dissolved phosphorus discharge at the 30^{th} flow percentile and all higher flows except the top 10^{th} percentile (Figure 48). The seven lowest of the flow decile categories would be able to receive increased PS discharges to a combined load of 1.7 tonnes/year. This is an increase in DRP load when compared to the current PS DRP load of 1.5 tonnes/year at all flows and 1.3 tonnes/year at flows less than the 10^{th} percentile.

Because the current PS load of DRP in the Mangatainoka River is near or within the Standard load limit for the Mangatainoka for some flow deciles, using the same ‘best case scenario’ for PS as in the upper Manawatu River will increase DRP loads both annually and within many flow decile categories. This case study shows us that the development of an appropriate Scenario 2 incorporating BMP for PS nutrient inputs needs to be catchment-specific to ensure annual loads are reduced and nutrient enrichment decreased.

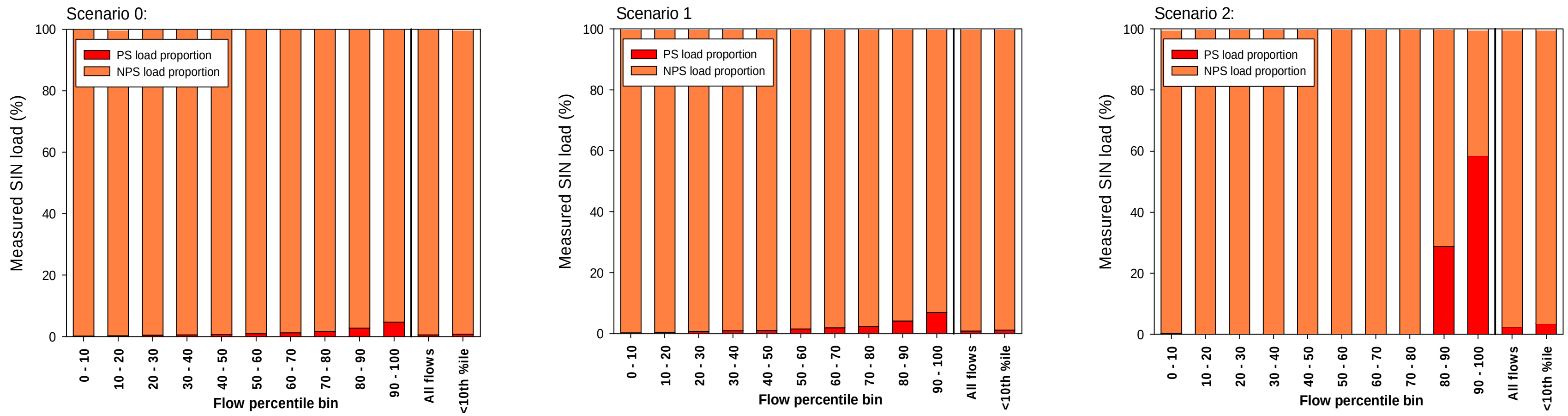


Figure 45: Actual and projected percentage contributions of Soluble Inorganic Nitrogen (SIN) from Non-Point Source (NPS) and Point Source (PS) inputs to the annual Measured load in the Mangatainoka River at SH2 under three nutrient management scenarios.

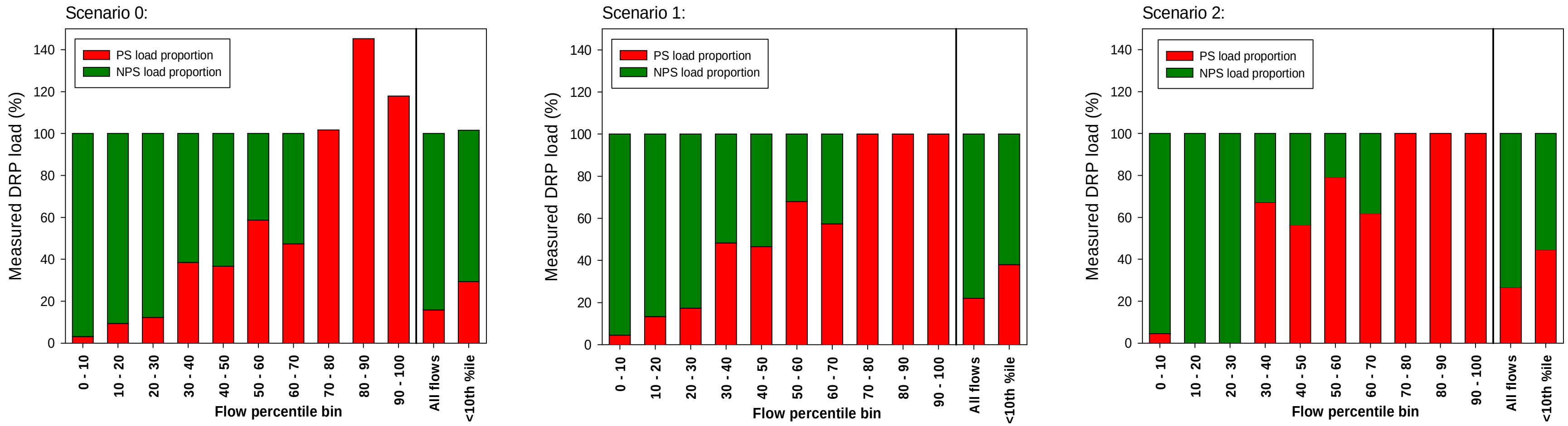


Figure 46: Actual and projected percentage contributions of Dissolved Reactive Phosphorus (DRP) from Non-Point Source (NPS) and Point Source (PS) inputs to the annual Measured load in the Mangatainoka River at SH2 under three nutrient management scenarios.

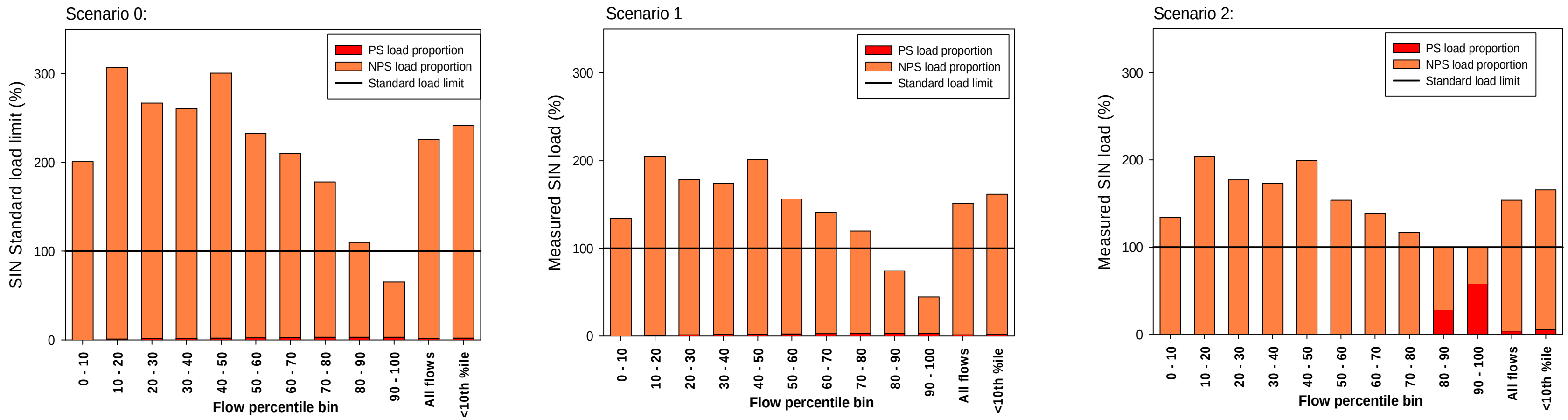


Figure 47: Actual and projected percentage contributions of Soluble Inorganic Nitrogen (SIN) from Non-Point Source (NPS) and Point Source (PS) inputs to the annual Standard load limit for the Mangatainoka River at SH2 under three nutrient management scenarios.

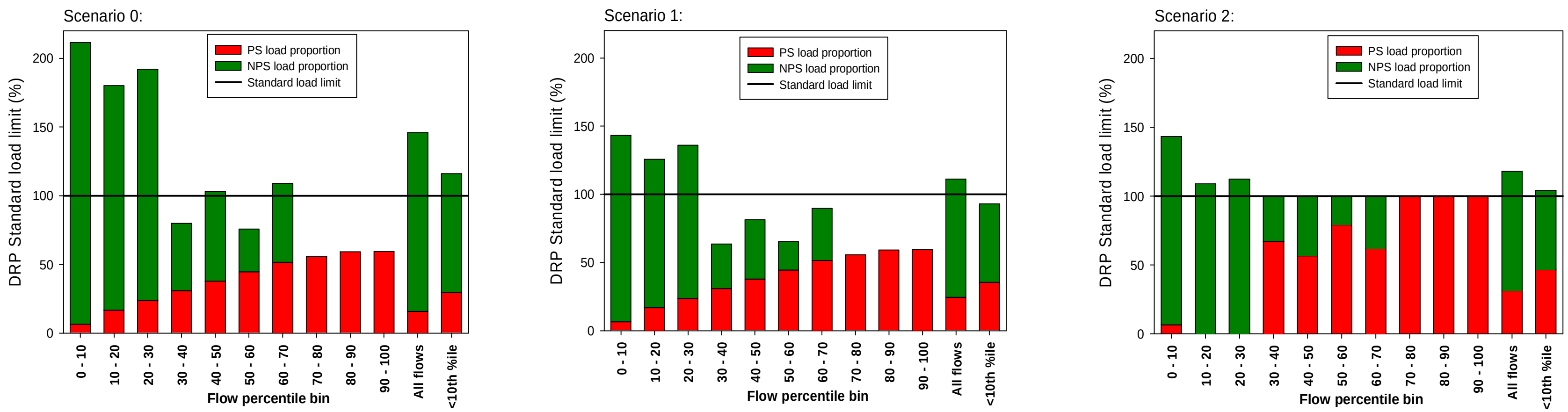


Figure 48: Actual and projected percentage contributions of Dissolved Reactive Phosphorus (DRP) from Non-Point Source (NPS) and Point Source (PS) inputs to the annual Standard load limit for the Mangatainoka River at SH2 under three nutrient management scenarios.

Summary of the BMP Scenarios 1 and 2 for the upper Manawatu

- Scenarios 1 and 2 would provide considerable reductions in SIN in the upper Manawatu, though Standard load limits would still be exceeded by 38%
- Scenarios 1 and 2 would provide considerable reductions in DRP in the upper Manawatu, though Standard load limits would still be exceeded by 50%
- Looking solely at SIN, PS would need to be removed from 6 flow deciles (10th – 70th), be discharged at a lesser rate in 1 decile (80th) and could have an increased discharge in the 2 lowest deciles (due to the absence of NPS SIN at these flows)
- Looking solely at DRP, PS would need to be removed from 4 flow deciles (10th – 50th) and be discharged at a lesser rate than current loads in the remaining 5 lower flow deciles
- In combination, to meet both SIN and DRP flow decile standards in the upper Manawatu, PS would need to be removed from below the 10th to the 70th percentile under Scenario 2, and discharged at a lesser rate (57–38% less than current loads) for the remaining flow percentiles (see Figure)
- For Scenario 2, PS discharge was assumed to continue at the current rate for the top 10th percentile of flows. However, the load at high flows could potentially be increased and/or discharge could occur at all flows greater than the top 20th percentile as an alternative to increasing discharge volumes at low flows and ceasing discharge for flow between to 10th and 70th percentiles.
- Combined Scenario 2 discharge regimes would result in annual loads of 12 tonnes per year of DRP and 490 tonnes per year of SIN.

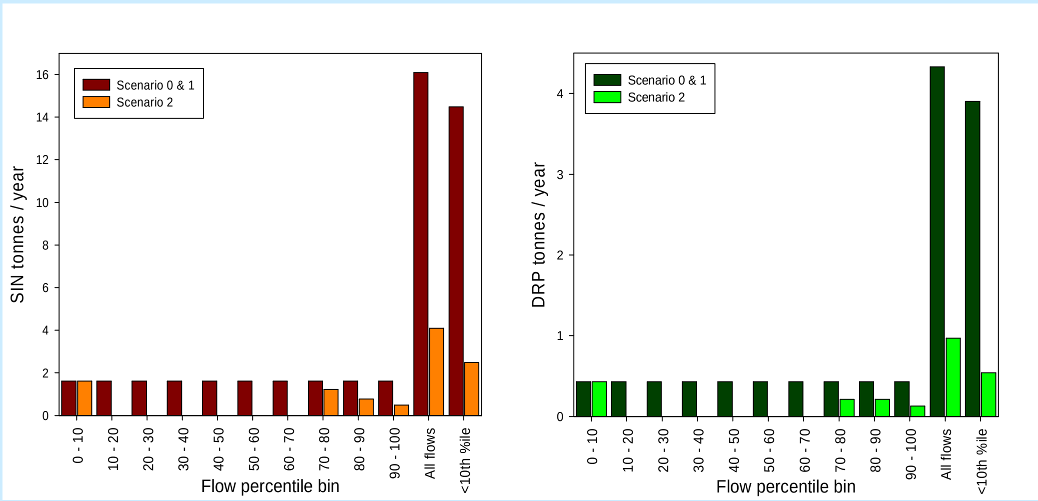


Figure: Comparison of PS loads of SIN and DRP to meet combined nutrient Standard load limits for all flow percentiles under BMP Scenario 2, upper Manawatu River.

Summary of the BMP Scenarios 1 and 2 for the Mangatainoka River

- Scenario 1 would provide considerable reductions in SIN in the Mangatainoka, though Standard load limits would still be exceeded by 52%
- Scenario 1 would provide considerable reductions in DRP in the Mangatainoka, though Standard load limits would still be exceeded by 11%
- Scenario 2 would increase both SIN and DRP loads in the Mangatainoka, if applied in the same manner as determined for the upper Manawatu
- Looking solely at SIN, PS would need to be removed from 7 flow deciles (10th – 80th) and could have an increased discharge rate in the remaining 2 lowest flow deciles
- Looking solely at DRP, PS would need to be removed from 2 flow deciles (10th – 30th) and could have an increased discharge rate in the remaining 7 lowest flow deciles
- Examining combined nutrient loads to meet both SIN and DRP flow decile standards in the Mangatainoka, PS would need to be removed from 7 flow deciles (10th - 80th). Discharge loads of both SIN and DRP could be 67% higher than current load estimates at flows < 80th percentile and still remain within the Standard load limits for those deciles (see Figure)
- For Scenario 2, PS discharge was assumed to continue at the current rate for the top 10th percentile of flows. However, the load at high flows could potentially be increased and/or discharge could occur at all flows greater than the top 20th percentile as an alternative to increasing discharge volumes at low flows and ceasing discharge for flow between to 10th and 70th percentiles.
- Combined Scenario 2 discharge regimes would result in annual loads of 5.9 tonnes/year of DRP and 401 tonnes/year of SIN.

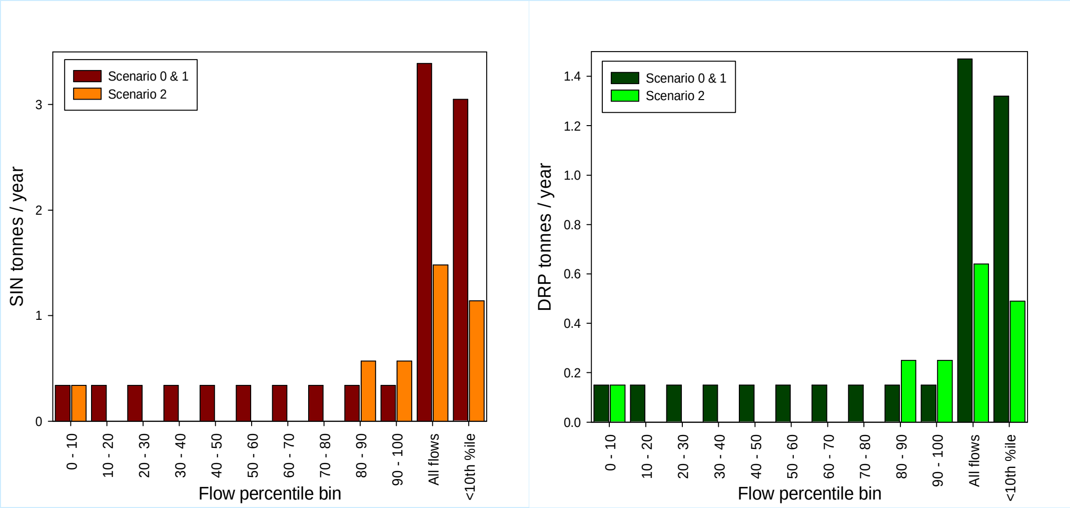


Figure: Comparison of PS loads of SIN and DRP to meet combined nutrient Standard load limits for all flow percentiles under BMP Scenario 2, Mangatainoka River.

7.4 Confounding issues in the combined management of PS and NPS loads to remain within Standard load limits for flow deciles

The difference in nutrient load and flow decile relationships between the two study catchments exemplifies the need for specific catchment management frameworks for both NPS and PS inputs. Given the above flow-stratified analysis, it appears that there is additional room for the discharge of PS nutrient loads at low flows in the Mangatainoka River. However, we know that high concentrations of both SIN and DRP have been measured at low flows in the Mangatainoka River at SH2 (Figure 8).

Reduction in nitrogen and phosphorus loads as a result of the implementation of best management practice for all dairy and sheep and beef farms, and reduction in PS discharges, will still result in nutrient loads in excess of the Standard load limits at most flow deciles and on an annual basis. Increasing the proportional contribution of PS nitrogen and phosphorus at lower flows (as described in Scenario 2 above), although viable in theory due to low NPS nutrient inputs at low flows, is counter-intuitive to reducing the risk of nuisance periphyton growth at times when longer biomass accrual periods occur (ie. low flows).

Separately examining the PS discharge of nitrogen and phosphorus is not a practicable or viable scenario for the management of effluent discharge in reality, as both contaminants occur within the same effluent stream. Thus the summaries for the upper Manawatu and Mangatainoka Rivers show the combined discharge requirements for PS under Scenario 2 in relation to both SIN and DRP Standard load limits.

If the effect of nutrient loads at high flows (i.e. > 10^{th} percentile) is negligible in terms of periphyton growth, it would be more appropriate to restrict PS discharges at low flows, allowing for discharge to occur mainly at the highest flows. Potentially, discharges could be allowed at elevated rates and loads during high flows, provided high flow conditions prevailed throughout the downstream catchment, although annually calculated Standard load limits may be exceeded. However, caution must be applied when allowing high PS nutrient loads at low flows to ensure that any particulate phosphorus in these discharges does not end up in bed sediments downstream, exacerbating the release of dissolved phosphorus during low flow events (as described by Parfitt *et al.,* 2007).

There are a number of biochemical in-stream processes that confound the estimated relationships between flow, nutrient load and Standard load limits at each site, such as:

- release of dissolved phosphorus from bed sediments during summer low flows (potentially as much as 4 tonnes/year in the upper Manawatu according to Parfitt *et al.* [2007]);
- attenuation and release of nutrients by periphyton accrual, and removal or luxury uptake and storage of nutrients by periphyton; and
- climatic influences and ecological thresholds affecting the biomass of nuisance periphyton growth in any given year.

The degree to which these factors affect nutrient and flow relationships is largely unknown and warrants considerably more examination.

More information is required to model different PS and NPS scenarios, specific to each catchment. For example, some of the current information gaps that have led to the assumptions underlying the scenarios above include:

- unknown maximum volumes (and loads) which could potentially be discharged from PS at high flows; and
- unknown variation in nutrient concentration and discharge volume from PS.

Several approaches have already been adopted to enable a better understanding of the complexities of PS nutrient loads. These approaches include the establishment of the Council's discharge monitoring programme (more detail is included in chapter 9 below), and recent consent decisions for PS discharges which include provision for telemetry of discharge volumes and the determination of water balance and concentration profiles under different rainfall conditions. Such studies, required by resource consent in many cases, are designed to characterise the effects of stormwater inflow and infiltration to treatment plants.

This framework has worked with the best available information at the time of writing, and as monitoring requirements are included via consent conditions or added to Council's monitoring programmes, our knowledge increases. We are currently in a much better state with regard to our level of knowledge and understanding than ever before, regarding the contributing factors to poor water quality. A number of projects that have contributed significantly to the development of this framework are ongoing, the findings of which will provide further evidence for the One Plan hearings process.

7.5 The Proposed One Plan nutrient output scenarios

7.5.1 One farm: One consent

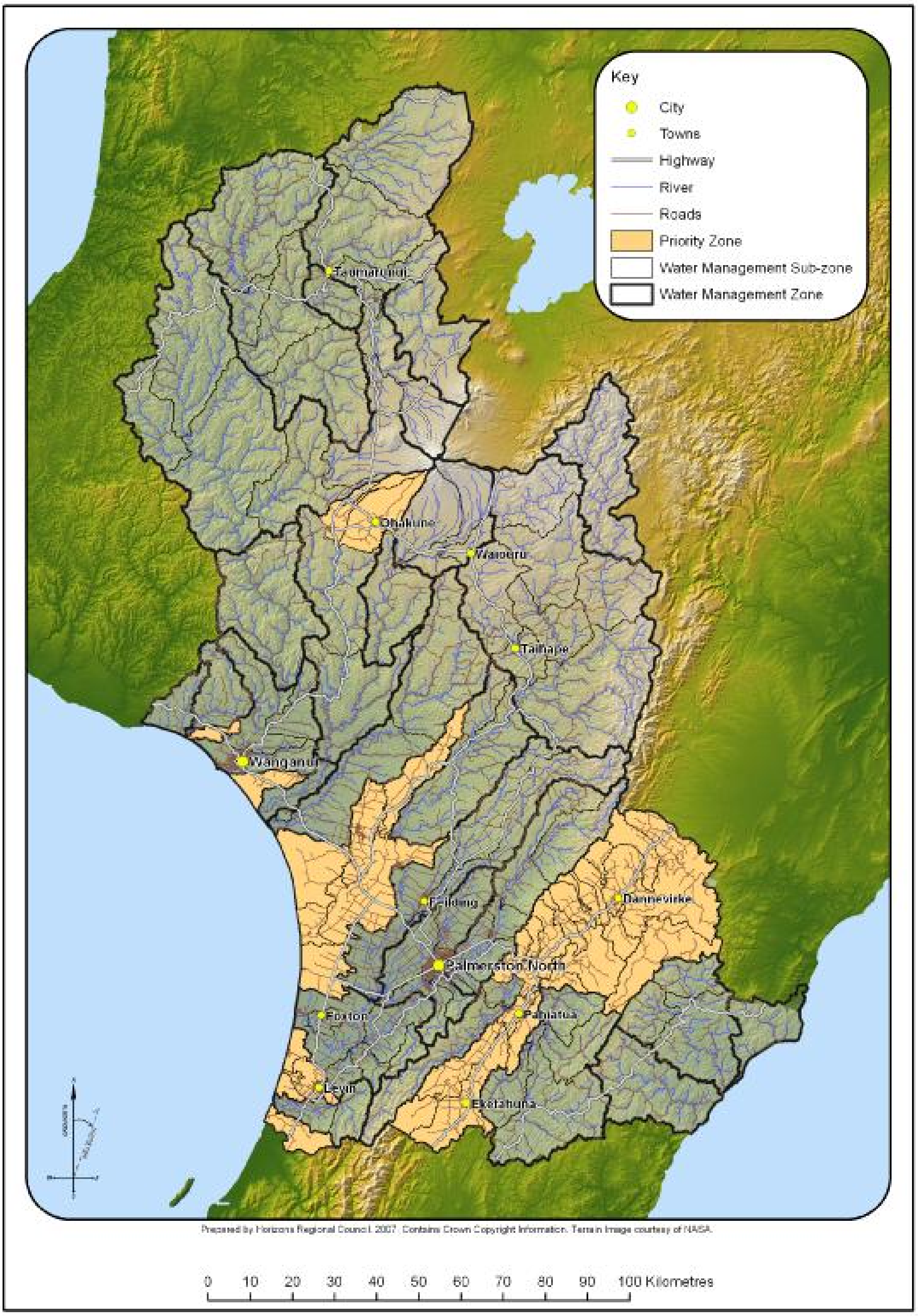
Under the Proposed One Plan, resource consent will be required for intensive land use operations such as dairying, irrigated sheep and beef, cropping or commercial vegetable growing within catchments affected by water quality pressure (Map 17). The Proposed One Plan defines nitrogen output limits for intensive land uses to achieve water quality objectives via Rule 13-1 (Table 26). The output limits are proposed to be phased in over time depending on water management zone, as determined within the Plan (Table 25).

An application for resource consent under Rule 13-1 will require the preparation of a FARM strategy (Farmer Applied Resource Management Strategy) according to the workbook specifications defined in the FARM strategy workbook (www.horizons.govt.nz/default.aspx?pageid=182). The purpose of the FARM strategy is to group the consent requirements under the Plan into a whole-farm package for improved manageability ie. 'one farm: one consent'. A key component of any FARM strategy is to minimise the environmental impacts associated with nitrogen, phosphorus and faecal contamination of freshwater resources.

There are no numerical loss limits for phosphorus defined in the One Plan; however, phosphorus and faecal contamination are key considerations addressed in the FARM whole-farm strategies. In conjunction with the FARM strategy, the sustainable land use initiative (SLUI) has a key goal of reducing erosion from highly erodible land, reducing particulate phosphorous inputs to waterways and the bed-deposited sediments that have the potential to remineralise DRP into the water column during low flow events (Parfitt *et al.,* 2007). Scenarios for phosphorus are not included in this section, however, all assumptions based on phosphorus reduction scenarios under the combined FARM strategy and SLUI approaches are addressed in the previous section of this chapter.

7.5.2 Resolution of LUC classification

Proposed Rule 13-1 specifies output targets for different Land Use Capability classes (LUC). The proposed nitrogen output limits were calculated using regional-scale LUC classifications contained in the New Zealand Land Resource Inventory (NZLRI) database. The FARM strategy allows for mapping of LUC classifications at the finer farm-scale via farm surveys, ie. high resolution LUC class maps for each individual farming enterprise. Changing the LUC resolution for each land use enterprise may alter the proportion of each LUC class within the catchment (Manderson & Mackay, 2008). In testing the FARM strategy, Manderson & Mackay (2008) found that using the higher resolution on-farm LUC class maps had the potential to either decrease or increase SIN loss limits.



Map 17: Priority water management zones and sub-zones designated for the implementation of FARM strategy and Rule 13.1 of the Proposed One Plan.

Table 25: Water Management Zones within which Rule 13.1 of the Proposed One Plan will apply and dates when rules will come into force (*Source: Table 13.1, Proposed One Plan*)

Catchment	Water Management Zone	Date the rules of the Plan come into force
Mangapapa	Mana_9b	1 April 2009
Mowhanau	West_3	1 April 2009
Mangatainoka	Mana_8a Mana_8b Mana_8c Mana_8d Mana_8e	1 April 2010
Upper Manawatu above Hopelands	Mana_1a Mana_1b Mana_1c Mana_2a Mana_2b Mana_3 Mana_4 Mana_5a Mana_5b Mana_5c Mana_5d Mana_5e	1 April 2011
Lake Horowhenua	Hoki_1a Hoki_1b	1 April 2012
Waikawa	West_9	1 April 2012
Manawatu above gorge	Mana_6 Mana_9a Mana_9c	1 April 2013
Other south-west catchments (Waitarere and Papaitonga)	West_7 West_8	1 April 2013
Other coastal lakes	West_4 West_5 West_6	1 April 2013
Coastal Rangitikei	Rang_4	1 April 2014
Mangawhero/Makotuku	Whau_3b Whau_3c Whau_3d	1 April 2015

Table 26: Land Use Capability (LUC) Nitrogen Leaching/Run-off Values proposed to apply under Rule 13.1 for Water Management Zones and by dates specified in Table 13.1 of the Proposed One Plan (*Source: Table 13.2, Proposed One Plan*).

	LUC I	LUC II	LUC III	LUC IV	LUC V	LUC VI	LUC VII	LUC VIII
Year 1 (when rule comes into force) (kg of N/ ha/year)	32	29	22	16	13	10	6	2
Year 5 (kg of N/ ha/year)	27	25	21	16	13	10	6	2
Year 10 (kg of N/ ha/year)	26	22	19	14	13	10	6	2
Year 20 (kg of N/ ha/year)	25	21	18	13	12	10	6	2

7.5.3 Testing the Rule 13-1 nitrogen loss limits

Following on from Scenarios 0, 1 and 2 described in the previous section of this chapter, four more nitrogen management scenarios have been proposed which model the implementation of Rule 13-1 output loss limits over a 20-year time-span. These scenarios are the basis for the upper Manawatu and Mangatainoka catchment results included below. Any underlying assumptions regarding the input of nitrogen from PS remain as detailed in the section above.

Proposed One Plan scenarios for nitrogen loss limits in the upper Manawatu and Mangatainoka Rivers

Scenario 3: The Year 1 NPS target load and BMP for PS SIN

Scenario 4: The Year 5 NPS target load and BMP for PS SIN

Scenario 5: The Year 10 NPS target load and BMP for PS SIN

Scenario 6: The Year 20 NPS target load and BMP for PS SIN

7.5.4 Upper Manawatu results

Using the One Plan NPS target loads for nitrogen based on LUC classes in the upper Manawatu, loads of 859, 824, 773, and 751 tonnes/year for years 1, 5, 10 and 20 respectively were determined (Table 28). These NPS Target loads were higher than the current Measured load of 745 tonnes/year and the NPS load of 729 tonnes/year. The NPS target loads are 18%, 13%, 6% and 3% higher than the measured NPS load for the upper Manawatu River at Hopelands.

Furthermore, the NPS target loads are higher than the estimated load of 486 tonnes SIN/year calculated from the recommendations of Clothier *et al.* (2007) to achieve a one-third improvement in NPS loads. At present, the Measured load is a result of the nutrient losses from the proportion of the study catchment that is being intensively used. Some intensive enterprises may currently have higher nitrogen losses than the output limits specified in Table 28 and others may have losses within the limits specified.

According to the LUC classification, there is still potential for the expansion of intensive farming enterprises or the conversion of sheep and beef to more intensive land uses in the upper Manawatu catchment. Therefore calculating NPS target loads from all LUC classes reflects the potential future increases in nitrogen losses to waterways under an intensified scenario.

Table 30 shows the projected changes by flow decile in NPS nitrogen loads measured in the Upper Manawatu at Hopelands for each nutrient management scenario. Scenarios 0 and 2 show the current state and 'One-third improvement' scenarios respectively. The combined PS discharge load calculated to meet both the SIN and DRP standards has been used as the projected PS load for Scenarios 2 through 6.

The shaded cells in Table 30 highlight SIN loads that are projected to fall within the Standard load limit for the flow decile category. As can be seen from the table, Scenario 2 provides the highest contribution to reducing nitrogen loads at low flow deciles with loads below the Standard load limit in the three lowest flow deciles. Although scenarios 3 through 6 project nitrogen loads lower than the current Measured load at the lowest flow decile, over all flow deciles no further reductions are achieved. However, it is important to keep in mind that loads for these scenarios were determined assuming full intensive utilisation of all land in the upper Manawatu capable of being intensively used, according to the LUC classification.

7.5.5 Mangatainoka results

The One Plan NPS target loads for nitrogen in the Mangatainoka River calculated loads of 360, 334, 311, and 301 tonnes/year for years 1, 5, 10 and 20 respectively (Table 29). Unlike the scenario in the upper Manawatu catchment, the NPS target loads are much lower than the current Measured load of 603 tonnes/year and the NPS load of 600 tonnes/year. The NPS target loads are 40%, 56%, 52% and 50% lower than the measured NPS load for the Mangatainoka River at State Highway 2.

The NPS target loads for nitrogen are lower than the estimated load of 400 tonnes SIN/year calculated from the one-third improvement recommendations of Clothier *et al.* (2007). At present the Measured load comes from the proportion of the study catchment that is being intensively used. Some intensive enterprises will have higher nitrogen losses than the output limits specified in Table 29, and others may have losses within the limits specified.

Land use in the Mangatainoka catchment is already intensified to a greater degree than in the upper Manawatu catchment, with a larger proportion of the Mangatainoka catchment in dairying (Table 27 and appendices). Because of this greater degree of intensification the loss limits calculated using Rule 13-1 are closer to the one-third improvement (Scenario 2) loads (Table 31).

7.5.6 Catchment comparison

The differences between the proposed NPS target loads, the Measured loads and estimates of Clothier *et al.* (2007) in the upper Manawatu and Mangatainoka catchments, are a reflection of the proportion of intensive land use by LUC class in each of the study catchments. As discussed in an earlier section the upper Manawatu catchment above Hopelands has a higher proportion of sheep and beef farming than dairying or any other intensive land use, whereas the Mangatainoka catchment has a greater proportion of intensively used land in more productive LUC classes.

The outcome of this is that the NPS target loads, based on LUC classification, allow for intensive land use to expand considerably in the upper Manawatu catchment.

Table 27: Comparison of proportional land use type and Land Use Capability (LUC) class in the upper Manawatu (whole catchment above Hopelands) and the Mangatainoka River catchments (*Source: Clark & Roygard, 2008*)

Land use type	upper Manawatu	Mangatainoka	LUC class	upper Manawatu	Mangatainoka
Built-up/Parks	-	1%	1	-	1%
Cropping	-	-	2	10%	22%
Dairy	16%	28%	3	16%	13%
Exotic Cover	3%	2%	4	9%	3%
Horticulture	-	-	5	1%	1%
Native Cover	10%	18%	6	13%	37%
Other	1%	-	7	8%	16%
Sheep & Beef	69%	51%	8	5%	8%
Water Body	-	-	Blank	-	1%

Table 28: Proposed nitrogen output limits and Measured loads resulting from the implementation of Rule 13-1 of the Proposed One Plan for the water management zones of the upper Manawatu River above the Hopelands monitoring site. *(Note: Nitrogen attenuation of 50% between the land and river was assumed according to Clothier et al., 2007 and Mackay et al., 2008).*

upper Manawatu		LUC I	LUC II	LUC III	LUC IV	LUC V	LUC VI	LUC VII	LUC VIII	Total
Output loss limit	**Year 1** (when rule comes into force) (kg of N/ ha/year)	32	29	22	16	13	10	6	2	
	Year 5 (kg N/ha/year)	27	25	21	16	13	10	6	2	
	Year 10 (kg N/ha/year)	26	22	19	14	13	10	6	2	
	Year 20 (kg N/ha/year)	25	21	18	13	12	10	6	2	
Area of LUC in upper Manawatu (ha)		0	12424	20257	11508	907	57254	22108	5180	129638
Measured load (in-river)	**Year 1** (Tonnes/year)	0	180	223	92	6	286	66	5	859
	Year 5 (Tonnes/year)	0	155	213	92	6	286	66	5	824
	Year 10 (Tonnes/year)	0	137	192	81	6	286	66	5	773
	Year 20 (Tonnes/year)	0	130	182	75	5	286	66	5	751
Standard load limit (Tonnes/year)										358
Measured load (Tonnes/year)										745
NPS load (Tonnes/year)										729[13]

[13] Note: the Measured load figure differs from the 'current state' figure published by Mackay *et al.* (2008) due to differences in the calculation of PS nitrogen loads for the upper Manawatu catchment.

Table 29: Proposed nitrogen output limits and Measured loads resulting from the implementation of Rule 13-1 of the Proposed One Plan for the water management zones of the Mangatainoka River. *(Note: Nitrogen attenuation of 50% between the land and river was assumed according to Clothier et al., 2007 and Mackay et al., 2008).*

Mangatainoka		LUC I	LUC II	LUC III	LUC IV	LUC V	LUC VI	LUC VII	LUC VIII	Total
Output loss limit	**Year 1** (when rule comes into force) (kg of N/ ha/year)	32	29	22	16	13	10	6	2	
	Year 5 (kg N/ha/year)	27	25	21	16	13	10	6	2	
	Year 10 (kg N/ha/year)	26	22	19	14	13	10	6	2	
	Year 20 (kg N/ha/year)	25	21	18	13	12	10	6	2	
Area of LUC in Mangatainoka (ha)		549	10394	6074	1498	409	18110	8057	3874	48965
Measured load (in-river)	**Year 1** (Tonnes/year)	8.8	150.7	66.8	12	2.7	90.6	24.2	3.9	360
	Year 5 (Tonnes/year)	7.4	129.9	63.8	12.0	2.7	90.6	24.2	3.9	334
	Year 10 (Tonnes/year)	7.1	114.3	57.7	10.5	2.7	90.6	24.2	3.9	311
	Year 20 (Tonnes/year)	6.9	109.1	54.7	9.7	2.5	90.6	24.2	3.9	301
Standard load limit (Tonnes/year)										266[14]
Measured load (Tonnes/year)										603
NPS load (Tonnes/year)										599.6[15]

[14] Note: this figure also differs from Mackay *et al.* (2008) due to differences in the calculation of Standard load limits for the Mangatainoka catchment.

[15] Note: this figure also differs from the figure published by Mackay *et al.* (2008) due to differences in the calculation of PS nitrogen loads for the Mangatainoka catchment.

Table 30: Projected results for the upper Manawatu River at Hopelands Measured Soluble Inorganic Nitrogen (SIN) load (tonnes/year) for four management scenarios proposed under Rule 13-1 of the One Plan. Shaded cells show where loads were within the Standard load limit for that flow decile. (*Note: Scenario 2 used combined PS improvements to meet both DRP and SIN Standard load limits as described in the summaries above*).

Scenario	Flow decile	0-10th	10th -20th	20th -30th	30th -40th	40th -50th	50th -60th	60th -70th	70th -80th	80th -90th	90th -100th	All flows	Flows less than the 10th percentile
Scenario 0: No change: current state													
Standard load limit	**tonnes SIN/year**	**146.7**	**55.7**	**39.3**	**30.1**	**24.0**	**19.4**	**15.5**	**12.3**	**9.2**	**5.7**	**358.0**	**211.3**
PS load	tonnes SIN/year	1.61	1.61	1.61	1.61	1.61	1.61	1.61	1.61	1.61	1.61	16.1	14.49
NPS load	tonnes SIN/year	265.8	117.6	102.7	74.9	64.2	44.3	28.3	17.3	10.8	3.1	729	463.2
Measured load	tonnes SIN/year	267.4	119.3	104.3	76.5	65.8	45.9	30.0	18.9	12.4	4.7	745.1	477.7
Scenario 2: Combined BMP for NPS and PS													
PS load	tonnes SIN/year	1.61	0	0	0	0	0	0	1.23	0.77	0.48	4.09	2.48
NPS load	tonnes SIN/year	177.2	78.4	68.4	49.9	42.8	29.5	18.9	11.6	7.2	2.1	486	308.8
Measured load	tonnes SIN/year	178.8	78.4	68.4	49.9	42.8	29.5	18.9	12.8	8.0	2.6	490.1	311.3
Scenario 3: Year 1 output loss limits and BMP PS													
PS load	tonnes SIN/year	1.61	0	0	0	0	0	0	1.23	0.77	0.48	4.09	2.48
NPS load	tonnes SIN/year	313.2	138.6	121	88.3	75.6	52.2	33.4	20.4	12.7	3.7	859	545.8
Measured load	tonnes SIN/year	314.8	138.6	121	88.3	75.6	52.2	33.4	21.6	13.5	4.1	863.1	548.3
Scenario 4: Year 5 output loss limits and BMP PS													
PS load	tonnes SIN/year	1.61	0	0	0	0	0	0	1.23	0.77	0.48	4.09	2.48
NPS load	tonnes SIN/year	300.4	133	116	84.7	72.5	50.1	32	19.6	12.2	3.5	824	523.6
Measured load	tonnes SIN/year	302	133	116	84.7	72.5	50.1	32	20.8	13	4	828.1	526.1
Scenario 5: Year 10 output loss limits and BMP PS													
PS load	tonnes SIN/year	1.61	0	0	0	0	0	0	1.23	0.77	0.48	4.09	2.48
NPS load	tonnes SIN/year	281.8	124.7	108.8	79.4	68.1	47	30.1	18.4	11.4	3.3	773	491.2
Measured load	tonnes SIN/year	283.4	124.7	108.8	79.4	68.1	47	30.1	19.6	12.2	3.8	777.1	493.7
Scenario 6: Year 20 output loss limits and BMP PS													
PS load	tonnes SIN/year	1.61	0	0	0	0	0	0	1.23	0.77	0.48	4.09	2.48
NPS load	tonnes SIN/year	273.8	121.2	105.7	77.2	66.1	45.6	29.2	17.8	11.1	3.2	751	477.2
Measured load	tonnes SIN/year	275.4	121.2	105.7	77.2	66.1	45.6	29.2	19.1	11.9	3.7	755.1	479.7

Table 31: Projected results for the Mangatainoka River at State Highway 2 Measured Soluble Inorganic Nitrogen (SIN) load (tonnes/year) for four management scenarios proposed under Rule 13-1 of the One Plan. Shaded cells show where loads were within the Standard load limit for that flow decile. (*Note: Scenario 2 used combined PS improvements to meet both DRP and SIN Standard load limits as described in the summaries above*).

Scenario	Flow decile	0-10th	10th -20th	20th -30th	30th -40th	40th -50th	50th -60th	60th -70th	70th -80th	80th -90th	90th -100th	All flows	Flows less than the 10th percentile
Scenario 0: No change: current state													
Standard load limit	**tonnes SIN/year**	**100.5**	**38.9**	**27.6**	**21.2**	**17.2**	**14.6**	**12.6**	**11.7**	**11.0**	**11.0**	**266.3**	**165.8**
PS load	tonnes SIN/year	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	3.39	3.05
NPS load	tonnes SIN/year	201.6	119.3	73.3	54.9	51.4	33.8	26.2	20.5	11.8	6.8	599.4	397.9
Measured load	tonnes SIN/year	201.9	119.6	73.6	55.2	51.8	34.1	26.6	20.8	12.1	7.2	602.8	400.9
Scenario 2: Combined BMP for NPS and PS													
PS load	tonnes SIN/year	0.34	0	0	0	0	0	0	0	0.57	0.57	1.48	1.14
NPS load	tonnes SIN/year	134.4	79.5	48.8	36.6	34.3	22.5	17.5	13.7	7.8	4.6	399.6	265.2
Measured load	tonnes SIN/year	134.7	79.5	48.8	36.6	34.3	22.5	17.5	13.7	8.4	5.1	401.1	266.4
Scenario 3: Year 1 output loss limits and BMP PS													
PS load	tonnes SIN/year	0.34	0	0	0	0	0	0	0	0.57	0.57	1.48	1.14
NPS load	tonnes SIN/year	121.1	71.6	44.0	33.0	30.9	20.3	15.7	12.3	7.1	4.1	360	238.9
Measured load	tonnes SIN/year	121.4	71.6	44.0	33.0	30.9	20.3	15.7	12.3	7.6	4.7	361.5	240.1
Scenario 4: Year 5 output loss limits and BMP PS													
PS load	tonnes SIN/year	0.34	0	0	0	0	0	0	0	0.57	0.57	1.48	1.14
NPS load	tonnes SIN/year	112.3	66.4	40.8	30.6	28.7	18.8	14.6	11.4	6.6	3.8	334	221.7
Measured load	tonnes SIN/year	112.7	66.4	40.8	30.6	28.7	18.8	14.6	11.4	7.1	4.4	335.5	222.8
Scenario 5: Year 10 output loss limits and BMP PS													
PS load	tonnes SIN/year	0.34	0	0	0	0	0	0	0	0.57	0.57	1.48	1.14
NPS load	tonnes SIN/year	104.6	61.9	38.0	28.5	26.7	17.5	13.6	10.6	6.1	3.5	311	206.4
Measured load	tonnes SIN/year	104.9	61.9	38.0	28.5	26.7	17.5	13.6	10.6	6.7	4.1	312.5	207.6
Scenario 6: Year 20 output loss limits and BMP PS													
PS load	tonnes SIN/year	0.34	0	0	0	0	0	0	0	0.57	0.57	1.48	1.14
NPS load	tonnes SIN/year	101.2	59.9	36.8	27.6	25.8	16.9	13.2	10.3	5.9	3.4	301	199.8
Measured load	tonnes SIN/year	101.6	59.9	36.8	27.6	25.8	16.9	13.2	10.3	6.5	4.0	302.5	200.9

Summary of the One Plan nitrogen Scenarios 3, 4, 5 and 6

Upper Manawatu:

- One Plan NPS target loads, based on LUC class for the upper Manawatu were calculated at Year 1 = 859, Year 5 = 824, Year 10 = 773 and Year 20 = 751 tonnes SIN per year.
- The Standard load limit for the upper Manawatu at Hopelands is 358 tonnes SIN per year.
- The target NPS loads were higher than the current NPS load of 729 tonnes per year.
- The target NPS loads of the Proposed One Plan were higher than the ‘one-third improvement’ scenario suggested by Clothier *et al.* (2007) of 486 tonnes per year.
- The high target NPS loads are the result of the use of LUC classes to calculated potential nitrogen losses, based on the potential land use capability in the upper Manawatu catchment.
- Current nitrogen losses from intensive land uses (across the catchment as a whole), lower than the Rule 13-1 limits may also be interpreted from these results.
- The target NPS loads assume a full land use intensification scenario.
- Results show little room for PS nutrient inputs to the upper Manawatu under Scenarios 3, 4, 5 and 6, other than at the lowest flow decile.

Summary of the One Plan nitrogen Scenarios 3, 4, 5 and 6

Mangatainoka River:

- One Plan NPS target loads, based on LUC class for the Mangatainoka were calculated at Year 1 = 360, Year 5 = 334, Year 10 = 311 and Year 20 = 301 tonnes SIN per year.
- The Standard load limit for the Mangatainoka at SH2 is 266 tonnes SIN per year.
- If implemented, the NPS target load would significantly reduce nitrogen loads with the projected Year 20 load halving the current NPS load of 600 tonnes per year.
- The target NPS loads of the Proposed One Plan were lower than the 'one-third improvement' scenario suggested by Clothier *et al.* (2007) of 400 tonnes per year.
- The comparison between the target NPS loads, the one-third improvement loads and the current Measured load reflects the higher degree of land use intensification by LUC class in the Mangatainoka catchment, when compared to the upper Manawatu.
- Current nitrogen losses from intensive land uses (across the catchment as a whole), higher than the Rule 13-1 limits, may also be interpreted from these results.
- Results show some room for PS nutrient inputs to the Mangatainoka under Scenarios 3, 4, 5 and 6, though still only at the lowest flow deciles.

8. Conclusions

8.1 Which management scenario is the most effective?

This report has presented and compared a number of nutrient management scenarios using real data from two study catchments, subject to nutrient enrichment from point and non-point sources. In order to compare the projected results of these management scenarios on nutrient loads in the study catchments, a simplified summary of the scenarios for both nitrogen and phosphorus is presented in Figure 49, Figure 50, Figure 51 and Figure 52 below.

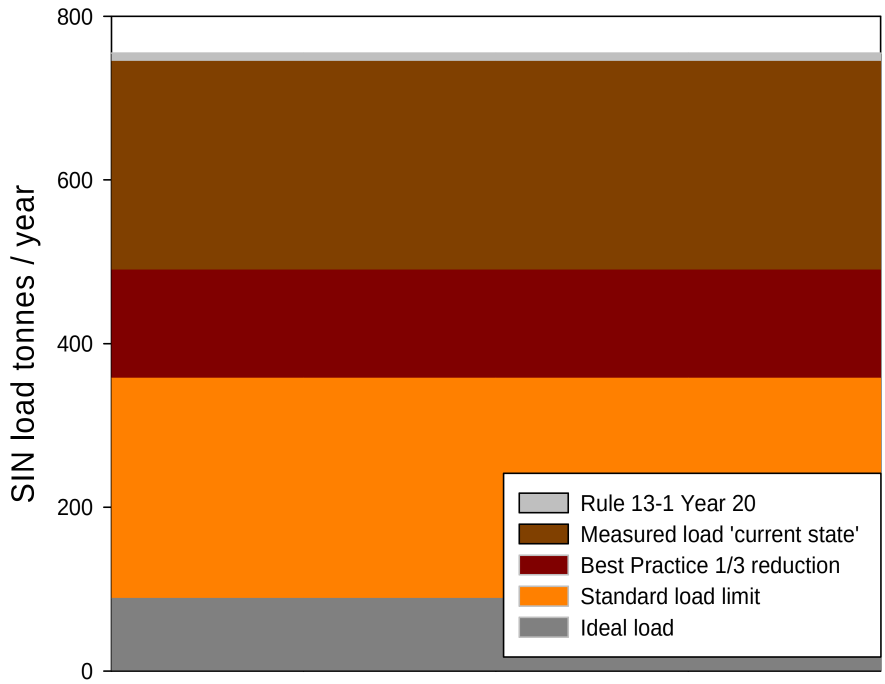


Figure 49: Simplified comparison of ideal, current and projected Soluble Inorganic Nitrogen (SIN) loads in the upper Manawatu River at Hopelands. The ideal load relates to the nitrogen standard proposed by Dr Biggs in Ausseil & Clark, 2007b)

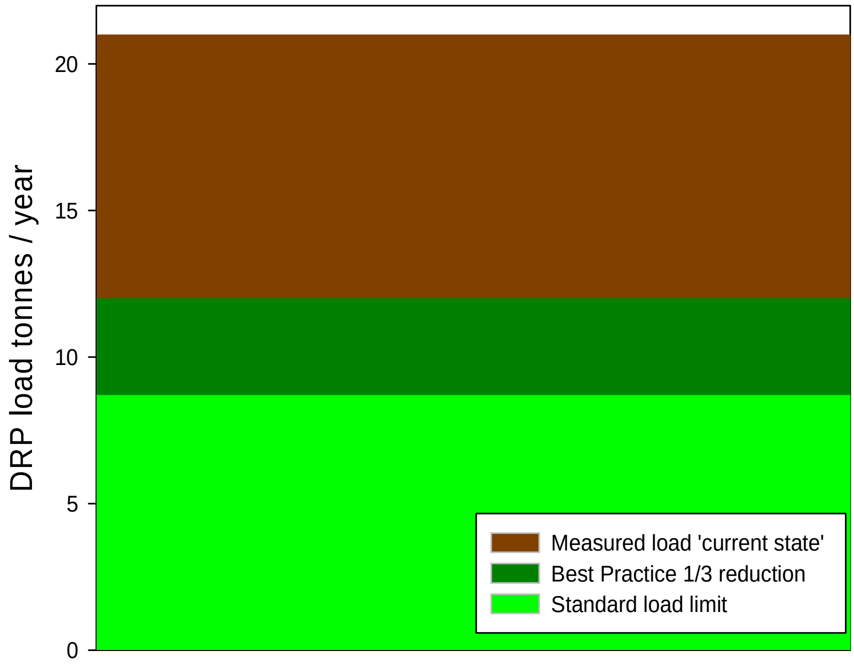


Figure 50: Simplified comparison of ideal, current and projected Dissolved Reactive Phosphorus (DRP) loads in the Manawatu River at Hopelands.

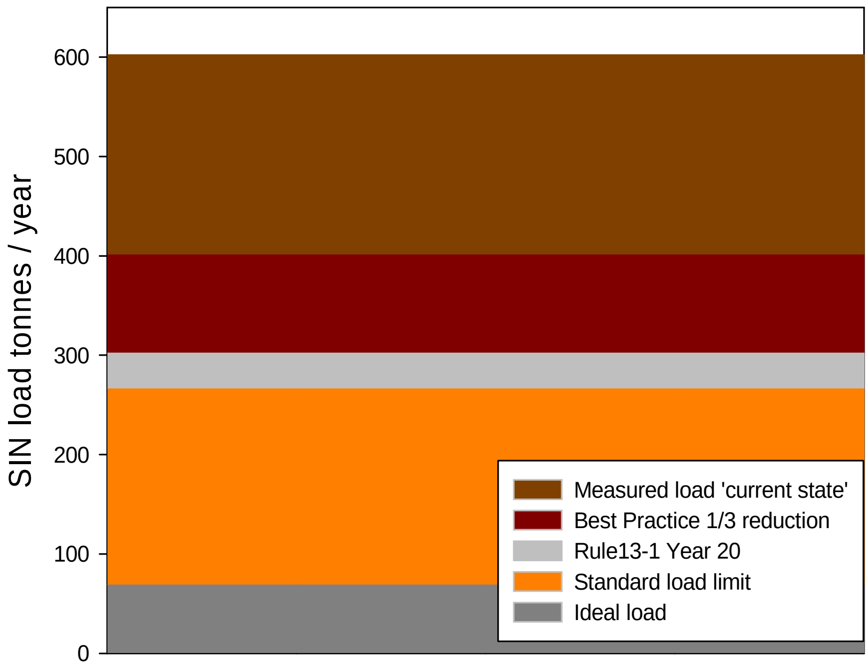


Figure 51: Simplified comparison of ideal, current and projected Soluble Inorganic Nitrogen (SIN) loads in the Mangatainoka River at SH2. The ideal load relates to the nitrogen standard proposed by Dr Biggs in Ausseil & Clark, 2007b)

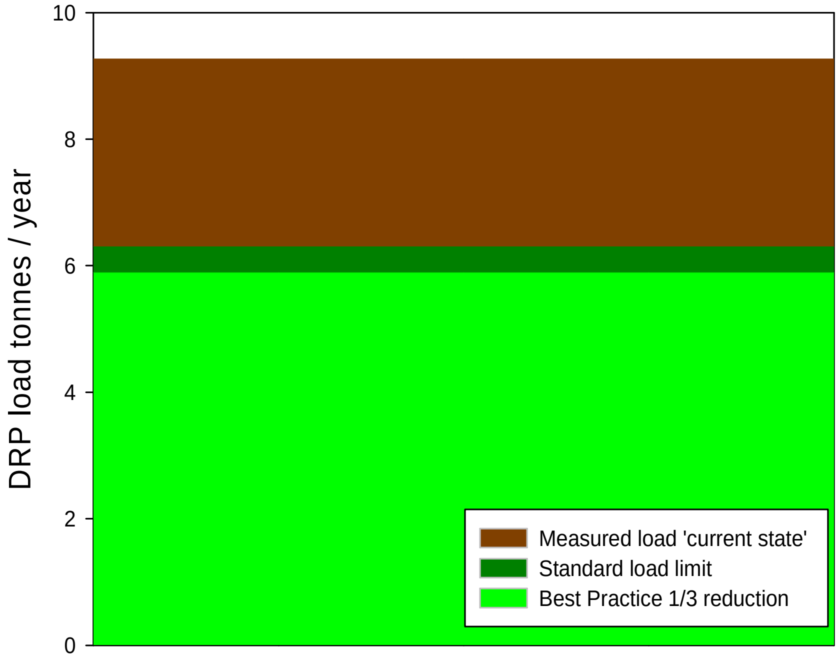


Figure 52: Simplified comparison of ideal, current and projected Dissolved Reactive Phosphorus (DRP) loads in the Mangatainoka River at SH2.

As the diagrams above show, the ideal soluble nitrogen (SIN) and dissolved phosphorus (DRP) loads are well exceeded when compared with the current state in the upper Manawatu and the Mangatainoka catchments. Results have shown that the majority of this annual nutrient load comes from NPS inputs, and occurs largely during higher flows.

In the upper Manawatu the 1/3 reduction proposed by Clothier *et al.* (2007) would significantly reduce SIN and DRP loads, but the Rule 13-1 Year 20 NPS target load proposed in the One Plan will allow for a considerably greater load of SIN in a total intensification scenario. It is difficult to know what the Measured load resulting from the implementation of the Year 20 NPS target loads will be in reality, as this will largely depend on the rate of any intensification in the upper Manawatu catchment and the implementation of the proposed Rule.

In the Mangatainoka the 1/3 reduction proposed by Clothier *et al.* (2007) will achieve a considerable reduction in SIN loads, but this may potentially be exceeded if the Rule 13-1 Year 20 NPS target loads are fully realised. With regards to DRP, best practice reduction methods may reduce annual loads to levels near the Standard load limit.

Deciding on a NPS target load for implementation in any catchment requires consideration of many factors. From a technical perspective, the annual variability in flow and Standard load limit or Measured nutrient load should be factored into the decision-making process (see section 4.3.1).

8.2 Summary

This report has provided an analysis framework to assist water resource decision-makers in understanding the complex and varied nutrient and flow relationships in catchments, subject to enrichment from point and non-point sources. The key aim of the report was to inform decision-making around water management from a technical perspective.

In comparing two study catchments, we have found that nutrient and flow relationships vary depending on the nutrient of interest, the environmental variables, and the human impacts that influence river flow regimes, total nutrient loads and nutrient transport from the landscape to surface water at the catchment scale. In order to make informed management decisions regarding the freshwater resources of individual catchments, based on a good understanding of the complex relationships at work, the process outlined in the preceding chapters should be followed.

In brief, any analysis of catchments for the purposes of managing water quality with respect to nitrogen and/or phosphorus enrichment should include the following steps:

1. Determine the Standard load limit for the catchment based on flow record and concentration-based water quality standards;
2. Determine the average annual Measured load and compare to the Standard load limit;
3. Describe the significant PS nutrient inputs and estimate the PS loads;
4. Calculate the relative inputs of PS and NPS using Measured loads and PS load estimates (Scenario 0);
5. Estimate the potential for NPS load improvements (Scenario 1) and describe the combined BMP for PS and NPS loads (Scenario 2);
6. Calculate the projected NPS target loads from Rule 13-1, based on LUC class (Scenarios 3, 4, 5 and 6); and
7. Recommend an approach for PS management, given the NPS loads under various nutrient management scenarios.

In undertaking this analysis a number of conservative and permissive steps have been applied to decisions on the technical approach and content of this framework. Table 32 outlines the nature of the technical decision-making involved in the development of the framework approach. At times taking the most pragmatic approach was necessary to develop the technical framework, due to limitations of the data or limitations of what could realistically be achieved, in terms of nutrient reduction.

Table 32: Conservative and permissive decisions on technical approaches to the framework for nutrient management in rivers of the Manawatu-Wanganui Region.

Conservative	Permissive
Adopting a 0.01 g/m^3 DRP standard: the operative DRP standard is 0.15 g/m^3. However, Dr Biggs recommended a 0.01 g/m^3 DRP standard for the upper Manawatu at Hopelands	Adopting a 0.444 g/m^3 SIN standard: the recommended standard from Dr Biggs was 0.110 g/m^3
Recommending the standards apply at < 10th percentile of flow: potentially the standards could be made to apply at flows < 20th percentile instead and still reflect the 3*Q_{50} approach currently proposed in the One Plan	
	When assessing compliance with the POP standards, comparing the annual average (based on monthly sampling) to the standards for DRP or SIN
Applying the sum of the average standard load for each flow decile as the Standard load limit: the sum of the medians for each flow decile produced a higher Standard load limit	
	Assuming only 'significant' PS discharges contribute to the Measured load
	Assuming all land is utilised to the maximum of the LUC class potential
	Assuming (via Overseer®) that best management practice occurs on all intensive land use enterprises
	Using an annual time step approach (via Overseer®) to determine nutrient losses and loss limits
	Averaging nutrient loss limits over all land area of a farming enterprise (see Manderson & Mackay, 2008)

To achieve a robust analysis under this framework, a high level of data collection is required, particularly with regard to flow recording, SOE water quality monitoring, and the monitoring of significant discharges. The following chapter outlines the data collection, research requirements and recommendations, and gives an overview of the approaches recently adopted to facilitate appropriate data collection and policy effectiveness monitoring throughout the Manawatu-Wanganui Region.

9. Monitoring and Reporting

9.1 SOE review

As a result of the development of this framework and the work by McArthur & Clark (2007) to define nutrient loads throughout the Region, and work undertaken to define and test the framework recommended in this report, a review of the water quantity and SOE water quality monitoring programmes was undertaken. In the same manner as McArthur *et al.* (2007) defined key selection criteria in the development of the water management zones, selection criteria for the SOE review were determined and ranked according to the Council's strategic monitoring priorities.

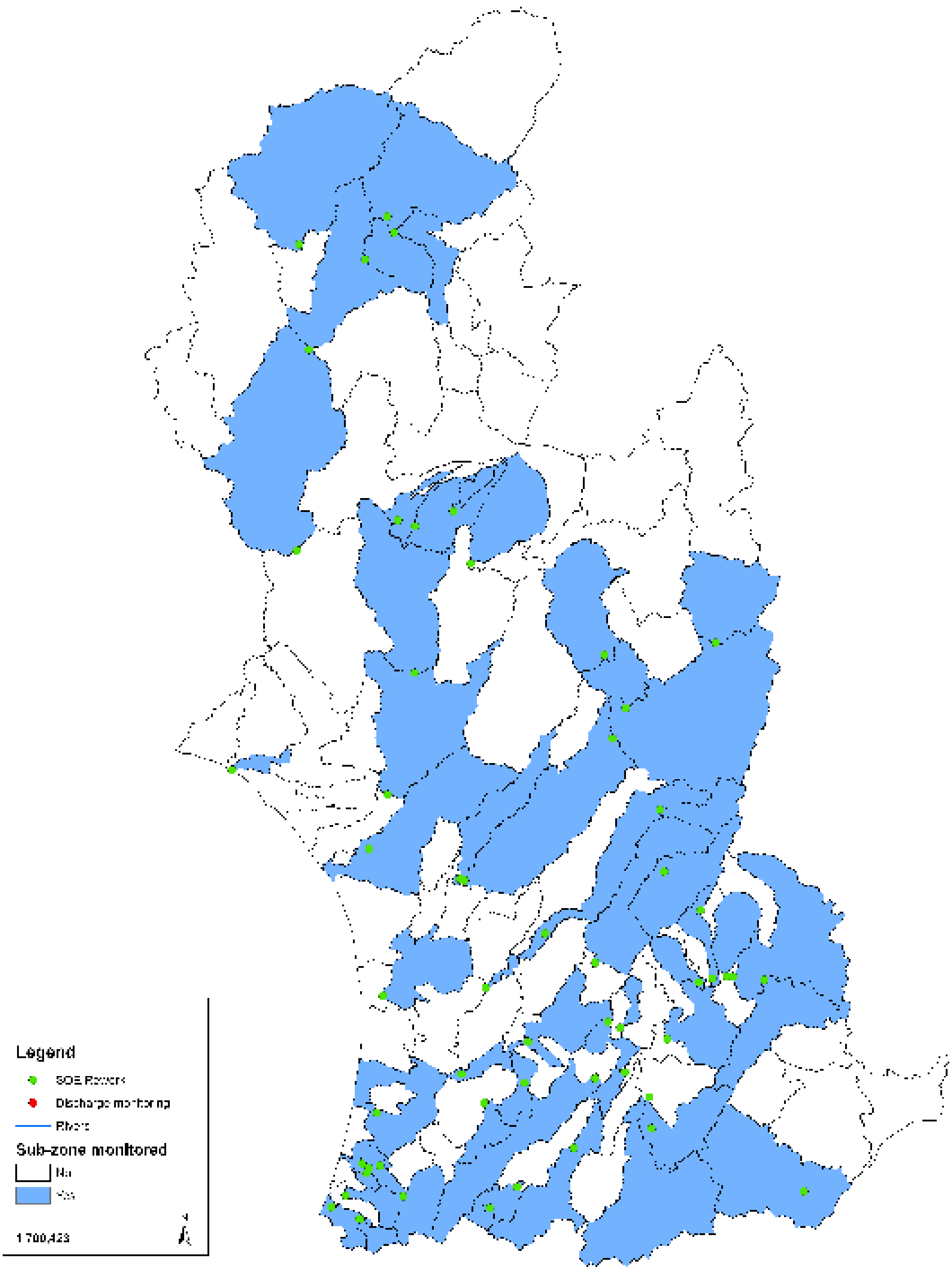
The key selection criteria for the review of SOE sites included the following policy effectiveness measures:

- FARM strategy priority catchments and the implementation of Rule 13-1;
- Proposed SLUI (Sustainable Land Use Initiative) priority catchments;
- Significant discharge compliance with proposed water quality standards;
- Compliance with proposed water quality standards in water management zones and sub-zones;
- Flow monitoring (and water quality) for the proposed water allocation framework; and
- The monitoring of the proposed Sites of Significance-Aquatic (SOS-A).

Additional site selection criteria included:

- the length of the existing water quality record and the presence of 'core' (annually monitored) sites, to ensure the realization of prior investment in SOE monitoring;
- any monitoring gaps identified in the development of the water management zones;
- the presence of existing flow recorders and continuous turbidity meters;
- sites with existing contact recreation monitoring record;
- sites with existing biomonitoring data and period of biomonitoring record; and
- sites monitored for Didymo surveillance, determined in agreement with Regional long-term management partners (Regional river stakeholders).

A total of fifty-eight SOE sites were defined as a result of the review (Map 18).



Map 18: Map of State of the Environment (SOE) water quality monitoring sites and water management sub-zone coverage, as at the 2008/2009 financial year.

9.1.1 Changes in the water quality SOE data collection

As well as reviewing the SOE sites for their effectiveness at monitoring policy and science data collection needs, the frequency, parameters and timing of sample collection were also reviewed.

One of the key factors in determining the total number of sites to be included in the reviewed SOE programme was the ability for annual data collection at all sites. Previously, a ‘core’ set of SOE sites had been monitored annually, with the remainder of the sites monitored for one year in every three on a rolling basis.

The potential risks associated with less frequent SOE monitoring have been examined by Stansfield (2001) and Scarsbrook & McBride (2007). Both Stansfield (2001) and Scarsbrook & McBride (2007) found that reducing water quality sample frequency from monthly to quarterly meant many potential water quality trends were not detected. The reason for this was that smaller data sets had larger standard errors in the estimation of statistics, sometimes large enough to discount a trend that was apparent in a larger dataset. This theory also applies when comparing annually to three-yearly collected data.

Additionally, the number of years of data collection required for robust trend analysis is approximately six to 10 years for annually collected data. This period is tripled for sites only sampled one year in every three, approximately 30 years (Stark, 2008).

Given the findings of Stansfield (2001) and Scarsbrook & McBride (2007), and the recommendations of Stark (2008), biomonitoring and water quality SOE annual monitoring was implemented at all sites from July 2008.

Changes in the nutrient parameters analysed from samples collected for the SOE programme were initiated in July 2007. To measure nitrogen species consistent with national sample collection in the NRWQ network, nitrate sampling was discontinued in favour of total oxidised nitrogen (also known as NNN or NOx-N). This meant that total oxidised nitrogen could be added to ammoniacal nitrogen to determine Soluble Inorganic Nitrogen (SIN) and thereby account for all bioavailable forms of nitrogen in the rivers.

Analysis of Total nitrogen (TN) and Total Phosphorus (TP) was also started at this time, as per the recommendations of Parfitt *et al.* (2007) to help estimate nutrient sources associated with erosion. In late 2008 Dissolved Organic Phosphorus (DOP) was also included in the SOE programme to better estimate the potential phosphorus inputs from bed sediments during low flows.

The timing of sampling in relation to sites within the same water management zone and the location of any significant discharges was also considered. In order to calculate proportional contribution of nutrient load from water management sub-zones and discharges, sampling needed to be undertaken in a coordinated fashion. Sampling at all sites within a water management zone to determine proportional catchment nutrient inputs was trialled in July 2007 in the Manawatu and Whangaehu catchments in conjunction with the discharge monitoring programme (described below), and then fully implemented within the new SOE programme in July 2008.

Because weighting was given to SOE sites with established flow recorders, the collection of flow and water quality data at SOE sites would automatically improve the accuracy of load calculations when analysing SOE data.

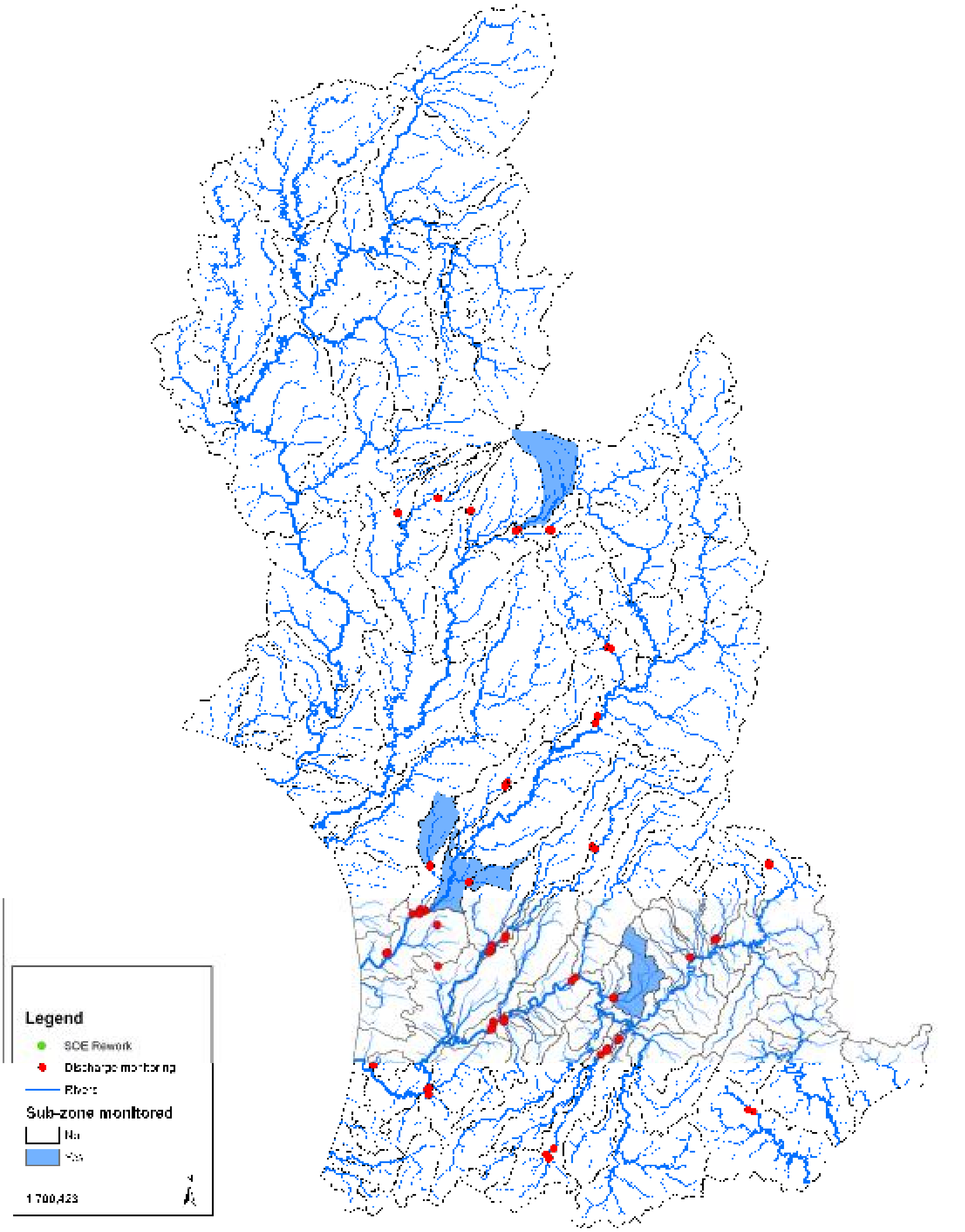
9.1.2 The discharge monitoring programme

McArthur & Clark (2007) aimed to apply the flow-stratified method developed in this report to determine PS nutrient loads and thereby estimate NPS contributions to the Region’s waterways. However, as documented in McArthur & Clark (2007) the many shortfalls in the former monitoring programme constrained their ability to apply the method effectively. To address these issues, and to effectively understand the proportional contributions of PS and NPS to Measured nutrient loads, the monitoring of significant discharges in conjunction with the SOE monitoring was suggested.

Combined discharge and SOE monitoring was begun in the Manawatu, Whangaehu and Pongaroa River catchments in July 2007. In July 2008 significant discharges in the Rangitikei were added to this programme and the remaining significant discharges in the Region are planned for inclusion in July 2009.

The discharge monitoring and SOE programmes collect samples from all SOE sites and upstream and downstream, and the effluent of all significant discharges on the same day and under similar river flow conditions. Flow gauging is undertaken at all discharge monitoring sites where there is not nearby access to a flow recording station. Accurate effluent volume measures are required to determine load from significant discharges. Many discharges can be telemetered to the Council’s system, and the process of implementing this is ongoing.

In the 2007/2008 year 65 sites were monitored monthly under the discharge monitoring programme. In the 2008/2009 financial year this was increased to 89 sites (Map 19) and in the 2009/2010 financial year this is expected to increase to approximately 101 sites.

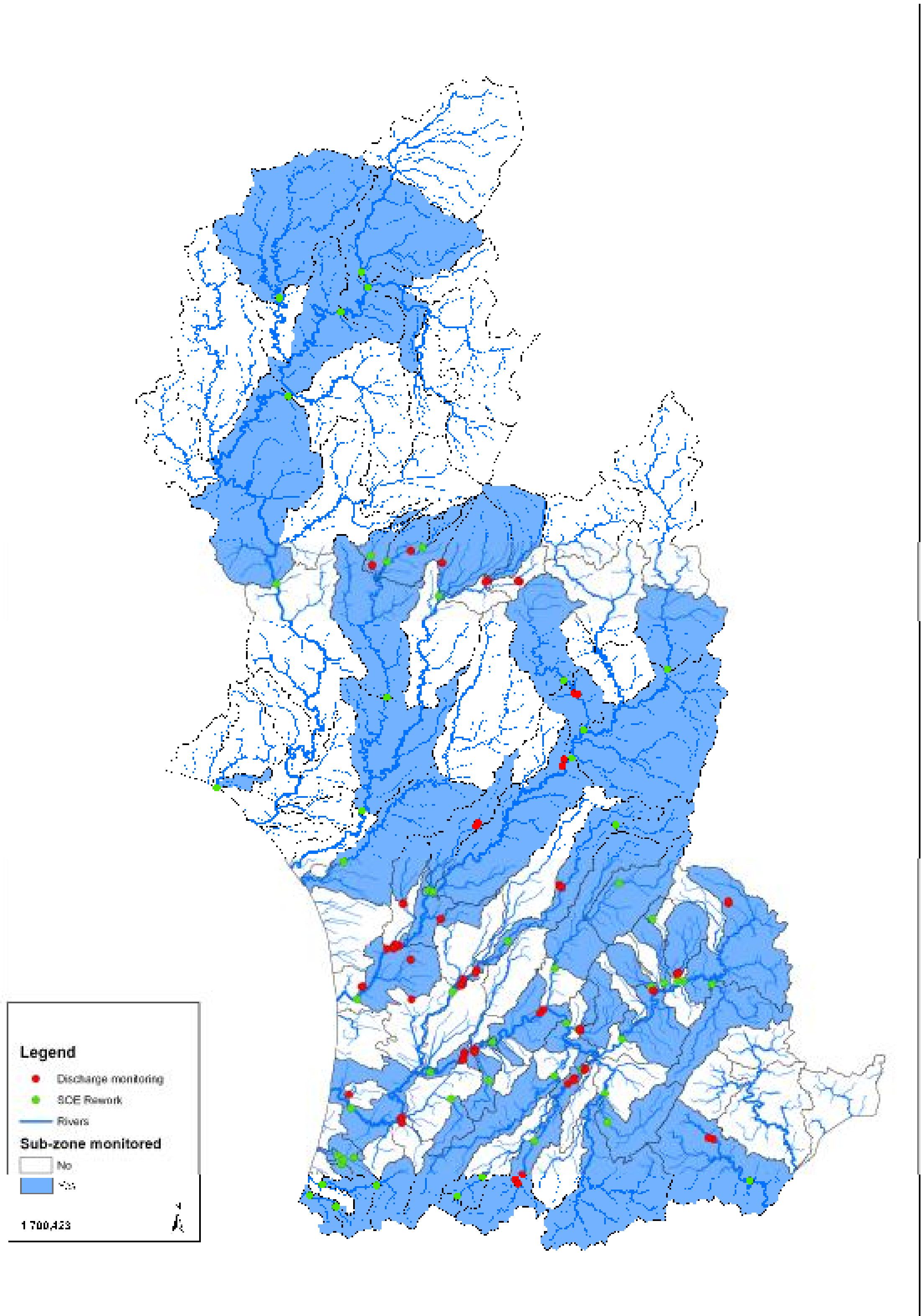


Map 19: Map of discharge monitoring programme sites, as at 2008/2009 financial year.

9.1.3 Data reporting: the Water Quality Matters website

An automated reporting system is currently in the final stages of development to support the combined monitoring programme and to supply data for further framework analyses. This system will enable the automatic calculation of nutrient loads at SOE sites and from discharges to water, allowing the relative NPS loads to be estimated easily and quickly, and will use data from the combined SOE and discharge monitoring programmes (Map 20).

As well as facilitating easy SOE reporting for Council staff, this information will be available publicly via a website. The website will display water quality results Regionally, by major catchment, by water management zone and for individual consents. The period of record displayed via the sites, maps and graphs can range from the whole period of record to the last twelve months and the latest sample result. This website will run in conjunction with the established water allocation website known as 'Watermatters' www.horizons.govt.nz/watermatters, and will be known as 'Waterquality Matters' www.horizons.govt.nz/waterqualitymatters. An automated compliance checking function is also under construction as part of the website development.



Map 20: Map of combined monitoring coverage by SOE water quality and discharge monitoring programme sites as at the 2008/2009 financial year.

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Appendix 1: Background information on the upper Manawatu upstream of Hopelands study catchment

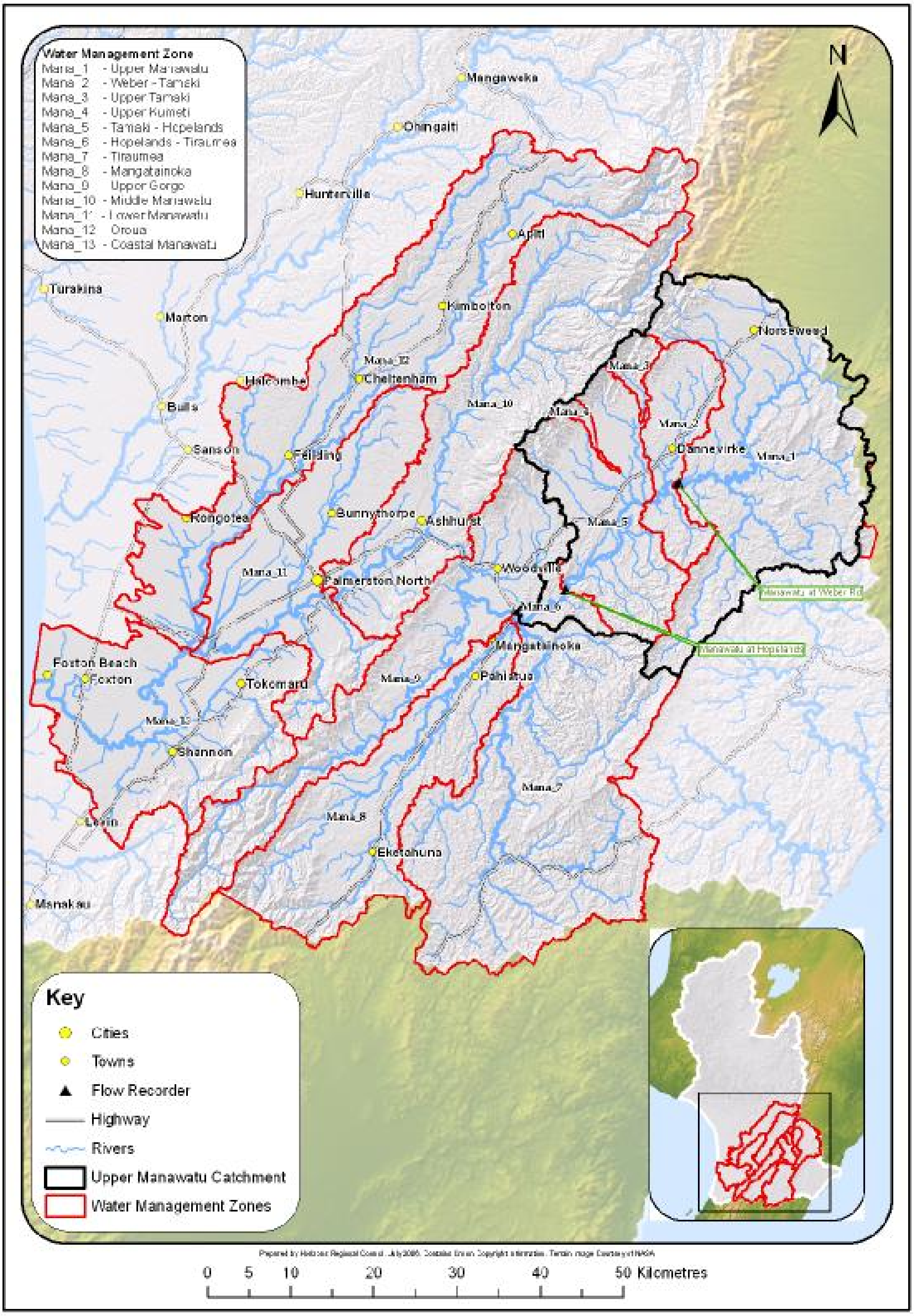
The upper Manawatu River catchment summary

The Manawatu River is one of the four main river catchments within the Horizons Region, draining an area of approximately 5895 km^2. Of this land area, the upper Manawatu above the Hopelands SOE monitoring site drains approximately 1267 km^2. The total catchment area upstream of the Hopelands flow recorder is 126,669 ha. Land use in the upper Manawatu consists predominantly of sheep and beef farming (58%), dairying (16%), conservation estate (8.4%), exotic forestry (3%), cropping (0.4%) with urban and other various land uses making up approximately 14% (Clark & Roygard, 2008) (Map 22). Land use capability for the upper Manawatu catchment is displayed in Map 23 below.

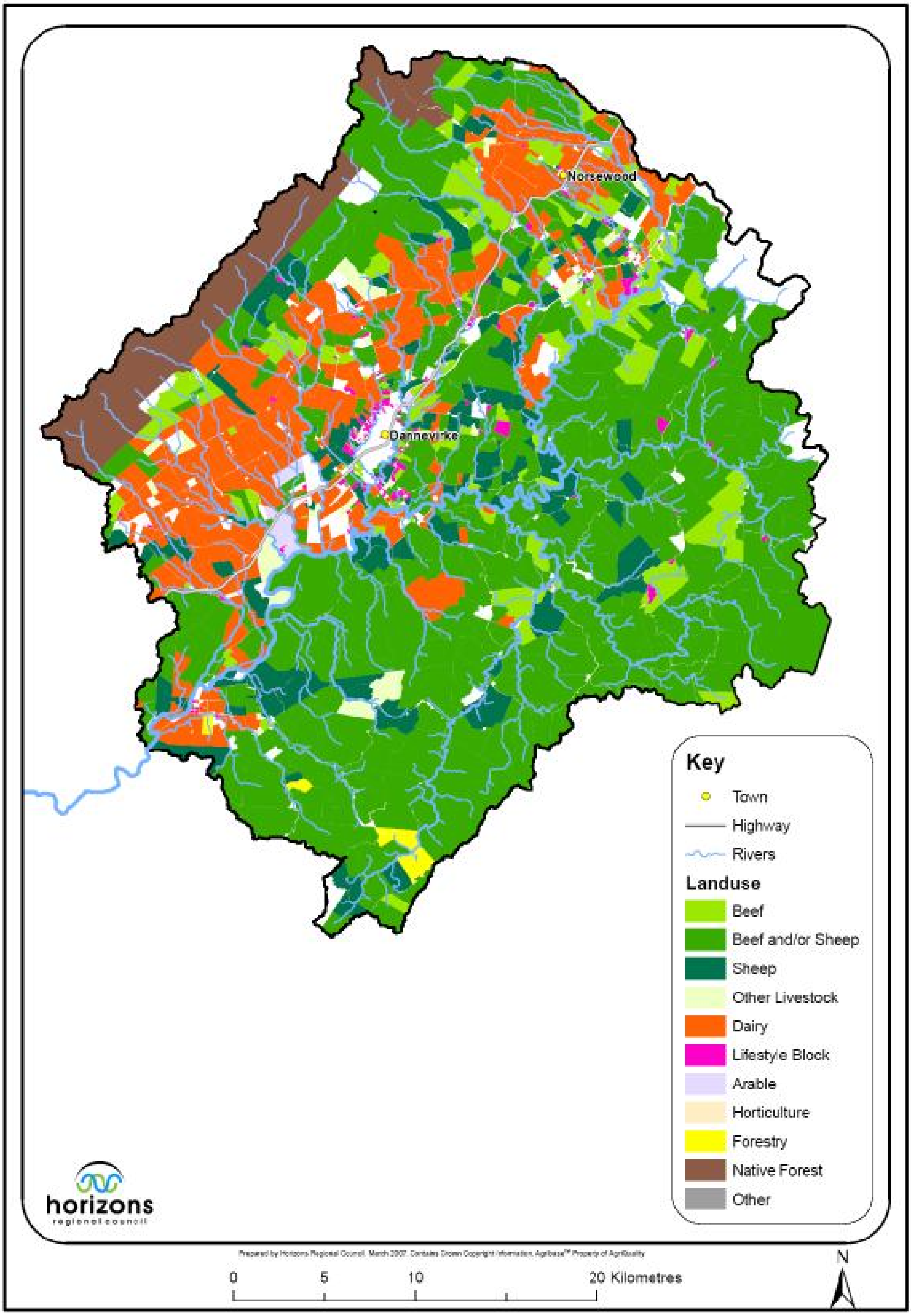
The reasons for selecting the upper Manawatu above Hopelands for a study catchment in this report include:

- The poor state of water quality leaving this catchment area as monitored at the Hopelands SOE site (Horizons, 2005; Roygard *et al.,* 2006; Ledein *et al.*, 2007; McArthur & Clark, 2007);
- Water quality trends at the site showing increasing nutrient concentrations over time (Gibbard *et al.,* 2006; Scarsbrook, 2006);
- The identified values (Ausseil & Clark, 2007a) and proposed water quality standards for the upper Manawatu catchment (Ausseil & Clark, 2007b);
- Good availability of flow and water quality monitoring information, including point source nutrient inputs from Dannevirke STP; and
- The recent focus on determining the relative contributions of nutrients from point and non-point sources in this catchment from several completed studies (Ledein *et al.,* 2007; Clothier *et al.,* 2007; Parfitt *et al.,* 2007).

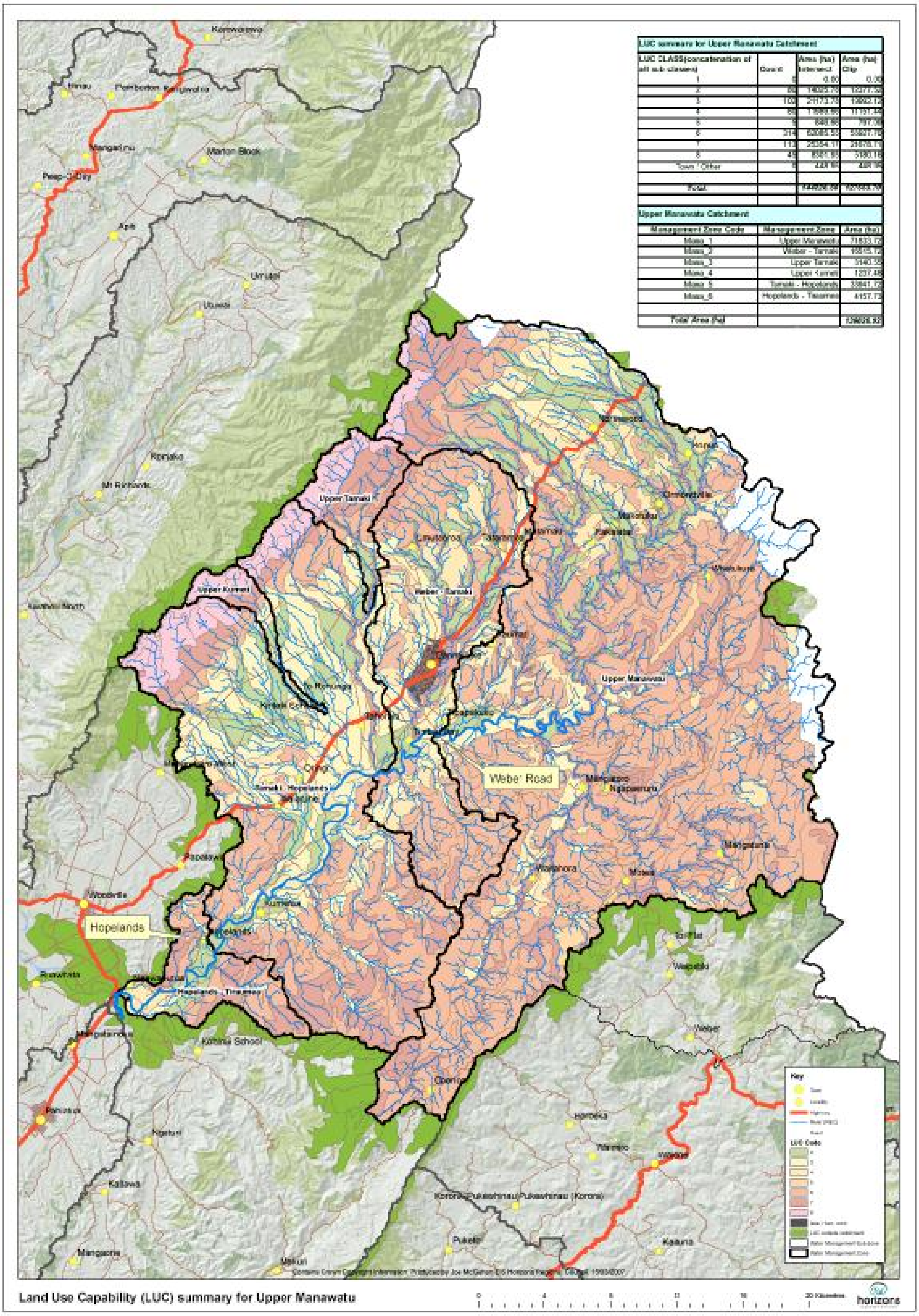
Horizons uses physical units known as water management zones and sub-zones (McArthur *et al.,* 2007) for integrating resource management on a catchment and sub-catchment basis. The upper Manawatu encompasses five water management zones, which are further split into 12 sub-zones (Map 21).



Map 21: Map of water management zones in the Manawatu catchment showing area defined as the upper Manawatu catchment for this report.



Map 22: Land use in the upper Manawatu Catchment. Data sourced from Agribase™.



Map 23: Land use capability map for the upper Manawatu area of the Manawatu catchment.

Appendix 2: The Mangatainoka catchment case study

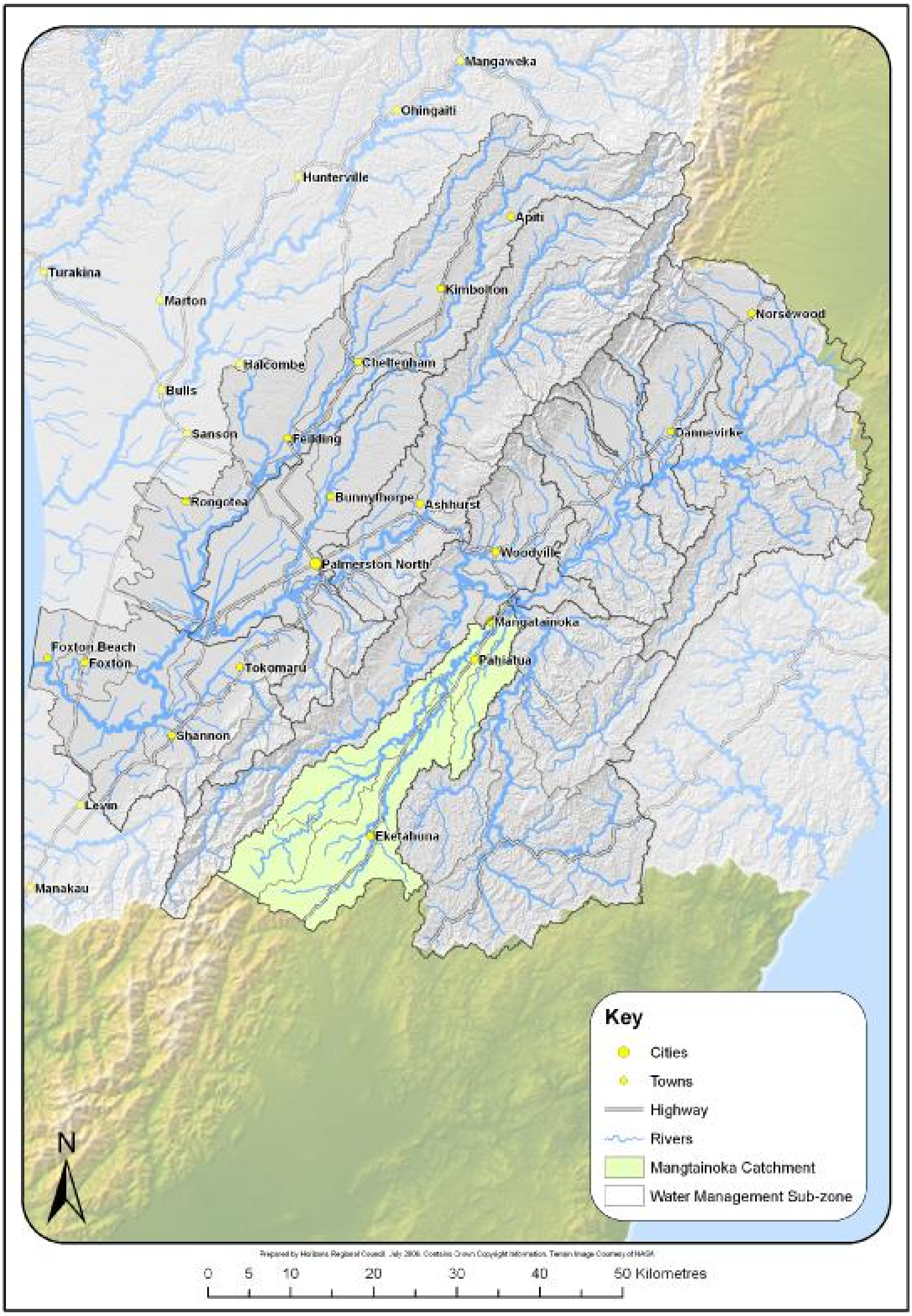
The Mangatainoka River catchment summary

The Mangatainoka River is a tributary of the Manawatu that drains the North Eastern Tararua Ranges and joins the Manawatu, East of the Gorge along with the Tiraumea River at Ngawapurua (Map 24). The catchment area is approximately 492 km^2 and the land use consists of 50.9% sheep and beef farming, 28% dairying, 18% in Conservation Estate, 1.8% exotic forestry and 1.2% urban and various other land uses (Clark & Nicholson, 2008) (Map 26).

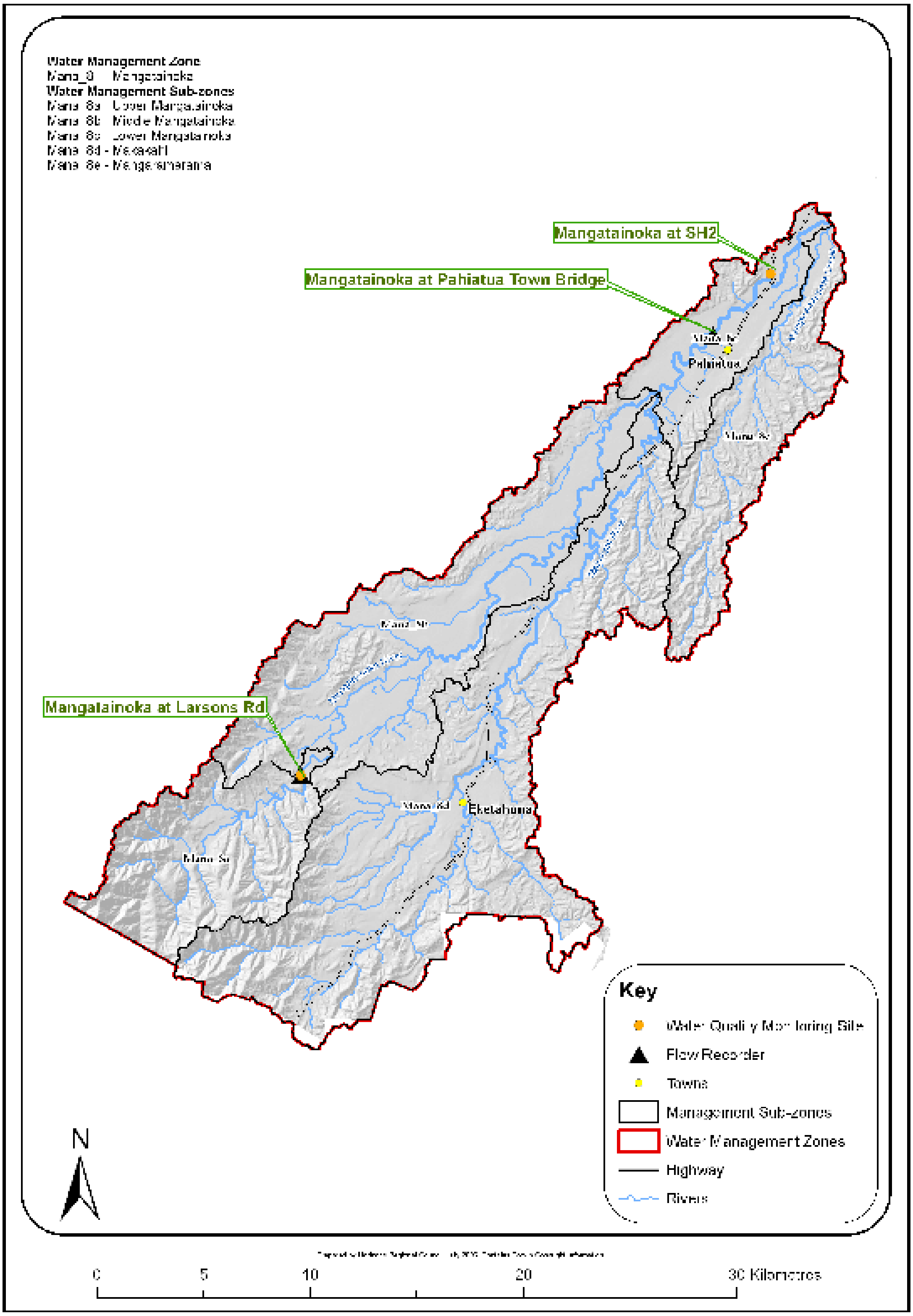
The Mangatainoka River catchment is one water management zone, split into five sub-zones. The mainstem of the Mangatainoka River is split into three zones (upper, middle and lower Mangatainoka) and the Makakahi and Mangaramarama tributary catchments are each their own sub-zones (Map 25).

The reasons for selecting the Mangatainoka River as a study catchment in this report include:

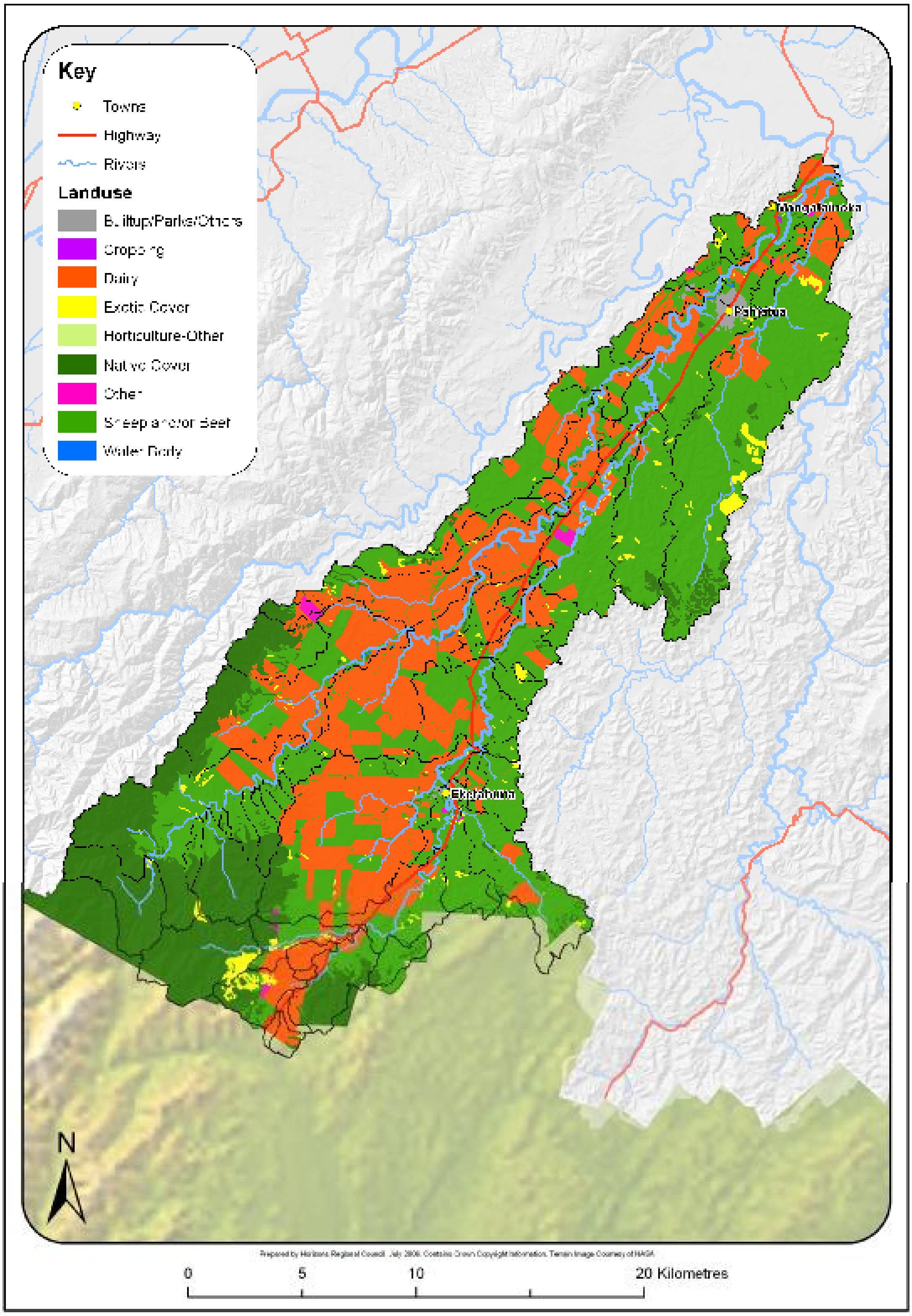
- The poor state of water quality leaving this catchment area as monitored at the State Highway Two (SH2) SOE site (Horizons, 2005; McArthur & Clark, 2007; Ledein *et al.*, 2007);
- Water quality trends at the site showing increasing nutrient concentrations over time (Gibbard *et al.,* 2006; Scarsbrook, 2006);
- The identified values (Ausseil & Clark, 2007a) and proposed water quality standards for the upper Manawatu catchment (Ausseil & Clark, 2007b);
- Good availability of flow and water quality monitoring information, including point source nutrient inputs from Pahiatua and Eketahuna STP; and
- The recent focus on determining the relative contributions of nutrients from point and non-point sources in this catchment from several completed studies (Ledein *et al.,* 2007; McArthur & Clark, 2007; Clark, 2008 draft).



Map 24: Overview of the Mangatainoka Catchment in relation to the wider Manawatu Catchment



Map 25: Water management sub-zones in the Mangatainoka River Water Management Zone, Manawatu catchment.



Map 26: Simplified land use in the Mangatainoka River catchment. Data sourced from Agribase™ (Clark & Nicholson, 2008).

Appendix 3: Comparison of 3*Q_{50} (three times median) flow against decile flow category for 63 sites

This report calculates nutrient loads within 10 flow decile categories and uses a load calculation method to determine the Standard load limit annually and across different flow deciles. The nutrient standards in Schedule D of the Proposed One Plan apply at flows less than three times the median flow (flood flows).

We recommend the use of a common approach to determining 'high flows' at which the concentration-based nutrient standards should apply and at which Measured loads in the river can be compared with Standard load limits. Applying concentration-based nutrient standards at flows less than those that exceeded only 10% of the time (the 10th or highest flow decile category) provides a delineation that will be commonly applicable for assessing concentration-based and load-calculated results and is an equally sensible and somewhat conservative approach to using the three times median flow.

A comparison between the 10th flow decile and the three times median flow was undertaken to determine how similar these two statistics were across the range of flow regimes in the Region's rivers. Table 33 shows the three times median (3*Q_{50}) flow statistic for all flow sites in the Region compared with the 10th flow decile category of that statistic. All flows statistics were calculated by Henderson and Diettrich (2007) based on current and historical flow information held by Horizons.

Only sites with actual (not synthetic or modelled) flow records were used. At sites affected by water takes for the Tongariro Power Development (TPD) or other hydroelectric takes, only the current, post diversion three times median flow statistics were used for this analysis. Periods of record and other information regarding the calculation of flow statistics can be found in Henderson and Diettrich (2007).

Table 34 shows that almost half of the 63 flow recorder sites used in the analysis have a 3* Q_{50} which lies between the 10th and 20th flow deciles. This report has recommended a conservative approach using the 0 – 10th flow decile as the flow below which concentration based nutrient standards should apply. Further analysis of using the 10th – 20th decile as the flow cut-off for nutrient standards should be undertaken in future to provide alternatives for decision-makers.

Table 33: Comparison of $3*Q_{50}$ (3 times median) flow statistics against flow percentile categories for 63 sites in the Manawatu-Wanganui Region (*from Henderson & Diettrich, 2007*). *Note: sites in italics have $3*Q_{50}$ at or above the 10^{th} flow percentile.*

Site	$3*Q_{50}$ (3 x median) flow m^3/s	Equivalent Flow Percentile category
Manawatu Catchment		
Manawatu at Weber Rd	22.82	$10 – 20^{th}$
Kumeti at Te Rehunga	*0.83*	*$0 – 10^{th}$*
Kumeti at SH2	1.11	$10 – 20^{th}$
Tamaki at Water Supply Weir	2.92	$10 – 20^{th}$
Tamaki at SH2	4.79	$10 – 20^{th}$
Tamaki at Stephensons	7.36	$10 – 20^{th}$
Manawatu at Hopelands	47.11	$10 – 20^{th}$
Tiraumea at Ngaturi	21.63	$10 – 20^{th}$
Makakahi at Hamua	9.54	$10 – 20^{th}$
Mangatainoka at Larsons Bridge	6.39	$10 – 20^{th}$
Mangatainoka at Pahiatua (all)	26.7	$10 – 20^{th}$
Mangaatua at Hopelands Rd	2.12	$10 – 20^{th}$
Makuri at Tuscan Hills	*11.53*	*$0 – 10^{th}$*
Mangahao at Ballance	22.10	$10 – 20^{th}$
Manawatu at Upper Gorge	151.11	$10 – 20^{th}$
Pohangina at Mais Reach	30.04	$10 – 20^{th}$
Manawatu at Palmerston North (all)	220.21	$10 – 20^{th}$
Turitea at Ngahere Park Rd	1.16	$10 – 20^{th}$
Oroua at Almadale (all)	21.31	$10 – 20^{th}$
Kiwitea at Spur Rd (all)	3.12	$10 – 20^{th}$
Oroua at Awahuri Bridge	23.45	$10 – 20^{th}$
Makino at Boness Rd	*0.73*	*$20 – 25^{th}$*
Tokomaru (all)	*3.75*	*$20 – 25^{th}$*
South-Western Coastal Catchments		
Ohau at Rongomatane	11.46	$10 – 20^{th}$
Manakau at Gleesons Rd	0.51	$10 – 20^{th}$
East Coast Catchments		
Akitio at Weber Rd	*1.88*	*$20 – 25^{th}$*
Owahanga at Branscombe Bridge	*4.48*	*$20 – 25^{th}$*
Rangitikei Catchment		
Rangitikei at Springvale	*41.89*	*$0 – 10^{th}$*
Rangitikei at Pukeokahu	*52.13*	*$0 – 10^{th}$*
Hautapu at Taihape (all)	8.4	$10 – 20^{th}$
Maungaraupi at Maungaraupi	*0.12*	*$30 – 40^{th}$*
Moawhango at Waiouru	*0.68*	*$40 – 50^{th}$*
Moawhango at Moawhango	9.23	$10 – 20^{th}$
Rangitikei at Mangaweka	*129.89*	*$0 – 10^{th}$*
Makohine at Viaduct	*0.96*	*$25 – 30^{th}$*
Rangitikei at Onepuhi	*159.82*	*$0 – 10^{th}$*
Porewa at Tututotara	*0.68*	*$25 – 30^{th}$*
Rangitawa at Halcombe	*0.02*	*$30 – 40^{th}$*
Tutaenui at Hammond St	*0.14*	*$30 – 40^{th}$*
Forest Rd Drain at Drop Structure	*0.01*	*$0 – 10^{th}$*
Rangitikei at Otara	*180.72*	*$0 – 10^{th}$*
North-Western Coastal Catchments		
Kai iwi at Handley Rd	*2.99*	*$0 – 10^{th}$*

Site	3^*Q_{50} (3 x median) flow m^3/s	Equivalent Flow Percentile category
Turakina at Otairi	*6.41*	*20 – 25th*
Turakina at SH3 Bridge	8.80	10 – 20th
Whangaehu Catchment		
Wahianoa at Karioi	*1.36*	*0 – 10th*
Waitangi at Tangiwai	*2.59*	*0 - 10th*
Tokiahuru at Whangaehu confl.	*20.22*	*0 – 10th*
Mangaetoroa at School	1.61	10 – 20th
Makotuku at SH49a	1.34	10 – 20th
Mangawhero at Ohakune (all)	*5.58*	*0 – 10th*
Mangawhero at Ore Ore	25.23	10 – 20th
Whangaehu at Karioi	*35.24*	*0 – 10th*
Whangaehu at Kauangaroa	*80.17*	*0 – 10th*
Whanganui Catchment		
Manganui o te Ao at Ashworth	34.55	10 – 20th
Mangaroa at Ohura Town Bridge	*9.41*	*20 – 25th*
Ohura at Tokorima	35.7	10 – 20th
Ongarue at Taringamotu	*73.62*	*0 – 10th*
Tangarakau at Tangarakau	*15.68*	*20 – 25th*
Whakapapa at Footbridge	*11.36*	*0 – 10th*
Whanganui at Te Porere	*3.45*	*0 – 10th*
Whanganui at Piriaka	*60.26*	*0 – 10th*
Whanganui at Te Maire	145.08	10 – 20th
Whanganui at Paetawa	393.41	10 – 20th

Table 34: Proportion of flow sites at which the 3^*Q_{50} (three times median) flow lies within various flow percentile categories out of 63 flow recorder sites in the Manawatu-Wanganui Region (*statistics from Henderson & Diettrich, 2007*).

Flow percentile	% sites 3^*Q_{50} within flow percentile
0 – 10th	30%
10th – 20th	49%
20th – 25th	11%
25th – 30th	3%
30th – 40th	5%
40th – 50th	2%

Appendix 4: The influence of the 1992 partial water year on nutrient load calculations

The Hopelands flow recorder was damaged during a high flow event in 1992. This damage resulted in more than three months of missing data between 24 July and 10 November 1992. The flow data used for this report excludes all data from this partial water year. Analysis of the effect of the removal of the partial year of data on the flow distribution and Standard load limit calculations for Hopelands was negligible (see below).

Flow distribution and exceedence percentile data for excluding (Table 36) and including (Table 37) the partial water year is included for reference below. The gaps in the data total approximately 30 percent of the 1992 water year (Table 35). The flow distribution for the Manawatu at Hopelands changes when the partial year of data is left out of the calculation (Figure 53). The effect of including this data for the calculation of the average annual Standard load limit for SIN changes the Standard load limit from 358 tonnes/year (Table 38) to 361 tonnes/year (Table 39). Additionally, the missing data, comprising 30% of the 1992-1993 water year could potentially have had more of an influence on Standard load limits and other load calculations if this data were available. All analysis in this report uses data which excludes the partial 1992 water year.

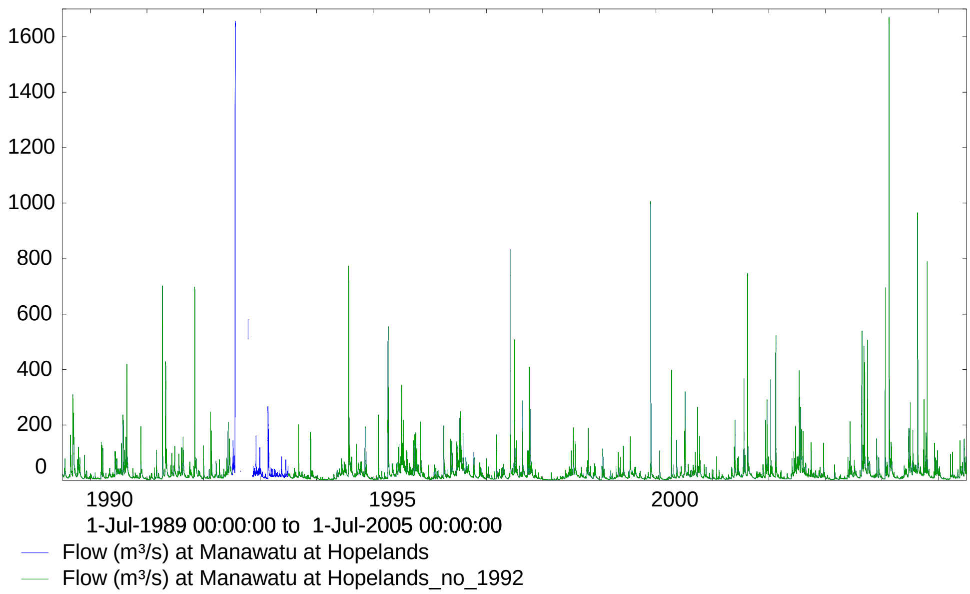


Figure 53: Flow record for Manawatu at Hopelands site with and without the 1992 water year.

Table 35: Gap summary of the Manawatu at Hopelands flow record**.**

Gap start	Gap end	Gap length (days)
24/07/1992 0:00	27/08/1992 13:30	34.56
27/08/1992 14:35	15/10/1992 9:00	48.77
15/10/1992 11:45	10/11/1992 15:30	26.16
	total days	109.49
	Percentage of year	30%

Table 36: Flow distribution for Manawatu at Hopelands excluding the partial water year (1992).

```
~~~ Hilltop Hydro ~~~ Version 5.40
~~~ PDist Version 3.1 ~~~

Source is N:\water\Loadings\hopelands.hts
Flow (m³/s) at Manawatu at Hopelands_no1992
From  6-Jul-1989 16:00:00 to  1-Jul-2005 00:00:00

Exceedance percentiles
            0        1        2        3        4        5        6        7        8        9

   0 1669.642  176.177  121.278   96.864   81.694   72.070   65.158   59.679   55.676   52.191
  10   49.496   47.088   44.699   42.770   40.953   39.156   37.502   36.154   34.964   33.801
  20   32.653   31.531   30.487   29.597   28.758   27.960   27.170   26.387   25.629   24.938
  30   24.289   23.642   23.060   22.487   21.915   21.386   20.881   20.420   19.960   19.533
  40   19.106   18.691   18.280   17.861   17.482   17.128   16.779   16.401   16.049   15.705
  50   15.400   15.073   14.768   14.449   14.147   13.844   13.548   13.255   12.978   12.698
  60   12.422   12.161   11.905   11.646   11.376   11.108   10.861   10.608   10.351   10.111
  70    9.900    9.677    9.449    9.219    8.976    8.744    8.521    8.335    8.136    7.931
  80    7.712    7.470    7.239    7.018    6.789    6.557    6.333    6.119    5.910    5.680
  90    5.439    5.192    4.922    4.658    4.388    4.157    3.889    3.595    3.274    2.864
 100    2.005

Mean = 25.575  Std Deviation = 43.672
 5473 days 07:45:00 hhmmss of data analysed
  365 days 00:15:00 hhmmss of missing record
The distribution was calculated over 2000 classes in the range 2.005 to 258.751 m³/s
```

Table 37: Flow distribution for Manawatu at Hopelands including the partial water year (1992).

```
~~~ Hilltop Hydro ~~~ Version 5.40                                       08-May-2007
~~~ PDist Version 3.1 ~~~

Source is N:\water\Loadings\hopelands.hts
Flow (m³/s) at Manawatu at Hopelands
From  6-Jul-1989 16:00:00 to  1-Jul-2005 00:00:00

Exceedance percentiles
            0        1        2        3        4        5        6        7        8        9

   0 1669.642  176.077  121.155   96.359   81.228   71.653   64.748   59.380   55.398   51.906
  10   49.260   46.814   44.465   42.541   40.742   38.987   37.381   36.057   34.874   33.721
  20   32.588   31.485   30.465   29.588   28.758   27.968   27.181   26.405   25.664   24.993
  30   24.360   23.733   23.167   22.615   22.066   21.537   21.038   20.585   20.134   19.709
  40   19.286   18.886   18.487   18.084   17.689   17.345   16.999   16.660   16.305   15.961
  50   15.645   15.342   15.036   14.745   14.443   14.159   13.872   13.593   13.321   13.054
  60   12.778   12.497   12.223   11.963   11.698   11.429   11.151   10.888   10.635   10.369
  70   10.131    9.901    9.681    9.449    9.209    8.963    8.726    8.501    8.304    8.101
  80    7.891    7.655    7.414    7.173    6.949    6.700    6.467    6.247    6.021    5.802
  90    5.552    5.300    5.022    4.746    4.465    4.208    3.938    3.639    3.307    2.885
 100    2.005

Mean = 25.792  Std Deviation = 45.770
 5728 days 20:20:00 hhmmss of data analysed
  109 days 11:40:00 hhmmss of missing record
The distribution was calculated over 2000 classes in the range 2.005 to 260.822 m³/s
```

Table 38: SIN annual Standard load limit standard calculation for Manawatu at Hopelands excluding flow data for 1992.

Manawatu at Hopelands no1992						Standard		0.444	g SIN/m3					
Years	Year	0	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	Total All	Total 10-100
1	1989		125	43	33	26	25	25	18	16	13	2.2	325.4	200.7
2	1990		178	63	39	24	21	17	19	15	8	5.1	389.7	211.5
3	1991		158	53	46	39	30	23	21	14	4	0.0	388.3	230.6
	1992		--	--	--	--	--	--	--	--	--	--	--	--
4	1993		25	21	28	27	27	17	16	13	8	15.2	198.2	172.8
5	1994		172	82	45	36	27	14	7	7	8	6.6	405.9	233.5
6	1995		191	80	50	36	18	14	11	11	8	2.8	424.7	233.6
7	1996		160	72	45	30	23	21	16	11	7	3.7	389.2	229.2
8	1997		104	37	30	21	19	20	12	9	10	13.6	276.1	172.1
9	1998		73	48	35	32	30	18	19	12	7	7.3	283.3	210.0
10	1999		86	26	23	25	19	21	24	18	14	8.2	263.6	178.1
11	2000		98	47	37	37	27	19	11	12	12	7.2	306.6	208.3
12	2001		164	65	41	35	28	24	17	11	12	0.1	395.6	231.4
13	2002		123	48	32	26	24	21	13	10	14	7.6	317.1	194.2
14	2003		335	62	43	27	23	25	18	12	6	1.4	552.8	217.7
15	2004		207	89	63	29	19	13	11	12	5	5	453.1	246
15	**Average**		**147**	**56**	**39**	**30**	**24**	**19**	**16**	**12**	**9**	**6**	**358**	**211**

Table 39: SIN annual Standard load limit calculation for Manawatu at Hopelands including flow data for 1992.

Manawatu at Hopelands inc.1992						Standard		0.444	g SIN/m3					
years	Year	0	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	Total All	Total 10-100
1	1989		125	43	32	26	23	25	18	17	13	2.7	325.4	200.3
2	1990		179	62	38	23	22	16	19	17	9	5.5	389.7	211.0
3	1991		158	53	45	38	29	22	22	15	5	0.0	388.3	229.9
4	1992		114	41	37	36	30	29	6	4	2	0.0	298.7	185.0
5	1993		25	21	28	27	26	18	15	14	9	15.8	198.2	172.7
6	1994		174	81	44	35	27	14	8	7	9	7.0	405.9	232.3
7	1995		192	80	50	36	18	14	12	11	9	3.2	424.7	232.5
8	1996		161	71	45	29	23	20	17	12	8	4.3	389.2	228.0
9	1997		104	37	29	20	19	20	12	10	10	14.0	276.1	171.7
10	1998		74	48	34	31	30	18	21	13	7	7.5	283.3	209.4
11	1999		86	27	22	24	18	19	25	19	15	8.4	263.6	177.9
12	2000		99	47	36	36	26	18	13	12	13	7.5	306.6	208.1
13	2001		165	65	40	34	27	23	18	11	13	0.4	395.6	230.9
14	2002		124	47	32	24	24	21	13	11	14	8.1	317.1	193.5
15	2003		336	61	43	26	23	24	20	12	6	1.6	552.8	217.0
16	2004		208	88	62	29	19	12	12	13	5	5	453.1	245
15.7	**Average***		**148**	**55**	**39**	**30**	**24**	**20**	**16**	**13**	**9**	**6**	**361**	**--**

*over 15.7 years

Appendix 5: Loading estimates for the upper Manawatu Catchment from Ledein *et al.* (2007)

Ledein *et al.* (2007) completed an analysis in 2005 of the sources of nutrients from non-point sources (NPS) and point sources (PS) in two catchments of the Manawatu River using a narrower definition of point sources than that used in this report (Ledein *et al* (2007) considered only the "large" industrial and municipal discharges as point source, excluding those linked with farming activities). Because the Ledein *et al.* (2007) study did not estimate nutrient inputs from natural sources, urban run-off, septic tanks, direct stock access to waterways or landfills, it is likely that the loading estimates determined in that study were slightly underestimated.

Ledein *et al.* (2007) examined several methods for calculating loads using 'summer' water quality and flow data from October to May between 2000 and 2003. These approaches included the regression approach, the Beale ratio estimator and the averaging approach.

Non-point (NPS) load estimates using the export coefficient method

To assess NPS contribution to in-stream nutrient loads, an export coefficient method was used by Ledein *et al.,* (2007). This is a simple approach based on the land use and export coefficient (or specific yield) for each land use type.

A nutrient export coefficient is the mass of that nutrient leaving the catchment, per unit area of catchment, and per unit of time (typically expressed in kg/ha/year). The advantages of using export coefficients are that they take into account the attenuation within the catchment (landscape and aquatic transport), like many SOE monitoring sites they are measured at the outlet of a catchment, and export coefficients based on national averages are available for the dominant land uses of the study catchments.

An obvious drawback of using an export coefficient method is that it does not take into account many of the physical characteristics of catchments which can determine pollution attenuation, such as geology, topography, climate, rainfall and flow regime. However, they enable an estimation of NPS contributions to river contaminant loads.

When no national average export coefficients for particular land uses were available, typical nutrient loss figures were used (which did not account for attenuation within the catchment, as they measured nutrient losses at the outlet of a paddock). Attenuation during landscape and aquatic transport were estimated as 50% of the load in these cases.

Export coefficients for dairy farming include land application of the dairy shed effluent. The export coefficients used in Ledein *et al.,* (2007) are summarized in Table 40. Catchment land use was assessed using both the Agribase™ Database and the land cover database (LCDB2).

Table 40: Nitrate and DRP export coefficients used in Ledein *et al.,* (2007). *Note: export coefficient rates are after attenuation (50% of loss from the land use).*

Land use	Nitrate export coefficient/specific yield (kg/ha/y)	DRP export coefficient (kg/ha/y)
Dairy pasture	20.0	0.3
Sheep and beef/sheep on hill pasture	7.2	0.20
Low intensity pasture	4.2	0.05
Cattle grazing	20.0	0.3
Arable farming	15 -30	0.25
Vegetable cropping	88.5	0.25
Forestry	1.5	0.005

Ledein *et al.* (2007) methods for estimation of PS inputs

The only discharge to land that was considered as a PS by Ledein *et al.,* (2007) was PPCS Oringi meat works. The interpretation of Ledein *et al.,* (2007) differs from this report, which treats the PPCS Oringi discharge to land as a NPS contribution to river nutrient loads on the upper Manawatu catchment (see Section 6.3).

To assess the contribution of consented activities that contribute to nutrient loads in surface water, the three following methods were used by Ledein *et al.,* (2007) in decreasing priority order:

- Method 1: when discharge volumes and nutrient concentration in the discharge were available, this data was used to calculate monthly and annual loads. In this case the annual load is the product of the volume by the concentration added up over the year.

Note: the two main differences between the methods used in this report to calculate PS loads and Method 1 of Ledein et al., (2007) was the use of monthly loads converted to annual loads by Ledein et al., (2007) compared to daily loads converted to annual and flow decile loads in this report using the 'Effluent PS load estimation method' and the use of average concentration and average flow to determine daily load in this report.

- Method 2: when the available data was insufficient to use method 1, upstream (u/s) and downstream (d/s) in-stream nutrient concentrations and river flow data were used to calculate the nutrient load, or

  Discharge load = $\int$ (conc. d/s - conc. u/s) * river flow

  Estimated using the formula:

  Annual discharge load (tonnes/year) = $\sum_{Months}$ (conc. d/s – conc. u/s) (January, February, …) (in g/m^3) * Average flow (January, February, …) (in m^3/s) 3600*****24 * 365/(12 ***** 1,000,000)

  River flow data at or near the discharge site is necessary for this method.

Note: this method (Method 2) was attempted in this report for determining the loads for Dannevirke STP and was referred to as the 'flow-stratified PS load estimation method'.

- Method 3: In all other cases, typical nitrogen and phosphorus load ranges corresponding to the discharge type (Table 41), and information supplied with resource consent applications (eg. population size for sewage treatment plants and herd size for dairy shed discharges) were used to estimate an annual load figure.

  Note: estimates of volume were used with known average contaminant concentrations for Eketahuna and Pahiatua STP load determination in this report, combining Methods 1 and 3 from Ledein et al., (2007).

  The typical loads provided in Table 41 correspond to total nitrogen and total phosphorus. To extract soluble inorganic nitrogen and the dissolved reactive phosphorus loads, it was assumed that on average:

  - Nitrogen losses from PS are generally in soluble form (particularly with respect to nitrogen); and
  - The proportion of DRP in the total phosphorus (TP) was:
    - § 85% in treated municipal sewage effluent (typical ratio used by the environmental agency of England and Wales); and
    - § 30% in dairy shed effluent spread onto land (this was the same ratio used for the export coefficient of DRP from dairying.)

Table 41: Typical nutrient loads for some point sources (PS) *(source: Ministry for the Environment, 2002).*

PS type	Degree of treatment	Total N load	Total P load
Dairy shed effluent	Untreated	5.4 kg/cow/year	0.66 kg/cow/year
	Treated (dual pond)	75 % removed	60 % removed
Domestic sewage	Untreated sewage and septic tank effluent	4.2 kg/p/year	1.5 kg/p/year
	Conventional secondary treatment	5-40 % removed	5 - 40 % removed
	Enhanced nutrient removal	50-95 % removed	70-85 % removed
Piggeries	Untreated	8 kg/pig/year	2.7 kg/pig/year
	Treated (anaerobic lagoon)	60 % removed	40 % removed

Ledein *et al.,* (2007) methods for estimating annual loads from water quality and flow data

The literature review undertaken as part of the Ledein *et al.* (2007) study found three main approaches to estimating in-river loads (Richards, 1998; Ferguson, 1985). The three approaches trialled in the study were:

1. An *averaging approach* when pollutant concentration and flow are independent variables;

2. A *regression approach* if pollutant concentration and flow are well correlated; and
3. A *ratio approach* if there is a positive linear relationship between pollutant flux (g/s) and flow, which passes through the origin.

The choice of the appropriate approach depends on the correlation between concentration and flow data. A description of each of these methods is provided below.

Averaging approach

If pollutant concentration and flow are independent variables, the monthly load is estimated by the monthly average concentration times the average flow for the month (Ferguson, 1987; Richards, 1998):

Equation 2.

$$Load(month_i) = [Pollut](month_i) \cdot \int_{01/month_i}^{31/month_i} Flow(t) \cdot dt$$

This leads to the estimator:

Equation 3.

$$Load(year_i) = \sum_i [pollut]_{monthi} \cdot Monthly\_average\_flow_{monthi} \cdot \Delta t$$

The precision of this estimator can be determined using the following formula (Hoare, 1982):

Equation 4.

$$\Pr ecision = \frac{S\tan dardDeviation(Concentration)}{\sqrt{NbOfObservationsInTheYear}} + Flow\Pr ecision$$

Little relationship between two variables is assumed when their correlation coefficient is between -0.5 and 0.5 and the averaging method is considered appropriate in these circumstances.

Regression approach

If the correlation between pollutant concentration and flow is better (ie. correlation coefficients are outside -0.5 to 0.5) then flow rates can be used to estimate concentrations by deriving a linear regression equation. The regression is often better if concentration and flow are log-transformed (this reduces the skew of the highest concentrations and flows). Time and seasonal variation may be used to account for possible linear trends.

Often, the regression is of the form:

$$\ln([pollut]) = l_0 + l_1 \cdot t + l_2 \cdot \sin(2pt) + l_3 \cdot \cos(2pt) + l_4 \cdot \ln(q) + l_5 \cdot \ln(q)^2$$

where t is decimal time, so that $\lambda_1 t$ accounts for linear trends and $\lambda_2 \sin(2\pi t)$ + $\lambda_3 \cos(2\pi t)$ approximate seasonal variations (Smith *et al*., 1997)

To get pollutant concentration, an exponentiation is required. This transformation creates a bias. Ferguson suggested this bias correction (Ferguson, 1986):

$$[pollut] = e^{\overline{\ln[pollut]} + \frac{s^2}{2}}$$

where $\overline{\ln[pollut]}$ is the log-concentration estimated from the regression model, and σ^2 is the variance of the residuals of the regression model (this correction is valid if the residuals are normally distributed, (Ferguson, 1986)).

Then, there are two options to estimate the annual load:

1. derive a daily concentration from the regression equation, multiply it by the average flow of the flow for this day, and sum up
2. derive a pollutant flux duration curve from the flow duration curve, using the regression equation. Integrate it over a year to get the annual load (Hoare, 1982 and Schouten *et al.,* 1981)

*Note: When using a linear regression, there is no use in trying to do a regression of ln(flux) = ln([pollut]*flow) on ln(flow). The regression seems to be better than a regression of ln[pollut] on ln(flow) (R^2 is higher) but this is artificial. The regression is exactly the same in both cases. R^2 may be higher in case of a regression of ln(flux) because variance (ln(flux)) is higher than variance (ln([pollut]). This statistical phenomenon was named "spurious self-correlations" by B.C Kenney, but it is not agreed by all statisticians.*

Ratio approach

If there is a positive linear relationship between pollutant flux and flow a ratio approach can be applied. According to Richards (1998) "If pollutant flux is proportional to the magnitude of the flow, the ratio estimator is known to be the best linear unbiased estimator, ie. the most precise among the class of estimators which assume a linear relationship".

Ratio estimators give an average daily pollutant load over the year. They assume that the ratio of load to flow for the entire year should be the same as the ratio of load to the flow on the days concentration was measured.

$$\frac{Average\_daily\_load_{year}}{Average\_daily\_flow_{year}} = \frac{Average\_daily\_load_{o}}{Average\_daily\_flow_{o}}$$

where the subscript "year" refers to an average for the year and o refers to an average over the days on which concentration was observed.

However, as daily load and daily flow are correlated variables, this ratio estimator is biased and a bias correction factor must be used.

The Beale Ratio estimator is one way to correct the bias:

$$Average\_daily\_load_{year} = Average\_daily\_load_{o} \cdot \frac{Average\_daily\_flow_{year}}{Average\_daily\_flow_{o}} \left[\frac{1 + \left(\frac{1}{n} - \frac{1}{N}\right)\frac{s_{lq}}{\overline{\overline{l_o q_o}}}}{1 + \left(\frac{1}{n} - \frac{1}{N}\right)\frac{s_{qq}}{\overline{\overline{q_o}}^2}} \right]$$

S_{lq} is the covariance between flow and pollutant flux, s_{qq} is the variance of the flow based on the days on which concentration was measured. N is the expected population size (365), and n is the number of concentration measures (12, as we have one measure for each month). l_o and q_o represent the average daily flux, and flow respectively, on the days concentrations were measured.

Ledein *et al.,* (2007) also trialled a screening method to calculate loads from NPS and used a variety of the methods described above to estimate PS estimates. The screening method was used to cross-validate the other methods outlined above.

Case study calculation for the Upper Manawatu

NPS load estimation

Using the export coefficient methods outlined above, the estimates for the upper Manawatu above Hopelands study catchment NPS loads of SIN and DRP were determined (Table 42).

Table 42: NPS nutrient load estimation for the upper Manawatu above Hopelands study catchment (Source: Ledein *et al.,* 2007).

	Area (ha)	% of the catchment area	SIN load (T/year)	% of SIN NPS load	DRP load (T/year)	% of the DRP NPS load
Sheep and beef farming or deer farming	70,499	56 %	508	51 %	14	67 %
Dairy Farming	20,724	16 %	414	41%	6.2	30 %
including Dairy shed effluents[16]			(90)	(9 %)	(4.8)	(23 %)
Sheep farming	14,891	12 %	62.5	6 %	0.7	3 %
Forestry	3,404	2.7 %	5	0.5 %	0.02	0.1%
Vegetable Cropping/ Market gardening (fruit, nuts, potatoes, vegetables)	57	0.05%	5	0.5 %	0.01	0.05 %
Barley, Wheat, Maize and Cropping	263	0.2 %	6	0.6 %	0.06	0.3 %
Total of NPS contributions			1000.5	100%	20.99	100%
Other	16,162					
Total farmed area (hectares)	109,838	87				
Total loading from farmed area (kg ha/year)			9.11		0.19	

PS load estimation

<u>PS nitrogen loads</u>

The monitoring of PS (using nitrogen concentration measurements downstream and upstream) indicates that:

[16] The dairy farm export coefficients take into account the different types of nitrate loss related to dairy farms: nitrate leaching and run-off from pasture, dairy shed effluents, etc. An estimate of the dairy shed effluent contribution to the total load is given here, using the Regional Council consents database (number of cows per dairy shed and treatment of the effluent).

- **Norsewood STP** has no impact on nitrate concentration in the Mangarangiora stream (nitrate concentrations are similar between the upstream and downstream sample sites);
- **Ormondville STP** has no impact on nitrate concentrations in the Mangarangiora stream (there was no discharge during most of 2003 and the discharge only appears to reach the stream during periods of high rainfall);
- **Dannevirke STP** has an impact on nitrate concentrations in the Mangatera stream (25% nitrate concentration increase on average). The annual soluble inorganic nitrogen load is estimated at 21 tonnes NO_3-N/year using typical ratio for sewage treatment plants (5500 people, 4.2 kg N/person/year with 10% of nitrate assumed to be eliminated by treatment);
- **PPCS Oringi** PS discharges have a minor impact on nitrate concentration in the Manawatu River from land-based discharge of meatworks waste, and in the Oruakeretaki Stream from the STP discharge to water (nitrate concentrations are similar upstream and downstream of the discharge);
- **Dannevirke landfill** has little impact on nitrate concentration in the Mangatera Stream (average nitrate concentrations are lower downstream than upstream of the landfill); and
- **Ormondville landfill** has no measurable impact on SIN concentrations of the Mangarangiora Stream.

Summary:
The total PS loading of SIN estimated to be exported from the upper Manawatu above Hopelands study catchment is 21 tonnes/year. This equates to 58 kg/day, which is entirely sourced from the Dannevirke STP which was the only discharge noted to impact measurably on the SIN loadings in the river.

<u>PS phosphorus loads</u>

Results from analysis of PS monitoring of DRP concentration measurements downstream and upstream show:

- **Norsewood STP** has an impact on DRP concentrations in the Mangarangiora Stream, with a DRP increase of 127% on average between the downstream and the upstream point (the annual DRP load is estimated at 0.25 tonnes DRP/year (using typical ratios for a 220 people sewage treatment plant);
- **Ormondville STP** has no impact on DRP concentrations in the Mangarangiora Stream (see above);
- **Dannevirke STP** has an impact on DRP concentrations in the Mangatera Stream (concentration increases of 256% on average. The annual DRP load is estimated at 1.6 tonnes DRP/year for the year 2003 (using the average DRP concentration in the discharge and a ratio of 200 l/person/day, for 5500 people connected to the sewage treatment plant);
- **PPCS Oringi** has an impact on DRP concentrations in the Manawatu River (DRP increase of 33% between monitoring sites upstream and downstream of the land treatment site. The impact of the STP discharge on the Oruakeretaki Stream is less certain (DRP mean increase of 15% on average but 0% median annual concentration);

- **Dannevirke landfill** has an impact on the DRP concentrations in the Mangatera Stream with an average increase of 55% between the points upstream and downstream of the landfill. This load was not included in the estimates of loadings for PS contributions but will be included in the NPS estimates;
- **Ormondville landfill** has no measurable impact on DRP concentrations in the Mangarangiora Stream.

Summary
The total PS load of DRP estimated to be exported from the upper Manawatu above Hopelands study catchment is 5.3 tonnes/year. This equates to 14.5 kg/day. This load is predominately sourced from PPCS Oringi (3.5 tonnes/year) and Dannevirke STP (1.6 tonnes/year).

Results summary upper Manawatu

In the upper Manawatu study catchment:

- NPS export rates from the 'farmed' part of the catchment were 9.1 kg SIN/ha/yr and 0.19 kg DRP/ha/yr.
- Soluble Inorganic Nitrogen (SIN) in the river predominately (98%) originated from NPS, both on an annual basis and during the 'summer' period of October to May.
- On an annual basis the DRP load was predominately (80%) sourced from NPS.
- The estimation of SIN loadings via calculation of NPS and PS contributions was in the range predicted by water quality and flow methods.
- The estimation of DRP loads via calculation of NPS and PS contributions (26.3 tonnes/year) was higher than estimates using water quality and flow data (20.6 to 23 tonnes/year).

Table 43: Comparison of annual loading estimates for the upper Manawatu above Hopelands study catchment using several methods as estimated by Ledein *et al.,* (2007) for the year 2003.

	SIN (tonnes/year)	**DRP (tonnes/year)**
Annual loading estimate		
<u>Screening method</u>		
NPS (NPS)	1000	20.99
PS (PS)	21	5.3
Total Load = NPS+ PS	1021	26.3
<u>Water quality and flow calculations</u>		
Averaging approach	991	20.6
Beale Ratio estimator, and 95% confidence interval	1099 [897 ; 1217]	22.99 [3.1 ; 39.9]

Appendix 6: Sensitivity analysis: how does the load calculation method change the Measured load?

Averaging and discharge weighted mean approaches

The averaging approach and the discharge weighted mean approach described by Ferguson (1987) are two methods for calculating loads in water-bodies where continuous flow data is available and concentration data is only available for subset of that flow data. For the Manawatu at Hopelands flow data is available on a 15-minute time step whilst water quality data is collected once per month.

The averaging method assumes that concentration and flow are independent variables.

If pollutant concentration and flow are independent variables, the monthly load is estimated by multiplying the monthly average concentration by the average flow for the month (Richards, 1998; Ferguson, 1987):

Equation 2.

$$Load(month_i) = [Pollut](month_i) \cdot \int_{01/month_i}^{31/month_i} Flow(t) \cdot dt$$

This leads to the estimator:

Equation 3.

$$Load\left(year_i\right) = \sum_i [\,pollut\,]_{monthi} \cdot Monthly\_average\_flow_{monthi} \cdot \Delta t$$

The precision of this estimator can be estimated with the following formula (Hoare, 1982):

Equation 4.

$$\Pr ecision = \frac{S\tan dardDeviation(Concentration)}{\sqrt{NbOfObservationsInTheYear}} + Flow\Pr ecision$$

Little relationship between two variables is assumed when their correlation coefficient is between -0.5 and 0.5.

Similar methods for estimating loads have been used in recently published studies in New Zealand (Monaghan *et al.,* 2006; Wilcock *et al.,* 2007b). The following sections apply this method to determining nutrient loads for the Manawatu at Hopelands site and investigate the validity of the underlying assumptions if using this method at this site. The particular methods of load calculation applied by Monaghan *et al.* (2006) and Wilcock *et al.* (2007b) are tested and compared.

Applying the averaging approach to the Manawatu at Hopelands site

To determine a long-term nutrient load estimate, average monthly flows were multiplied by the concentration of the monthly water quality samples (corrected for units into kg/month and tonnes/year). The load estimated to be exported from the Manawatu at Hopelands site was 963 tonnes SIN/year and 26.8 tonnes DRP/year (Table 44). The inter-annual variation in calculated loads was high.

In applying this method, water quality observations were not available for July and August of 1989 for analysis using complete water years (1 July–30 June). Data for the missing portion of the 1989 year was substituted with data from July and August of 2005. Again the record for the 1992 to 1993 partial water year was removed from the dataset.

Table 44: Nutrient loads for the Manawatu at Hopelands calculated using the averaging approach for data collected between July 1989 and July 2005.

		SIN load (tonnes SIN/year)	DRP load (tonnes DRP/year)
01-Jul-89	01-Jul-90	2101	104.8
01-Jul-90	01-Jul-91	1108	19.0
01-Jul-91	01-Jul-92	856	17.0
01-Jul-92	01-Jul-93	-	-
01-Jul-93	01-Jul-94	232	8.1
01-Jul-94	01-Jul-95	1044	20.9
01-Jul-95	01-Jul-96	1165	28.9
01-Jul-96	01-Jul-97	923	22.0
01-Jul-97	01-Jul-98	667	15.0
01-Jul-98	01-Jul-99	703	18.9
01-Jul-99	01-Jul-00	603	19.4
01-Jul-00	01-Jul-01	759	20.8
01-Jul-01	01-Jul-02	1004	23.0
01-Jul-02	01-Jul-03	904	24.7
01-Jul-03	01-Jul-04	1326	30.0
01-Jul-04	01-Jul-05	1045	29.4
		Average annual SIN load	Average annual DRP load
01-Jul-89 to 01-Jul-05		**962.8**	**26.8**
Load percentiles			
	0	232	8
	10	629	16
	20	696	19
	30	779	19
	40	885	20
	50	923	21
	60	1020	22
	70	1045	24
	80	1119	29
	90	1262	30
	100	2101	105

This type of averaging approach has been applied in recent studies in contrasting catchments in New Zealand by Wilcock *et al.* (2007b) and Monaghan *et al.* (2006), who estimated loads leaving a catchment in stream water using the product of discharge weighted mean concentration and true mean flow, for selected variables following the methods of Ferguson (1987). The loads in those studies were calculated using data collected at fortnightly and monthly intervals.

Applying the discharge weighted mean approach to the Manawatu at Hopelands site

The weighted mean discharge method adjusts for the variability in the flow distribution introduced by the use of average monthly flow statistics. Put simply, the sum of the average monthly flows divided by the number of months in the dataset is different to the average flow over the full length of flow record; this can be corrected for (Ferguson, 1987).

The Ferguson (1987) correction has been applied to the load results for the Manawatu at Hopelands in Table 44 and the corrected data is shown in Table 45. The final calculation in the weighted mean discharge concentration approach identifies a single concentration for the entire range of flows and then multiplies this by the true mean flow. The discharge weighted mean concentrations calculated for SIN and DRP are 1.20 g SIN/m^3 and 0.03 g DRP/m^3.

The product of discharge weighted mean concentration multiplied by the true mean flow changes the SIN load from 963 to 964 tonnes/year and does not alter the DRP load estimate of 26.8 tonnes/year. *Note: the average of the average monthly flows (25.54 m^3/s) is very close to the true mean flow of 25.58 m^3/s for the Hopelands site.*

Table 45: Calculation of the annual export loading from the Manawatu at Hopelands site via the discharge weighted mean concentration method for the dataset from 1989 to 2005.

Statistic	Units	SIN	DRP
Sum (average monthly flow x sampled concentration) – whole period of record	Tonnes/15 years	14443	401.8
Years of record	years	15	15
Average annual load - averaging method	Tonnes/year	963	26.8
Average of average monthly flows	m^3/s	25.54	25.54
Annual average monthly flow	m^3/year	805416152	805416152
Discharge weighted mean concentration	g/m^3	1.20	0.03
True mean flow for sample period	m^3/s	25.58	25.58
Discharge weighted mean load	Tonnes/year	964	26.8

*July 1992 to June 1993 are excluded from this analysis

Summary of Measured loads using different methods

Table 46 compares the nutrient loads calculated using the various methods discussed in this report. The flow-stratified method recommended in this report represents the most conservative determination of annual loads of nitrogen for the upper Manawatu at Hopelands site. Annual phosphorus loads determined using this method were very similar to those reported by Ledein *et al.* (2007).

Table 46: Comparison of nutrient load estimates for the upper Manawatu River above Hopelands using several methods.

Method	SIN load (tonnes/year)	DRP load (tonnes/year)
Flow-stratified, Roygard & McArthur (2008)	745	21
Averaging, Roygard & McArthur (2008)	963	26.8
Discharge weighted mean, Roygard & McArthur (2008)	964	26.8
Averaging, Ledein *et al*. (2007)	991	20.6
Screening, Ledein *et al.* (2007)	1021	26.3

Assumptions underlying the averaging approach

For the Manawatu at Hopelands site, the assumption that flow and concentration are unrelated is questionable as there appear to be patterns in the flow versus concentration plots, particularly when stratified by flow decile category (see Section 4.4.1), although there is still considerable scatter in these relationships. The regression coefficients for SIN and DRP against flow were less than 0.15 when applying log or linear relationships. However, there is a clear pattern of lower concentrations within lower flow deciles.

Another assumption integral to the use of the averaging method is that the flow at time of water quality sampling is representative of the average monthly flow, therefore the flow vs. concentration relationship is not impacted by the time of sampling in relation to flow. This assumption does not hold true (Figure 1,
Figure 54 and
Figure 55). Another assumption is that the nutrient concentration at the time of sampling is representative of the concentrations recorded throughout the month, regardless of flow. This would also be questionable given the range of flows that actually occur at flow sites during a month.

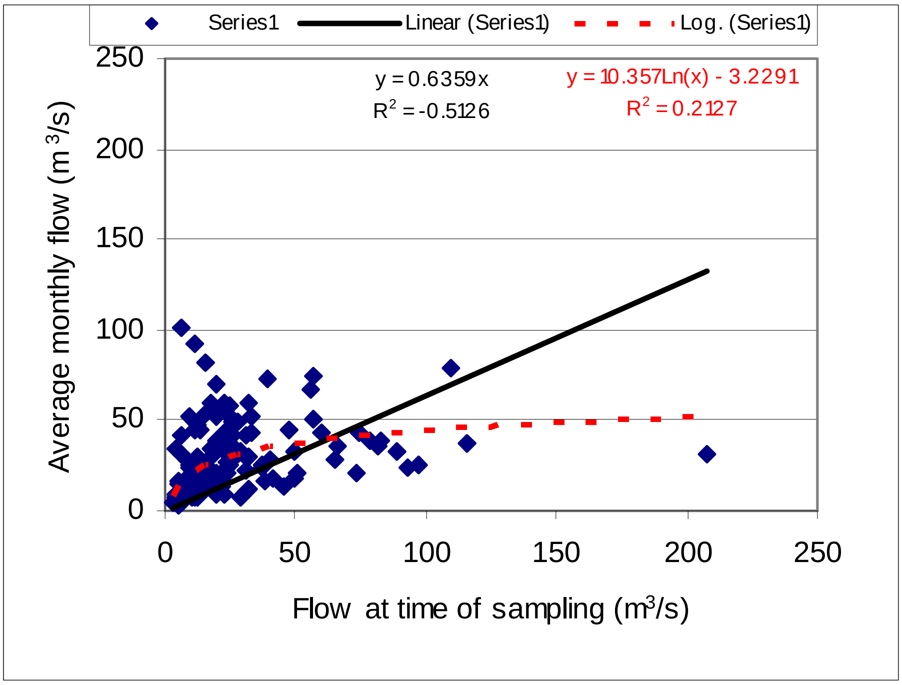


Figure 54: Relationship between flow at time of sampling and average monthly flow at the Manawatu at Hopelands site.

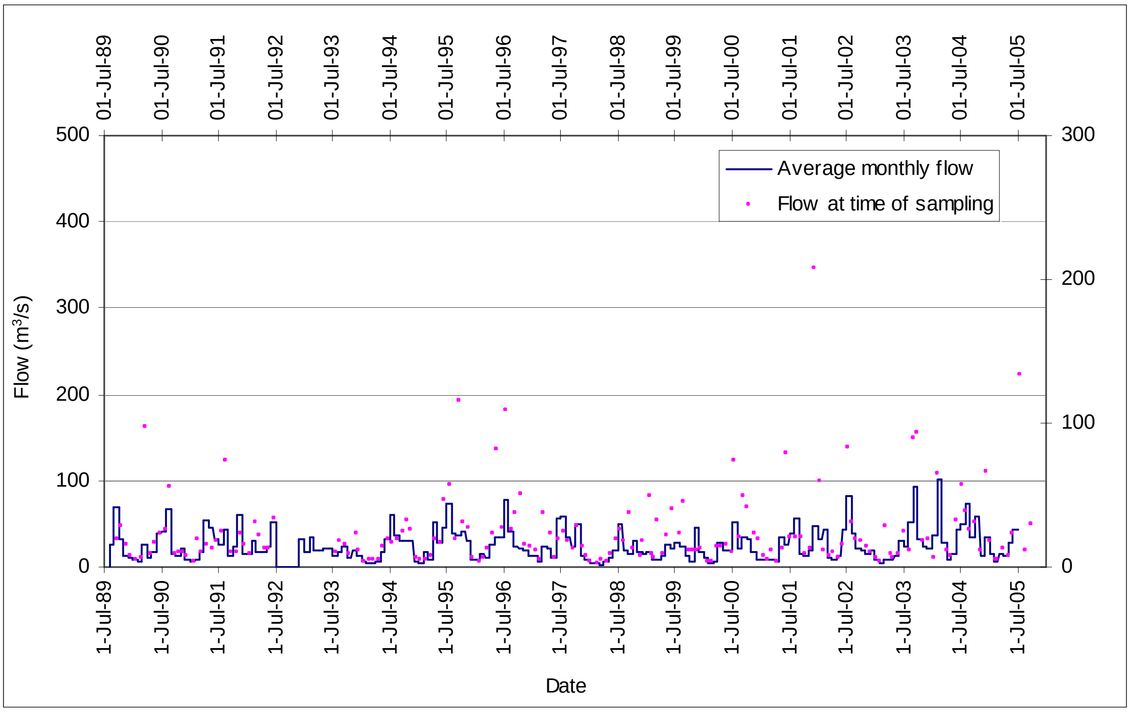


Figure 55: Time series of flow at time of sampling and average monthly flow at the Manawatu at Hopelands site.

Appendix 7: Sensitivity analysis: how does the length of record change the Measured load?

Because the SOE monitoring programme in the Manawatu-Wanganui Region has changed over the last two decades, the period of record for water quality data and continuous flow at each site also varies. To examine how these changes to the period of record might affect the estimation of Measured loads at a given site, an analysis of the water quality and flow record for the Manawatu at Hopelands site from July 1997 to September 2005 was undertaken. A comparison of the Measured load, determined using the full 1989 to 2005 record, against this shorter dataset is detailed below (Table 47).

For both analyses the flow decile categories and the flow record used to establish the Standard load limit were the same. Only the water quality concentrations and the flow in the years of monitoring varied. For the shorter record (1997–2005) the annual Measured load of SIN and DRP were higher over all flows and at flows less than the 10th percentile. As we saw in earlier sections of this report, considerable variation exists in the flow and water quality data; however the increased loads in the 1997–2005 dataset could be explained by either increased concentrations of SIN and DRP between 1989 and 1997, which raised the average daily load, or higher river flows over this shorter period of record.

The Measured SIN load, using the sum of the mean load for each flow decile, was approximately 5% higher for the shorter data set compared to the longer data set at all flows. The Measured DRP load was approximately 14% higher for the shorter data set compared to the longer data set at all flows. When the Measured loads for the flows less than the 10th percentile flow were compared, both SIN and DRP loads were between 7% and 8% higher for the shorter record. This may infer that nutrient concentrations (or potentially flows) have increased between 1997 and 2005, when compared with records averaged over 1989 to 2005. However, it may be important to note the increased DRP load at flow greater than the 10th percentile during the 1997 to 2005 period. This increase may have been influenced by the large amounts of phosphorus washed into the upper Manawatu River system as a result of the February 2004 storm event.

The general increases in nutrient load between the longer and shorter records may reflect a number of changes within the upper Manawatu River catchment over the last two decades. Increased intensification of land use is likely to be one of the major factors influencing nutrient loads over this time, particularly given the high proportion of Measured loads of both nitrogen and phosphorus that originate from NPS. Such land use changes are difficult to track over time due to the unreliability of earlier land use databases and models. However, the increase in nutrient concentrations, and thereby loads over time in the upper Manawatu catchment, are supported by the water quality trend analysis of Gibbard *et al.* (2006) and Scarsbrook (2006). In fact, Scarsbrook (2006) identified NPS contaminants from land use intensification as contributing to the national trend in increasing soluble nitrates in rivers.

Table 47: Comparison of Measured nutrient load for the Manawatu River at Hopelands site for two different time periods.

Period of record	Measured SIN load (tonnes/year)		Measured DRP load (tonnes/year)	
	All flows	< 10th %ile flows	All flows	< 10th %ile flows
July 1997 – September 2005	782	513	24	14
July 1989 – July 2005	745	478	21	13

Summary

So in summary, the period of record with respect to nutrient concentration data does influence the load calculation using the average flow-stratified method, especially where changes in land use or PS discharges have occurred. However, understanding the water resources, and the landscape and socioeconomic impacts on those resources, will allow for informed and pragmatic decision-making around data analysis and period of record examined.

Using the longest available period of record gives resource managers the most accurate overall impression of the state of nutrient loads to waterways and how these Measured loads compare to water quality standards over a long time scale.

Table 48: Calculation of the SIN Standard load limit and Measured load for the Manawatu at Hopelands State of the Environment (SOE) monitoring site using water quality data from July 1997 to September 2005.

Manawatu at Hopelands		0 – 10	10 - 20	20 - 30	30 - 40	40 - 50	50 - 60	60 - 70	70 - 80	80 - 90	90 - 100	All flows	Flows less than 10th percentile
Flow	m^3/s	49.496	32.653	24.289	19.106	15.4	12.422	9.9	7.712	5.439	2.005		
Standard load limit	**tonnes SIN/year**	**146.7**	**55.7**	**39.3**	**30.1**	**24.0**	**19.4**	**15.5**	**12.3**	**9.2**	**5.7**	**358.0**	**211.3**
Measured SOE results													
Maximum daily load	kg SIN/day	14275	4717	5538	3463	2807	1949	1122	1439	495	256		
Mean daily load	kg SIN/day	7362	3448	3132	2331	1908	1138	885	685	363	171		
Median daily load	kg SIN/day	8259	3371	2852	2269	1757	1033	933	626	399	174		
Minimum daily load	kg SIN/day	739	2259	1080	1600	1109	385	526	297	111	64		
Number of samples		13	7	11	11	7	11	12	12	7	10	101	88
Days per year flow occurrence	Days	36.5	36.5	36.5	36.5	36.5	36.5	36.5	36.5	36.5	36.5		
Maximum Measured load	tonnes SIN/year	521.0	172.2	202.1	126.4	102.5	71.1	41.0	52.5	18.1	9.4	1316.3	795.2
Mean Measured load	**tonnes SIN/year**	**268.7**	**125.8**	**114.3**	**85.1**	**69.6**	**41.5**	**32.3**	**25.0**	**13.2**	**6.3**	**782.0**	**513.3**
Median Measured load	tonnes SIN/year	301.4	123.0	104.1	82.8	64.1	37.7	34.0	22.8	14.6	6.4	791.1	489.6
Minimum Measured load	tonnes SIN/year	27.0	82.5	39.4	58.4	40.5	14.0	19.2	10.8	4.0	2.3	298.2	271.2
Difference between Standard load and Measured load (Measured load – Standard load)													
Maximum Measured load – Standard load	tonnes SIN/year	374.4	116.5	162.8	96.3	78.5	51.7	25.4	40.2	8.9	3.6	958.3	583.9
Mean Measured load – Standard load	tonnes SIN/year	122.0	70.2	75.0	55.0	45.7	22.1	16.8	12.7	4.1	0.5	424.0	301.9
Median Measured load – Standard load	**tonnes SIN/year**	154.8	67.4	64.7	52.7	40.1	18.3	18.5	10.5	5.4	0.6	433.1	278.3
Minimum Measured load – Standard load	tonnes SIN/year	-119.7	26.8	0.1	28.3	16.5	-5.4	3.7	-1.5	-5.1	-3.4	-59.8	59.9
Measured load as a percentage of Standard load (Measured load/Standard load)													
Maximum Measured load/Standard load	%	355	309	514	420	427	366	264	427	197	164	368	414
Mean Measured load/Standard load	%	183	226	291	283	290	214	208	203	144	109	218	267
Median Measured load/Standard load	**%**	**206**	**221**	**265**	**275**	**267**	**194**	**219**	**185**	**159**	**111**	**221**	**255**
Minimum Measured load/Standard load	%	18	148	100	194	169	72	124	88	44	41	83	141

Table 49: Calculation of the DRP Standard load limit and Measured load for the Manawatu at Hopelands State of the Environment (SOE) monitoring site using water quality data from July 1997 to September 2005.

Manawatu at Hopelands		0 – 10	10 - 20	20 - 30	30 - 40	40 - 50	50 - 60	60 - 70	70 - 80	80 - 90	90 - 100	All flows	Flows less than 10th percentile
Flow	m^3/s	49.496	32.653	24.289	19.106	15.4	12.422	9.9	7.712	5.439	2.005		
Standard load limit	**tonnes DRP/year**	**3.3**	**1.3**	**0.9**	**0.7**	**0.5**	**0.4**	**0.3**	**0.3**	**0.2**	**0.1**	**8.06**	**4.3**
Measured SOE results													
Maximum daily load	kg DRP/day	788.0	170.5	111.8	101.6	61.4	44.5	49.3	34.7	37.4	39.5		
Mean daily load	kg DRP/day	276.6	108.4	71.7	51.1	43.5	31.3	23.8	19.6	14.0	11.4		
Median daily load	kg DRP/day	187.8	85.4	67.6	49.2	43.7	31.7	21.0	17.9	10.1	7.0		
Minimum daily load	kg DRP/day	97.0	59.0	49.6	29.7	20.6	17.5	2.0	1.6	6.4	1.7		
Number of samples		13	7	11	11	7	11	12	12	7	10	101	88
Days per year flow occurrence	Days	36.5	36.5	36.5	36.5	36.5	36.5	36.5	36.5	36.5	36.5		
Maximum Measured load	tonnes DRP/year	28.8	6.2	4.1	3.7	2.2	1.6	1.8	1.3	1.4	1.4	52.5	23.8
Mean Measured load	**tonnes DRP/year**	**10.1**	**4.0**	**2.6**	**1.9**	**1.6**	**1.1**	**0.9**	**0.7**	**0.5**	**0.4**	**23.8**	**13.7**
Median Measured load	tonnes DRP/year	6.9	3.1	2.5	1.8	1.6	1.2	0.8	0.7	0.4	0.3	19.0	12.2
Minimum Measured load	tonnes DRP/year	3.5	2.2	1.8	1.1	0.8	0.6	0.1	0.1	0.2	0.1	10.4	6.9
Difference between Standard load and Measured load (Measured load – Standard load)													
Maximum Measured load – Standard load	tonnes DRP/year	25.5	5.0	3.2	3.0	1.7	1.2	1.4	1.0	1.2	1.3	44.5	19.0
Mean Measured load – Standard load	**tonnes DRP/year**	**6.8**	**2.7**	**1.7**	**1.2**	**1.0**	**0.7**	**0.5**	**0.4**	**0.3**	**0.3**	**15.7**	**8.9**
Median Measured load – Standard load	tonnes DRP/year	3.6	1.9	1.6	1.1	1.1	0.7	0.4	0.4	0.2	0.1	11.0	7.4
Minimum Measured load – Standard load	tonnes DRP/year	0.2	0.9	0.9	0.4	0.2	0.2	-0.3	-0.2	0.0	-0.1	2.3	2.1
Measured load as a percentage of Standard load (Measured load/Standard load)													
Maximum Measured load/Standard load	%	872	496	460	547	415	371	514	457	659	1119	651	550
Mean Measured load/Standard load	**%**	**306**	**316**	**295**	**275**	**294**	**261**	**248**	**258**	**247**	**322**	**295**	**316**
Median Measured load/Standard load	%	208	248	278	265	295	264	220	235	178	197	236	282
Minimum Measured load/Standard load	%	107	172	204	160	139	146	21	22	113	47	129	159

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