BEFORE THE ENVIRONMENT COURT

In the matter of	appeals under clause 14 of the First Schedule to the Resource Management Act 1991 concerning proposed One Plan for the Manawatu-Wanganui region.
between	**FEDERATED FARMERS OF NEW ZEALAND** **ENV-2010-WLG-000148**
and	**MINISTER OF CONSERVATION** **ENV-2010-WLG-000150**
and	**DAY, MR ANDREW** **ENV-2010-WLG-000158**
and	**HORTICULTURE NEW ZEALAND** **ENV 2010-WLG-000155**
and	**WELLINGTON FISH & GAME COUNCIL** **ENV-2010-WLG-000157** *Appellants*
and	**MANAWATU-WANGANUI REGIONAL COUNCIL** *Respondent*

JOINT TECHNICAL EXPERT STATEMENT DR JONATHON KELVIN FLETCHER ROYGARD, KATHRYN JANE MCARTHUR AND MAREE ELLEN CLARK ON THE TOPIC OF SURFACE WATER QUALITY – NON-POINT SOURCE DISCHARGES ON BEHALF OF MANAWATU-WANGANUI REGIONAL COUNCIL

Dated: 14 February 2012

horizons
regional council

Solicitor:	John W Maassen/Nicholas Jessen
Administrator:	Sharon Belk
Address:	11-15 Victoria Avenue Private Bag 11025 Palmerston North 4442
Telephone:	(06) 952 2800
Facsimile:	(06) 952 2929
Email:	sharon.belk@horizons.govt.nz

JOINT TECHNICAL EXPERT STATEMENT BY DR JONATHON KELVIN FLETCHER ROYGARD, KATHRYN JANE MCARTHUR AND MAREE ELLEN CLARK ON THE TOPIC OF SURFACE WATER QUALITY – NON-POINT SOURCE DISCHARGES ON BEHALF OF MANAWATU-WANGANUI REGIONAL COUNCIL

Terms

TEB = technical evidence bundle
NV = notified version of POP
DV = decisions version of POP
MV = mediated version of POP
MCB = mediated compilation bundle

Qualifications and experience

Dr Roygard

1. My full name is Jonathon Kelvin Fletcher Roygard. I have a Doctor of Philosophy degree (PhD in Natural Resources), with a specialisation in soil science, from Massey University, Palmerston North. My PhD involved measuring and modelling nutrient movement through soils in a land treatment research project. I hold a Bachelor of Science Honours Degree (Zoology) from Massey University, where my post graduate papers included Ecology, Limnology, and Conservation Biology. I have worked as a Post-Doctoral Scientist and Research Assistant Professor in the Department of Crop and Soil Environmental Science, at Virginia Polytechnic Institute and State University (Virginia Tech), in Blacksburg, Virginia, USA. My research during this time was primarily in the Mid-Atlantic Cropping Systems project.

2. I have been employed by Horizons for more than nine years in various roles, including Environmental Information Analyst, Environmental Scientist – Water, and Senior Environmental Scientist – Water. In these roles my duties have

ranged from processing hydrological data through to leading water resource assessments, developing the Water Management Zones framework, technical reporting on resource consents, and contributing to design and reporting of the State of Environment (SoE) monitoring programme. For more than five years, I have held the role of Manager Science within the Regional Planning and Regulatory Group of Horizons. In this role, I lead and manage the science programme at Horizons. The science programme includes research in relation to land, water, air, biodiversity, and fluvial resources and Horizons' SoE and policy effectiveness monitoring programmes. As the manager of the science team, I maintain a science role as well as a management role. My role includes initiating, scoping, project managing, and contributing to many projects relating to water allocation (surface and groundwater), water quality, fluvial science, and land use interactions with water quality.

3. I have lead and managed the technical reporting for the One Plan process for the water chapter. I have authored and co-authored a range of scientific reports and publications, including technical reports to support the Proposed One Plan. I have also authored and co-authored papers in international journals on topics relating to soil science, crop water use, water and nitrogen balances for land treatment of effluent systems, the relationship between flow and nutrient concentrations in rivers, the calculation of in-river nutrient loads and ecology. I am a member of the New Zealand Hydrological Society, the New Zealand Freshwater Sciences Society, the Regional Council Group Surface Water Integrated Management (SWIM) and the taskforce for the proposed measurement of water takes target. I am also Horizons' Envirolink coordinator, have had roles as co-champion of two national Envirolink tool projects and have participated as a part of the science advisory group of Envirolink. I have lead the development of the water quality module for the Land and Water New Zealand Website which presents water quality state and trend information from all regional councils in a common format to the public. I have been involved in the development of the Manawatu River Leaders Accord, the subsequent action plan and Horizons application to the Freshwater Cleanup fund.

4. I have read the Environment Court's practice note, Expert Witnesses – Code of Conduct and agree to comply with it.

Kate McArthur

5. My name is Kathryn (Kate) Jane McArthur. I hold a Bachelor of Science degree with Honours in Ecology and a Master of Applied Science with Honours in Natural Resource Management from Massey University. My areas of post-graduate research were the influence of land use on freshwater macroinvertebrate communities in the Manawatu-Wanganui Region and the interaction between policy and science for freshwater resource management. I have more than 9 years post-graduate experience working in the field of freshwater sciences and I am currently employed as the Senior Scientist – Water Quality with Horizons Regional Council. I have been a member of the New Zealand Freshwater Sciences Society (formerly the NZ Limnological Society) since 2001 and I am a member of the Resource Management Law Association of New Zealand. I have been an active participant in the Regional Council Surface Water Integrated Management interest group (SWIM) since July 2006 and I have championed an Envirolink Tools project developing methods to measure and guidelines to assess sedimentation in rivers.

6. Prior to my employment with Horizons in 2006 I worked as a Resource Management and Compliance Officer for the Wellington and Taranaki Fish and Game Councils, as a Laboratory Supervisor at Massey, and as a contractor (through Massey University) for both Greater Wellington and Horizons Regional Councils in the fields of native freshwater fish management and aquatic biomonitoring. Before specialising in freshwater ecology I worked in the fields of captive management of native and exotic birds and fish and veterinary nursing. I hold a diploma in Animal Science from the New Zealand Veterinary Association.

7. I have authored and co-authored a range of scientific reports and publications, including technical reports to support the Proposed One Plan. I have also authored and co-authored papers in international journals on topics relating to the relationship between flow and nutrient concentrations in rivers, methods for monitoring native fish, the calculation of in-river nutrient loads and the setting of water quality limits in resource management policy.

8. I have read the Environment Court's practice note, Expert Witnesses – Code of Conduct and agree to comply with it.

Maree Clark

9. My full name is Maree Ellen Clark. I have a Masters in Applied Science (Natural Resource Management) and a Postgraduate Diploma in Arts (Geographic Information Systems) from Massey University, Palmerston North, and a Bachelor of Science Degree (Geography) from the University of Canterbury, Christchurch. My research focussed on the management of point source discharges to the Mangatainoka catchment. I have been a member of the New Zealand Freshwater Sciences Society since 2007 and I am a member of the International Water Association. I am an active participant in the Regional Council Surface Water Integrated Management interest group (SWIM).

10. I have been employed by Horizons since May 2004 in the roles of Research Assistant, Research Associate and Environmental Scientist – Water. As Environmental Scientist - Water my role includes initiating, scoping, project managing and contributing to many projects relating to water quality and land use interactions with water quality, I am the GIS "expert" for the Horizons Science Team and I lead the surface water quality State of the Environment programme. I have authored and co-authored a range of technical reports, many of which have contributed to policy development for the One Plan, including water resource assessments and water quality investigations. With Dr Roygard I co-authored the Land Use and Land Use Capability in the Manawatu-Wanganui Region technical report (Clark and Roygard 2008). I have also co-authored two papers in scientific journals on the relationship between flow and nutrient concentrations in rivers and the calculation of in-river nutrient loads.

11. I have read the Environment Court's practice note, Expert Witnesses – Code of Conduct and agree to comply with it.

Introduction

Scope of evidence

12. This joint evidence statement has the following purposes:

    a. Update the information on the state and trends in water quality and aquatic ecosystem health at sites across the region since publication of our s. 42A and supplementary reports (Roygard: TEB v.1 p. 193-500; Clark: TEB v.2 p. 501-582; McArthur: TEB v. 2 p. 591-928). This update is presented in Section 1.

    b. Provide more detail regarding this updated information specifically in relation to the targeted catchments in Table 13.1 of the Proposed One Plan. This update is presented in Section 2.

    c. Explore a number of scenarios in relation to in-river loads of nitrogen and various approaches to management of nitrogen losses from farms or other sources (e.g. other land use types, point sources). The scenarios include using management of losses from dairy farms using LUC based nitrogen loss limits. The scenarios are presented complete in section 1c and a summary of findings for each of the target catchment is presented in Section 2. The rationale and methodologies for modelling these scenarios will follow in a subsequent document.

13. This statement has been compiled jointly to allow for the integrated presentation of information for each of the target catchments. While the expertise of the contributing scientists overlap, the analyses have been undertaken separately. For clarity the responsibilities for topics in this statement are set out below and any questions on these topics should be directed according to the table.

Dr Roygard	Water quality, nutrient loads and leaching losses, in particular: Methods of nutrient load calculation Calculation of nutrient losses Scenarios for in-river nutrient loads
Kate McArthur	Aquatic ecosystems and water quality, in particular: Aquatic macroinvertebrates, periphyton and suspended algae Northern Manawatu Lakes target catchment Coastal and estuarine water quality
Maree Clark	Land and Water New Zealand (LAWNZ) water quality data Calculation of point source discharge loads Land use and Land Use Capability land area data

Terms

14. Throughout this evidence we have used the term “target” to mean the Schedule D numeric for each indicator (eg. Nitrogen, phosphorus, periphyton, MCI etc.) as in the DV of the Proposed One Plan. This term has been used for simplicity of use in analyses and data presentation.

15. The water management sub-zones listed in Table 13-2 of the DV POP are referred to as target catchments throughout this evidence.

16. Summaries of the key points of each section are summarised at the end of that section in boxes.

Section 1A: Updated state and trends in water quality and aquatic ecosystem – a regional summary

Water quality

17. A detailed examination of the state of water quality in the region can be found in section 4.3 of the s.42A report of Kathryn McArthur (TEB v. 2 p. 640-642). The

compilation of national analyses in the s.42A evidence concluded that freshwater quality in the region was poor in a number of catchments (especially the Manawatu) that are subject to high proportions of pastoral land use or significant point source discharges, particularly with respect to high faecal contaminants, nutrient enrichment (by nitrogen and phosphorus), poor aquatic ecosystem health and poor native fish diversity (TEB v. 2 p. 655) and paragraphs 13 & 103-112 of the s. 42A report of Dr Davies-Colley (TEB v. 3 p. 1173, v. 3 p. 1201-1204).

18. The state of water quality (using median concentration) at eighty-eight sites across the region was compared with 891 regional council sites nationally using the Land and Water New Zealand (LAWNZ) data (www.landandwater.co.nz) (

Table 1).

19. Across the five parameters examined, the proportion of Horizons sites where the median fitted within the best 25% (upper quartile) of all sites ranged between 3 and 19%. Thirty-three per cent of Horizons sites fitted into the lowest (worst) quartile for visual clarity, 27% for faecal indicators, 24% for phosphorus, 25% for ammonia and 23% for nitrogen.

20. Reports on the state and trend of water quality nationally have concluded that elevated, and in some areas increasing, concentrations of nitrogen and phosphorus are strongly associated with the degree of pastoral land use in the catchment, particularly at lowland sites (Scarsbrook 2006; Ballantine and Davies-Colley 2010; Davies-Colley 2011). Data from Horizons sites also shows this association (Ballantine and Davies-Colley 2009).

21. More detailed information on the LAWNZ quartiles and summary water quality data for the Horizons sites can be found in Appendix 1.

Table 1: Proportion of water quality monitoring sites in the Horizons Region with median data within each quartile of the national data for visual clarity (measured as black disc), dissolved reactive phosphorus (DRP), *Escherichia coli (E. coli)*, Ammonia (NH_3) and total oxidised nitrogen (TOx). Data range May 2004 – April 2011.

New Zealand quartile	**Proportion of Horizons sites in each NZ quartile**				
	Visual Clarity	*E. coli*	DRP	NH_3	TOx
Best 25%	16%	11%	8%	3%	19%
25-50%	24%	19%	38%	53%	28%
50-75%	27%	42%	31%	18%	30%
Worst 25%	33%	27%	24%	25%	23%

22. Trends in water quality have been examined by Ballantine and Davies-Colley (2009) and Ballantine and Davies-Colley (2010) for significant changes in water quality over time at sites in the Horizons Region using Horizons' own data and national network monitoring data from NIWA. Analyses of trends in water quality data are heavily influenced by sample size. Horizons data was monitored over various timeframes depending on the site, so the reliability of the trend results varies, increasing in reliability for the sites monitored the longest. In comparison, the NIWA dataset provides a stable basis for comparing trend data between sites as all sites were monitored over the same time period and at the same frequency.

23. For the Horizons monitored sites there are few degrading trends with the exception of water clarity (measured by black disc and turbidity) in the Hautapu and lower Manawatu Rivers. The faecal indicator bacteria *Escherichia coli* has also increased meaningfully in the upper Ohau River.

24. Improving trends are found in soluble nitrogen at several sites in the Whanganui, upper Mangawhero, Hautapu and lower Oroua Rivers, with improvements in clarity and *E. coli* at some sites, including the Mangatainoka, Manawatu at Hopelands and upper Gorge. No trends for dissolved phosphorus are seen in the Horizons data.

25. Data from the NIWA national monitoring network shows some improvements in water clarity with only one declining clarity trend in the Rangitikei at Kakariki. Nutrient trends are less encouraging with only one improving trend in phosphorus in the lower Manawatu and several declining trends for both phosphorus and nitrogen at sites in each of the major catchments. Notably, nitrogen is

meaningfully increasing at three sites on the upper, middle and lower Manawatu River.

Table 2: Water quality trend results for sixteen Horizons and seven NIWA monitoring sites in the Manawatu-Wanganui Region. DRP = dissolved reactive phosphorus, SIN = soluble inorganic nitrogen, Black disc = water clarity, Turb = turbidity, *E. coli* = *Escherichia coli*, NO_3 = nitrate nitrogen (modified from Ballantine and Davies-Colley 2009).

Horizons Sites	**First sampled**	**DRP**	**SIN**	**Black disc**	**Turb**	***E. coli***
Whanganui at Cherry Grove	1991	⬜	⬜	⬜	⬜	⬜
Whanganui d/s Retaruke	1997	⬜	⬜	⬜	⬜	⬜
Whanganui at Pipiriki	1998	⬜	🟩	⬜	🟩	⬜
Mangawhero at DOC HQ	1998	⬜	🟩	⬜	🟩	⬜
Hautapu u/s Rangitikei	1998	⬜	🟩	🟥	🟩	🟩
Tamaki at Reserve	1999	⬜	⬜	⬜	⬜	⬜
Tamaki at SH2	1999	⬜	⬜	⬜	⬜	⬜
Manawatu at Hopelands	1989	⬜	⬜	▨	⬜	⬜
Makuri at Tuscan Hills	1999	⬜	⬜	⬜	⬜	⬜
Mangatainoka at SH2	1993	⬜	⬜	⬜	🟩	⬜
Manawatu at Upper Gorge	2003	⬜	⬜	⬜	⬜	🟩
Oroua at Almadale	2005	⬜	⬜	⬜	⬜	⬜
Oroua at Awahuri	1993	⬜	🟩	⬜	⬜	⬜
Manawatu at Whirokino	1991	⬜	⬜	🟥	🟥	⬜
Lake Horowhenua	1998	⬜	⬜	⬜	⬜	⬜
Ohau at Rongomatane	1999	⬜	⬜	⬜	⬜	🟥
Trend interpretation						
Meaningful improvement		0	4	0	4	2
Significant improvement		0	0	1	0	0
No change		16	12	13	11	13
Significant degradation		0	0	0	0	0
Meaningful degradation		0	0	2	1	1
NIWA Sites	**First sampled**	**DRP**	**NO_3**	**Black disc**	**Turb**	
Whanganui at Paetawa	1989	⬜	⬜	⬜	⬜	
Whanganui at Te Maire	1989	🟥	⬜	⬜	▨	
Rangitikei at Mangaweka	1989	⬜	⬜	🟩	⬜	
Rangitikei at Kakariki	1989	🟥	⬜	⬜	🟧	
Manawatu at Opiki	1989	🟩	🟥	⬜	⬜	
Manawatu at Teachers College	1989	⬜	🟥	🟩	⬜	
Manawatu at Weber Rd	1989	🟥	🟥	⬜	⬜	
Trend interpretation						
Meaningful improvement		1	0	2	0	
Significant improvement		0	0	0	1	
No change		3	4	5	5	

Horizons Sites	**First sampled**	**DRP**	**SIN**	**Black disc**	**Turb**	***E. coli***
Significant degradation		0	0	0	1	
Meaningful degradation		3	3	0	0	

Aquatic ecosystems

26. This section summarises the state of water quality at a number of sites in the Manawatu-Wanganui Region with a particular focus on aquatic macroinvertebrate communities and periphyton growth. It is compiled from data collected since the collation of evidence presented at hearings on the water chapter of the One Plan. More detail on the state of water quality and aquatic ecosystem health can be found in Chapter 4 of Kathryn McArthur's s. 42A report and supplementary evidence (TEB v. 2 p. 629-656; p. 879-928) as well as the s. 42A and supplementary evidence of Dr Roygard (TEB v. 1 p. 193-500) and other experts on behalf of Horizons (Biggs: TEB v.2 p. 953-1020; Davies-Colley: TEB v. 3 p. 1169-1211; Wilcock: TEB v. 3 p. 1115-1148; Young: TEB v. 3 p. 1149-1168; Zeldis: TEB v. 3 p. 1077-1114; McBride: TEB v. 3 p. 1375-1382; Quinn: TEB v. 3 p. 1213-1240) that have been previously presented to the Court. Detailed information on the water quality, aquatic ecosystems, characteristics and values of each target catchment are detailed in Chapter 9 of Kathryn McArthur's s. 42A evidence (TEB v. 2 p. 744-851).

27. Since the preparation of s. 42A and supplementary evidence on water quality and aquatic ecosystem health in 2009, Horizons has extended the number and scope of monitoring programmes to measure the policy effectiveness of the One Plan and measure the state of the region's environment into the future. Information from extended or newly introduced monitoring programmes has been incorporated into the following sections in order to provide an up to date indication of the state of water quality and aquatic ecosystem health at a number of sites in the region, to better inform policy development.

Interpretation of aquatic macroinvertebrate community indices

28. The Macroinvertebrate Community Index (MCI) is a biological indicator widely used throughout New Zealand to report on the state of aquatic macroinvertebrate communities at freshwater sites and to make inferences about the water quality influencing the site's ecosystem health. Traditionally, the scoring system used to

present the results of the MCI uses degradation categories that range from clean water to probable severe pollution depending on a site's index score (Boothroyd and Stark 2000; Stark 1998; Stark 1993; Stark 1985). MCI results are also displayed using water quality classes that range from excellent to poor (Stark and Maxted 2007). The targets proposed for aquatic macroinvertebrate communities in Schedule D of the DV of the Proposed One Plan have MCI scores of either >100 or >120, depending on the values at a given water management sub-zone. The relationship between the classifications presented by Boothroyd and Stark (2000), Stark and Maxted (2007) and the Proposed One Plan targets for MCI are presented in Table 3 below.

Table 3: Relationship between degradation categories, water quality classes and Proposed One Plan targets for interpretation of the Macroinvertebrate Community Index (MCI).

Degradation category (Boothroyd & Stark 2000)	Quality class (Stark & Maxted 2007)	MCI score	Proposed One Plan target
Clean water	Excellent	> 119	> 120 some sub-zones
Doubtful quality or possible mild pollution	Good	100-119	> 100 some sub-zones
Probable moderate pollution	Fair	80-99	Below target
Probable severe pollution	Poor	< 80	Below target

29. Life-Supporting Capacity and Trout Fishery are two values closely linked to the health of aquatic macroinvertebrates. Expert technical advice was sought to determine the most appropriate MCI targets to support the classes and significance categories of the Life-Supporting Capacity and Trout Fishery values (Ausseil and Clark 2007; Hay et al. 2006). These targets are also supported in the s. 42A expert evidence of Dr John Quinn and Dr Roger Young (Quinn: TEB v. 3 p. 1213-1234; Young: TEB v. 3 p. 1149-1168).

30. MCI targets of >100 or >120 for the Region indicate a desired minimum degradation category of mild pollution or water quality class of 'good', as measured by the MCI score at a site. In my opinion these are appropriate

expectations for the Region’s rivers if the advancement of the values is a key policy objective of the Plan. As such, the following sections assess the latest aquatic macroinvertebrate data against the DV POP MCI targets to indicate the current state at each site.

Aquatic macroinvertebrate state and trend

31. Horizons permanently monitors aquatic macroinvertebrates at forty-eight sites regionally. Twelve of these sites have been monitored for thirteen years and the remainder of the sites range from one to twelve years of monitoring. Analysis of the data is undertaken annually. The most recent report on the annual monitoring also summarises the mean MCI score over the total period of monitoring for each site (Stark 2011). The mean MCI scores from this report are used to determine which sites meet the One Plan MCI targets (Table 4). The annual MCI scores for each site are also compared to the One Plan target to determine the percentage of samples that meet the target over time. Table 4 also shows the uncorrected significant Mann-Kendall trend results for sites with six or more sampling observations reported by Stark (2011).

32. Of the forty-eight sites monitored, the mean MCI at twenty one sites (44%) met the DV POP targets. Of these sites, most met the target in more than 70% of sampled years with the exception of the Mangawhero at Pakihi Rd and Ohau at Gladstone Reserve sites, which met the target in 50% of sampling years or less. Thirteen sites did not meet the target in any sampling year, four of which were in target catchments including two sites in the lower Mangatainoka, the Makakahi at Hamua and the Manawatu at Hopelands sites. Few trends were found over the period of record and the only trend which remained significant after correction using the Benjimini-Hochberg false discovery rate procedure (FDR; Stark 2011) was a negative trend for the site at the bottom of the Hautapu River catchment (Hautapu u/s Rangitikei).

Table 4: Comparison of mean MCI score for variable monitoring periods (*n*) with DV POP MCI targets for forty-eight permanent biomonitoring sites in the Manawatu-Wanganui Region. Annual comparison with targets is displayed as percentage of samples which meet the target (depending on *n*). Sites within target catchments are marked with an asterisk (*). Uncorrected significant trends are displayed for sites with more than six years of monitoring data. *N.B. the only trend which remained significant after correction using the Benjamini-Hochberg false discovery rate procedure was at the Hautapu u/s Rangitikei. Blank cells = no trend or not enough data to reliably detect a trend.*

Site	Water Management sub-zone	DV POP MCI target	*n*	Mean MCI	Meets MCI target	% samples meeting target	Mann-Kendall significant trend
Arawhata at Hokio Beach Rd	Lake Horowhenua	100	3	66	No	0	
Hautapu at Alabasters	Upper Hautapu	120	4	96	No	0	
Hautapu u/s Rangitikei	Lower Hautapu	100	13	90	No	23	**-ve**
Hokio at Lake Outlet Weir	Hokio	100	3	70	No	0	
Kahuterawa at Johnstons Rata	Kahuterawa	120	4	108	No	0	
Kawahatau at Potaka Road	Pukeokahu - Mangaweka	120	1	123	Yes	100	
Makakahi at Hamua*	Makakahi	120	6	98	No	0	
Makotuku u/s Raetihi	Lower Makotuku	120	4	98	No	0	
Makuri at Tuscan Hills	Makuri	120	6	104	No	17	
Manawatu at Hopelands*	Tamaki-Hopelands	120	13	97	No	0	
Manawatu at Opiki Bridge	Lower Manawatu	100	9	84	No	22	
Manawatu at Teachers College	Middle Manawatu	100	13	96	No	38	
Manawatu at Upper Gorge*	Upper Gorge	100	7	104	Yes	71	
Manawatu at Weber*	Upper Manawatu	120	5	106	No	20	
Mangahao at Ballance	Upper Mangahao	120	6	111	No	17	
Manganui o te Ao at Ashworth Bridge	Lower Manganui o te Ao	120	3	115	No	33	
Mangapapa at Troup Rd Bridge*	Mangapapa	100	4	115	Yes	75	
Mangatainoka at Putara*	Upper Mangatainoka	120	6	139	Yes	100	
Mangatainoka at SH2*	Lower Mangatainoka	120	13	95	No	0	**+ve**
Mangatainoka u/s Tiraumea*	Lower Mangatainoka	120	1	107	No	0	
Mangatera at Timber Bay*	Mangatera	100	13	95	No	31	
Mangawhero at Pakahi Rd Bridge	Upper Mangawhero	120	4	120	Yes	50	
Mangawhero at DOC Headquarters	Upper Mangawhero	120	13	133	Yes	100	
Ohau at Gladstone Reserve	Upper Ohau	120	7	123	Yes	43	
Oroua at Almadale Slackline	Upper Oroua	100	6	108	Yes	83	

Site	Water Management sub-zone	DV POP MCI target	*n*	Mean MCI	Meets MCI target	% samples meeting target	Mann-Kendall significant trend
Oroua at Apiti Gorge Bridge	Upper Oroua	100	6	126	Yes	100	
Oroua at Awahuri Bridge	Middle Oroua	100	13	90	No	23	
Oruakeretaki at SH2*	Oruakeretaki	100	3	126	Yes	100	
Owahanga at Branscombe Bridge	Owahanga	100	5	99	No	20	
Patiki at Kawiu Rd	Lake Horowhenua	100	3	88	No	0	
Pohangina at Mais Reach	Middle Pohangina	100	4	112	Yes	100	
Pohangina at Piripiri	Upper Pohangina	120	5	126	Yes	80	**+ve**
Porewa at Onepuhi Rd	Porewa	100	7	93	No	0	
Rangitikei at Mangaweka	Pukeokahu-Mangaweka	120	12	107	No	17	
Rangitikei at McKelvies	Coastal Rangitikei	100	3	97	No	33	
Rangitikei at Onepuhi	Lower Rangitikei	120	3	103	No	0	
Rangitikei at Pukeokahu	Middle Rangitikei	120	13	117	No	38	**+ve**
Tamaki at Reserve*	Upper Tamaki	120	6	140	Yes	100	
Tamaki at Stephensons*	Lower Tamaki	100	3	125	Yes	100	
Tiraumea at Ngaturi	Lower Tiraumea	100	3	109	Yes	100	
Tokiohuru at Karioi	Upper Whangaehu	120	4	130	Yes	75	
Tokomaru at Horseshoe Bend	Upper Tokomaru	120	5	128	Yes	80	
Turakina at O'Neils	Lower Turakina	100	1	89	No	0	
Waikawa at Nth Manakau Rd*	Waikawa	100	3	135	Yes	100	
Whanganui at Cherry Grove	Cherry Grove	100	13	114	Yes	100	
Whanganui at Pipiriki	Pipiriki	100	13	97	No	46	
Whanganui at Te Maire	Te Maire	100	13	106	Yes	92	
Whanganui d/s Retaruke	Middle Whanganui	100	13	106	Yes	85	

Periphyton growth at sites in the Manawatu-Wanganui Region

33. Following the recommendations of Kilroy et al. (2008) Horizons has monitored forty-eight sites for periphyton cover and biomass (chlorophyll *a*) monthly since December 2008. A further eight sites were added in 2009. An analysis of the dataset from December 2008 to November 2011 (inclusive) has been used in this evidence to examine the current state of periphyton growth at sites in the Region. Periphyton growth and biomass is affected by flood frequency (accrual period), nitrogen and phosphorus concentration, invertebrate grazing, shading, and substrate composition. Table 5 shows the total number of observations that exceed the targets for filamentous and mat algal cover and chlorophyll *a* concentration for each site. Table 5 also shows the within-year (annual) range of exceedance based on the number times each site exceeds the targets in 12 month blocks starting December 2008 to November 2011.

34. Over all observations, thirty sites always met the chlorophyll *a* targets and twenty-six did not (Figure 1). The number of times any site exceeded the target ranged from 1 to 25. Twenty-five sites always met the filamentous per cent cover target, while thirty-one sites did not at some time (Figure 2).The number of times the target was exceeded at any site ranged from 1 to 17. Thirty-nine sites met the mat per cent cover target and seventeen sites did not (Figure 3).The number of times the target was exceeded at any site ranged between 1 and 9.

Table 5: Summary of monthly periphyton observations in comparison with DV POP targets for per cent cover of filamentous algae (30% target), mat algae (60% target) and chlorophyll *a* (mg/m^2) for fifty-six sites in the Manawatu-Wanganui Region monitored between Dec 2008 and Nov 2011. The within-year range of the number of observations exceeding the targets at each site is shown as the annual range (fils, mats and Chl *a*). Sites within target catchments are marked with an asterisk (*), *n* = number of monthly observations at each site.

Site	*n*	No. above % cover target (fils)	Annual range (fils)	No. above % cover target (mats)	Annual range (mats)	No. above Chl *a* target	Annual range (Chl *a*)	Chl *a* target
Kumeti at Te Rehunga*	36	0	0	0	0	0	0	50
Makakahi at Hamua*	35	2	0-1	1	0-1	0	0	120
Makotuku at Raetihi	27	2	0-1	9	0-6	6	0-3	50
Makotuku at SH49	36	0	0	0	0	0	0	50
Makotuku d/s Raetihi STP	35	17	0-8	2	0-1	25	0-9	50
Makotuku u/s Raetihi STP	17	4	0-3	1	0-1	8	0-5	50
Makuri at Tuscan Hills	36	0	0	0	0	6	0-4	120
Manawatu at Hopelands*	36	4	0-3	2	0-2	8	0-3	120

Site	*n*	No. above % cover target (fils)	Annual range (fils)	No. above % cover target (mats)	Annual range (mats)	No. above Chl *a* target	Annual range (Chl *a*)	Chl *a* target
Manawatu at Opiki	35	5	0-2	0	0	3	0-1	120
Manawatu at Teachers College	36	0	0	0	0	0	0	120
Manawatu at Upper Gorge*	34	0	0	0	0	0	0	120
Manawatu at Weber Rd*	34	5	0-4	0	0	1	0-1	120
Manawatu d/s PNCC STP	36	5	0-3	2	0-1	5	0-3	120
Manawatu u/s PNCC STP	36	4	0-2	1	0-1	2	0-1	120
Mangaatua d/s Woodville STP*	14	0	0	0	0	0	0	120
Mangaatua u/s Woodville STP*	14	1	0-1	0	0	0	0	120
Mangapapa at Troup Rd*	36	0	0	0	0	0	0	120
Mangatainoka at Putara*	35	0	0	0	0	0	0	50
Mangatainoka at SH2*	36	4	0-2	1	0-1	1	0-1	120
Mangatainoka d/s DB Breweries*	36	4	0-2	1	0-1	2	0-2	120
Mangatainoka d/s Pahiatua STP*	35	7	0-6	2	0-2	3	0-2	120
Mangatainoka u/s Pahiatua STP*	36	2	0-2	2	0-2	1	0-1	120
Mangatainoka u/s Tiraumea*	11	0	0	1	0-1	1	0-1	120
Mangatepopo d/s Genesis	14	0	0	0	0	0	0	120
Mangatera d/s Dannevirke STP*	36	5	0-4	0	0	1	0-1	120
Mangatera u/s Dannevirke STP*	36	0	0	0	0	0	0	120
Mangawhero at DoC	36	1	0-1	0	0	0	0	50
Mangawhero at Pakihi Rd	34	0	0	0	0	4	0-3	50
Mangawhero d/s Ohakune STP	33	0	0	1	0-1	2	0-1	50
Mangawhero u/s Ohakune STP	36	0	0	0	0	2	0-1	50
Moawhango at Waiouru	13	0	0	6	0-6	3	0-3	50
Ohau at Gladstone	36	1	0-1	0	0	0	0	50
Ohau at SH1	36	2	0-1	2	0-2	1	0-1	120
Oroua at Almadale	35	0	0	0	0	0	0	120
Oroua at Apiti Gorge	35	1	0-1	0	0	0	0	120
Oroua at Awahuri Bridge	35	3	0-2	0	0	2	0-1	120
Oroua d/s Feilding STP	35	3	0-2	0	0	3	0-1	120
Oroua u/s Feilding STP	35	4	0-3	0	0	0	0	120
Oruakeretaki at SH2*	36	0	0	0	0	0	0	120
Pohangina at Mais Reach	36	5	0-3	0	0	0	0	120
Pohangina at Piripiri	36	0	0	0	0	0	0	50
Rangitikei at Mangaweka	34	5	0-3	0	0	0	0	120
Rangitikei at McKelvies	33	4	0-3	2	0-2	0	0	120
Rangitikei at Onepuhi	34	0	0	0	0	0	0	120
Rangitikei at Pukeokahu	32	0	0	0	0	0	0	50
Tamaki at Reserve*	36	2	0-1	0	0	0	0	50

Site	*n*	No. above % cover target (fils)	Annual range (fils)	No. above % cover target (mats)	Annual range (mats)	No. above Chl *a* target	Annual range (Chl *a*)	Chl *a* target
Tamaki at Stephensons*	36	0	0	0	0	1	0-1	120
Tiraumea at Ngaturi	34	3	0-2	2	0-1	4	0-4	120
Tiraumea d/s Mangatainoka	17	2	0-1	0	0	1	0-1	120
Tokiahuru at Karioi	35	0	0	0	0	0	0	50
Tokomaru at Horseshoe Bend	36	0	0	0	0	0	0	50
Waikawa at Nth Manakau Rd*	36	4	0-2	0	0	0	0	120
Waitangi d/s Waiouru STP	36	7	0-6	0	0	11	0-6	120
Waitangi u/s Waiouru STP	36	0	0	0	0	0	0	120
Whakapapa d/s Genesis	14	1	0-1	0	0	0	0	120
Whanganui d/s Genesis	15	0	0	0	0	0	0	120

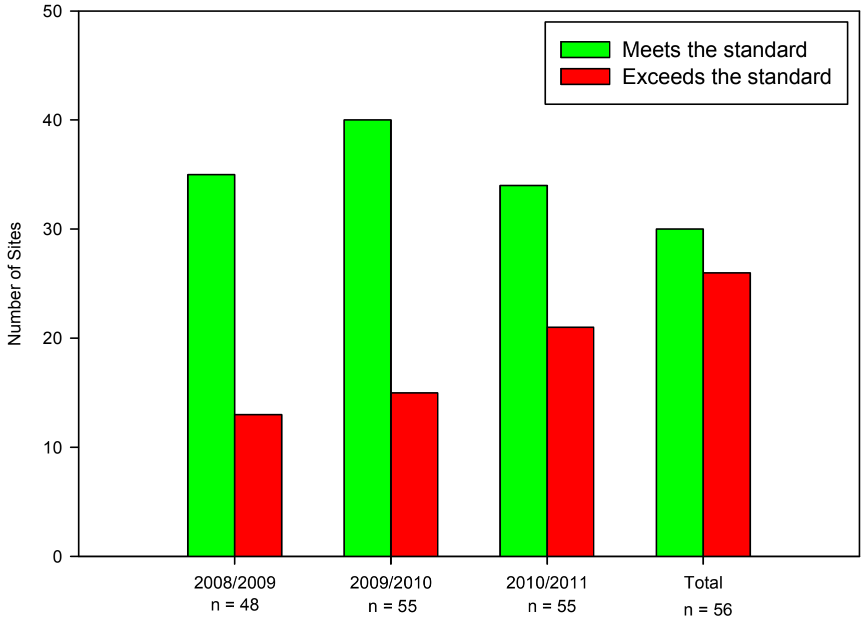


Figure 1: Number of sites in the Manawatu-Wanganui Region meeting or exceeding the DV One Plan periphyton targets (chlorophyll a mg/m^2) compiled from monthly data collected between Dec 2008 and Nov 2011. n = number of sites sampled.

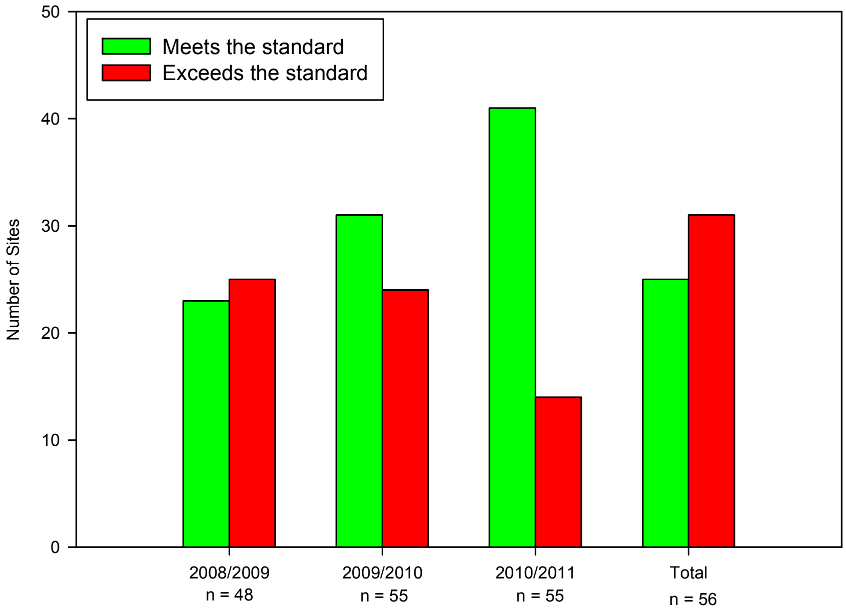


Figure 2: Number of sites in the Manawatu-Wanganui Region meeting or exceeding the DV One Plan periphyton targets (per cent cover by filamentous algae) compiled from monthly data collected between Dec 2008 and Nov 2011. n = number of sites sampled.

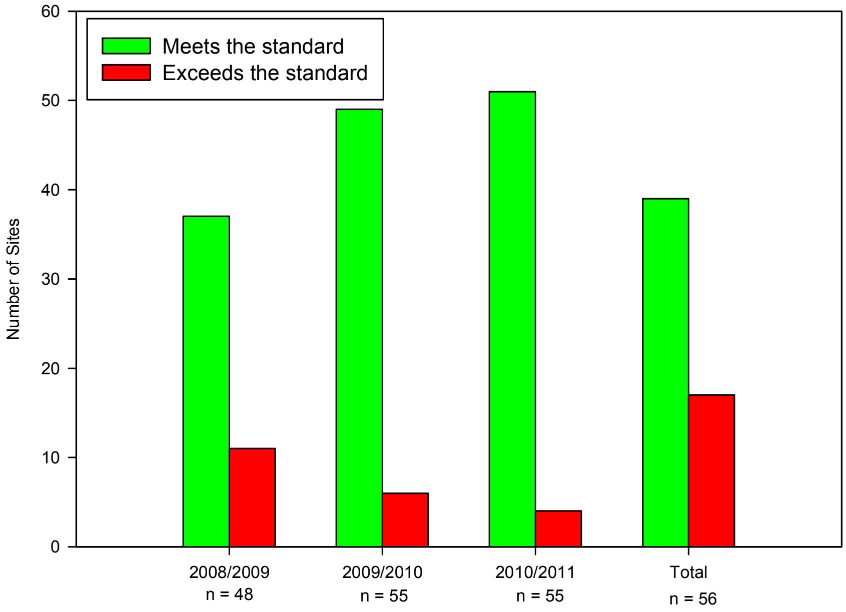


Figure 3: Number of sites in the Manawatu-Wanganui Region meeting or exceeding the DV One Plan periphyton targets (per cent cover by mat algae, diatoms and cyanobacteria) compiled from monthly data collected between Dec 2008 and Nov 2011. n = number of sites sampled.

Summary of water quality and aquatic ecosystem state and trend update

35. **The state of water quality in the region is generally poor in catchments that have high proportions of pastoral land use and/or significant point source discharges.** Water quality in the headwaters of most rivers is good. A number of catchments, particularly in the Manawatu River and tributaries, are degraded by faecal contamination, nutrient enrichment (by nitrogen and phosphorus) and poor water clarity.

36. **Trends in water quality across the region vary.** Results show some improvements in water clarity, *E.coli* and nitrogen, but there are degrading trends for nitrate in the Manawatu. Dissolved phosphorus improved (lower Manawatu) and degraded (Whanganui, Rangitikei and upper Manawatu) depending on the site in the NIWA monitoring programme but no DRP trends were found for the Horizons data.

37. **More than half (56%) of the sites monitored for aquatic macroinvertebrates do not meet the One Plan MCI target.** The sites were not selected using a randomised study design and many were selected to monitor specific impacts (both point and diffuse sourced). Any inferences about the state of aquatic macroinvertebrate health are limited only to the sites themselves. The degree to which many sites do not meet the MCI targets indicates that life-supporting capacity and trout fishery values are being compromised at more than half of the sites monitored in the region. Few significant trends were found, indicating that the state of aquatic macroinvertebrates has changed little over the period of monitoring at each site.

38. **Periphyton exceeds per cent cover and biomass targets at a number of sites.** Sites downstream of point source discharges most commonly exceed the filamentous cover targets, and sites known to have elevated nutrient concentrations (from either point and/or diffuse sources) tend to exceed the chlorophyll *a* targets.

Section 1B: Updated nutrient load data for target catchments

39. Nutrient loads were calculated for seventeen sites from the target catchments. The key results are presented in this section and in the catchment summaries in Section 2.

40. The Measured Loads are estimated from flow and recent water quality information. The Point Source Loads are calculated from known wastewater concentration and discharge volume data. The Non-point Source Loads are estimated as the remainder after the Point Source Load is subtracted from the Measured Load. The Non-point Source Loads are comprised of the contribution of nutrients from all land use types in the catchment. A break down of the relative contributions of each land use type to the Non-point Source Load is included in the Scenario modelling that follows. Target Loads are the annual average load calculated from the concentration-based targets in Schedule D of the DV POP.

41. Table 6 compares Target Loads with Measured Loads for seventeen sites. Note: whilst the Mangahao and Tiraumea sites are not within target catchments these sites are included in the analysis because the data for these sites is required to calculate loads for the Manawatu at upper Gorge. Three reference sites are also identified in the table. These are used to establish nutrient loads from relatively unmodified land uses.

42. Sites within target catchments all exceed the Target Loads for nitrogen by more than 50 per cent (with the exception of the three upstream reference sites). Many sites also exceed the phosphorus target. Of the sites tested (including the Rangitikei target catchments from the NV POP) nitrogen loads ranged from approximately twice to more than four times the Target Load. In all cases non-point (diffuse) sources were the key contributors of contaminants.

Table 6: Annual average nutrient loads for seventeen sites in the Manawatu-Wanganui Region expressed as tonnes per year (T/yr). SIN = soluble inorganic nitrogen, DRP = dissolved reactive phosphorus. Shaded sites exceed the annual average SIN or DRP Target Loads. Sites in bold exceed either the SIN or DRP Target Load by more than 50% as a result of non-point sourced inputs.

Catchment and site	SIN (T/yr)				DRP (T/yr)			
	Target Load	Measured Load	Point Source (PS) Load	Non-Point Source (NPS) Load	Target Load	Measured Load	Point Source (PS) Load	Non-Point Source (NPS) Load
Manawatu catchment								
Manawatu at Weber Rd	**69.6**	**296.5**	**0**	**296.5**	**4.2**	**11.18**	**0**	**11.18**
Tamaki at Reserve[1]	1.6	2.08	0	2.08	**0.1**	**0.26**	**0**	**0.26**
Mangatoro at Mangahei Rd	**18.8**	**111.16**	**0**	**111.16**	**1.7**	**5.01**	**0**	**5.01**
Manawatu at Hopelands	**364.3**	**786.51**	**24.15**	**762.36**	**8.2**	**23.14**	**5.84**	**17.30**
Tiraumea at Ngaturi	222.4	283.47	0	283.47	5.0	7.67	0	7.67
Mangatainoka at Putara[1]	3.2	1.26	0	1.26	0.3	0.21	0	0.21
Mangatainoka at Larsons Rd	11.6	15.16	0	15.16	1.0	0.68	0	0.68
Makakahi at Hamua	**91.1**	**168.05**	**0.47**	**167.58**	2.1	2.1	0.16	1.94
Mangatainoka at SH2	**264.3**	**542.33**	**4.04**	**538.29**	6.0	6.17	1.12	5.05
Mangahao at Ballance	79.5	110.55	0	110.55	**2.9**	**4.80**	**0**	**4.80**
Manawatu at Upper Gorge	**1193.5**	**2281.2**	**29.76**	**2251.48**	**26.9**	**54.87**	**7.20**	**47.67**
Waikawa catchment								
Manakau at SH1	**2.0**	**5.57**	**0**	**5.57**	0.1	0.15	0	0.15
Waikawa at Nth Manakau Rd[1]	8.1	4.48	0	4.48	0.5	0.48	0	0.48
Waikawa at Huritini	**10.0**	**43.7**	**0**	**43.7**	**1.2**	**0.600**	**0**	**1.2**
Rangitikei catchment								
Rangitikei at Mangaweka	220.0	251.69	2.63	249.07	20.0	22.05	0.86	21.19
Rangitikei at Onepuhi	**230.1**	**504.44**	**2.63**	**501.82**	20.9	27.13	0.86	26.27
Rangitikei at McKelvies	**248.3**	**573.06**	**30**	**543.07**	**22.6**	**41.73**	**7.28**	**34.45**

---

[1] Reference site: very low proportions of pastoral land use in the upstream catchment. Concentration-based nutrient targets may be exceeded as Schedule D of the DV POP allows for natural levels to exceed the target.

43. Roygard et al (2012 *in press*) found high annual variability (+/- 31 to 54%) in the annual Target Loads for two case study rivers. Variability was predominately driven by the frequency of flood flows in any given year. Year to year variability should be considered when setting annual load targets and assessing the effectiveness of actions to achieve these. However, we consider the length of the records used considerably reduced this variability and the conclusions drawn from the comparison between Measured and Target Loads in the target catchments is unaffected as Measured Loads exceeded Target Loads by almost 200 to more than 500 per cent.

Summary of nutrient load update

44. **Nitrogen loads measured in target catchments (including the Rangitikei) ranged from approximately twice to more than four times the Target Load. In all cases non-point sources were the key contributors of contaminants.**

45. In many cases, target catchments also considerably exceeded the phosphorus target loads.

Section 1C: Scenario outputs

46. Scenario modeling has been undertaken in the target catchments to provide instream outcomes for a number of different approaches to managing non-point sourced nitrogen. The following paragraphs provide a brief description of the scenarios.

47. The first scenario presents the current load of nitrogen measured at each site using existing rates of dairy leaching.

48. Scenarios 2 – 6 use the natural capital LUC loss limit approach across varying landuse scenarios

    a. Scenario 2 models the expected outcome of the DVPOP in river using an 11% dairy expansion applying the loss limits only to the expanded area and assuming current loss rates on the area currently in dairy to stay the same.

b. Scenario 3 models the expected N load in river if the LUC loss limits from DVPOP applied to all dairy land under the current scenario (i.e. land in dairy from Clark and Roygard, 2008).

c. Scenario 4 models the expected N load in river if the LUC loss limits applied to all dairy land under an 11% expansion scenario (i.e. current dairy area + an 11% increase).

d. Scenario 5 models the expected N load in river if the Yr 1 LUC loss limits from the NVPOP were applied to all dairy land under an 11% expansion scenario.

e. Scenario 6 models the expected N load in river if the Yr 20 LUC loss limits from the NVPOP were applied to all dairy land under an 11% expansion scenario

49. Scenarios 7 – 15 use a single number loss limit and apply it to dairy farming under an 11% dairy farm expansion Scenario 7 uses the average regional loss limit from nutrient budgets for dairy farms provided to Horizons as a part of regulatory processes or on a voluntary basis (Appendix 3) and applies this to all dairy land under an 11% expansion scenario

a. Scenario 8 uses the average loss limit from nutrient budgets for dairy farms upstream of the monitoring site provided to Horizons as a part of regulatory processes or on a voluntary basis (Appendix 3) and applies this to all dairy land under an 11% expansion scenario.

b. Scenario 9 uses a loss limit of 15 kg N/ha/yr and applies and applies this to all dairy land under an 11% expansion scenario.

c. Scenario 10 uses a loss limit of 18 kg N/ha/yr and applies and applies this to all dairy land under an 11% expansion scenario.

d. Scenario 11 uses a loss limit of 21 kg N/ha/yr and applies and applies this to all dairy land under an 11% expansion scenario.

   e. Scenario 12 uses a loss limit of 24 kg N/ha/yr and applies and applies this to all dairy land under an 11% expansion scenario.

   f. Scenario 13 uses a loss limit of 27 kg N/ha/yr and applies and applies this to all dairy land under an 11% expansion scenario.

   g. Scenario 14 uses a loss limit of 30 kg N/ha/yr and applies and applies this to all dairy land under an 11% expansion scenario.

   h. Scenario 15 uses a loss limit of 33 kg N/ha/yr and applies and applies this to all dairy land under an 11% expansion scenario

50. Scenarios 16 – 19 provide the do nothing approach under an expansion scenario with a number of different loss rate scenarios.

   a. Scenario 16 assumes the loss rates of dairy stay the same as current loss rates combined with 11% increase in dairy area

   b. Scenario 17 assumes the loss rates of dairy increase by 5% on current loss rates combined with an 11% increase in dairy area

   c. Scenario 18 assumes the loss rates of dairy increase by 10% on current loss rates combined with an 11% increase in dairy area

   d. Scenario 19 assumes the loss rates of dairy increase by 15% on current loss rates combined with an 11% increase in dairy area.

51. Table 7 presents the outputs of the modeling for the Upper Manawatu at Mangatainoka catchments and Table 8 summarises the predicted loads from table 7 as a percentage improvement or degreadation from current load.

Table 7: Predicted SIN Load (Tonnes /Year) under 19 dairy N loss scenarios. All results provisional.

Site	**Part of Target Catchmet (Y/N)**	**CURRENT LOAD**	**LUC APPROACHES**					**SINGLE NUMBER LIMITS APPROACHES**									**DO NOTHING APPROACHES**			
		Scenario	**Scenario**					**Scenario**									**Scenario**			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Upper Manawatu Catchment																				
Manawatu at Weber Road	Yes	297	301	280	286	283	270	291	302	266	275	285	294	303	312	321	302	306	310	315
Manawatu at Hopelands	Yes	762	775	708	733	718	670	745	779	655	689	722	756	789	823	856	779	794	808	823
Tiraumea at Ngaturi	No	283	284	283	284	284	284	284	285	284	284	284	285	285	285	285	285	286	287	288
Mangatainoka at Larsons Road	Yes	15	15	14	15	14	14	15	15	14	15	15	15	16	16	17	15	16	16	16
Makakahi at Hamua	Yes	168	166	151	157	152	142	164	167	142	150	159	167	175	184	192	167	171	174	177
Mangatainoka at SH2	Yes	538	528	496	512	504	472	518	530	460	482	503	525	546	568	589	530	539	547	556
Mangahao at Ballance	No	111	112	109	112	112	112	112	114	111	111	112	112	113	113	113	114	116	119	121
Manawatu at Upper Gorge	Yes with some upstream areas excluded*	2251	2269	2133	2191	2158	2053	2221	2278	2022	2097	2171	2246	2321	2396	2471	2278	2312	2346	2380
Waikawa Catchment																				
Manakau at SH1	Yes	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Waikawa at North Manakau	Yes	4	5	5	5	5	5	5	5	5	5	5	5	6	6	6	5	5	5	5
Waikawa at Huritini	Yes	44	44	47	49	48	44	49	43	42	45	47	50	53	55	58	43	44	44	45

Table 8: Loading scenario results expressed as a percentage improvement from current state (positive percentages) or a percentage degradation from the existing state (a negative percentage). All results provisional.

Site	**Part of Target Catchment (Y/N)**	**CURRENT LOAD**	**LUC APPROACHES**					**SINGLE NUMBER LIMITS APPROACHES**									**DO NOTHING APPROACHES**			
		Scenario	**Scenario**					**Scenario**									**Scenario**			
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**
Manawatu Catchment																				
Manawatu at Weber Road	Yes	0%	-1%	6%	3%	4%	9%	2%	-2%	10%	7%	4%	1%	-2%	-5%	-8%	-2%	-3%	-5%	-6%
Manawatu at Hopelands	Yes	0%	-2%	7%	4%	6%	12%	2%	-2%	14%	10%	5%	1%	-4%	-8%	-12%	-2%	-4%	-6%	-8%
Tiraumea at Ngaturi	No	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	-1%	-1%	0%	-1%	-1%	-2%
Mangatainoka at Larsons Road	Yes	0%	-1%	5%	3%	6%	8%	-1%	-2%	7%	4%	1%	-2%	-5%	-7%	-10%	-2%	-3%	-4%	-5%
Makakahi at Hamua	Yes	0%	1%	10%	6%	9%	15%	2%	0%	15%	10%	5%	0%	-5%	-10%	-15%	0%	-2%	-4%	-6%
Mangatainoka at SH2	in	0%	2%	8%	5%	6%	12%	4%	2%	14%	10%	7%	3%	-1%	-5%	-9%	2%	0%	-2%	-3%
Mangahao at Ballance	No	0%	-1%	2%	-1%	-1%	-1%	-1%	-3%	0%	-1%	-1%	-1%	-2%	-2%	-3%	-3%	-5%	-7%	-10%
Manawatu at Upper Gorge	Yes with some upstream areas excluded*	0%	-1%	5%	3%	4%	9%	1%	-1%	10%	7%	4%	0%	-3%	-6%	-10%	-1%	-3%	-4%	-6%

Waikawa Catchment																				
Manakau at SH1	Yes	0%	0%	-1%	-1%	-1%	0%	-1%	0%	0%	0%	-1%	-1%	-2%	-2%	-3%	0%	0%	0%	0%
Waikawa at North Manakau	Yes	0%	-6%	-12%	-16%	-11%	-4%	-20%	-5%	-3%	-9%	-16%	-22%	-28%	-35%	-41%	-5%	-7%	-9%	-10%
Waikawa at Huritini	Yes		0%	-9%	-13%	-10%	-2%	-12%	2%	4%	-2%	-8%	-14%	-20%	-27%	-33%	2%	0%	-2%	-3%

Summary of scenario modelling

52. **Doing nothing will not maintain or enhance water quality**

53. **Of the LUC approaches to managing nitrogen, some improvement may be gained from applying limits to new conversions only in the Lower Mangatainoka but not in the Upper Manawatu, Upper Gorge or Waikawa Catchments.** Large improvements will generally only come about if limits were to apply equally to existing dairy farms as well as new conversions.

54. **Of the single number limit approaches continued degredation of water quality can be expected if loss limits were set above 24kg N/ha/yr in the Upper Manawatu and 27kg N/ha/yr in the Mangatainoka.**

55. **Any further dairy expansion in the Waikawa is likely to affect water quality.**

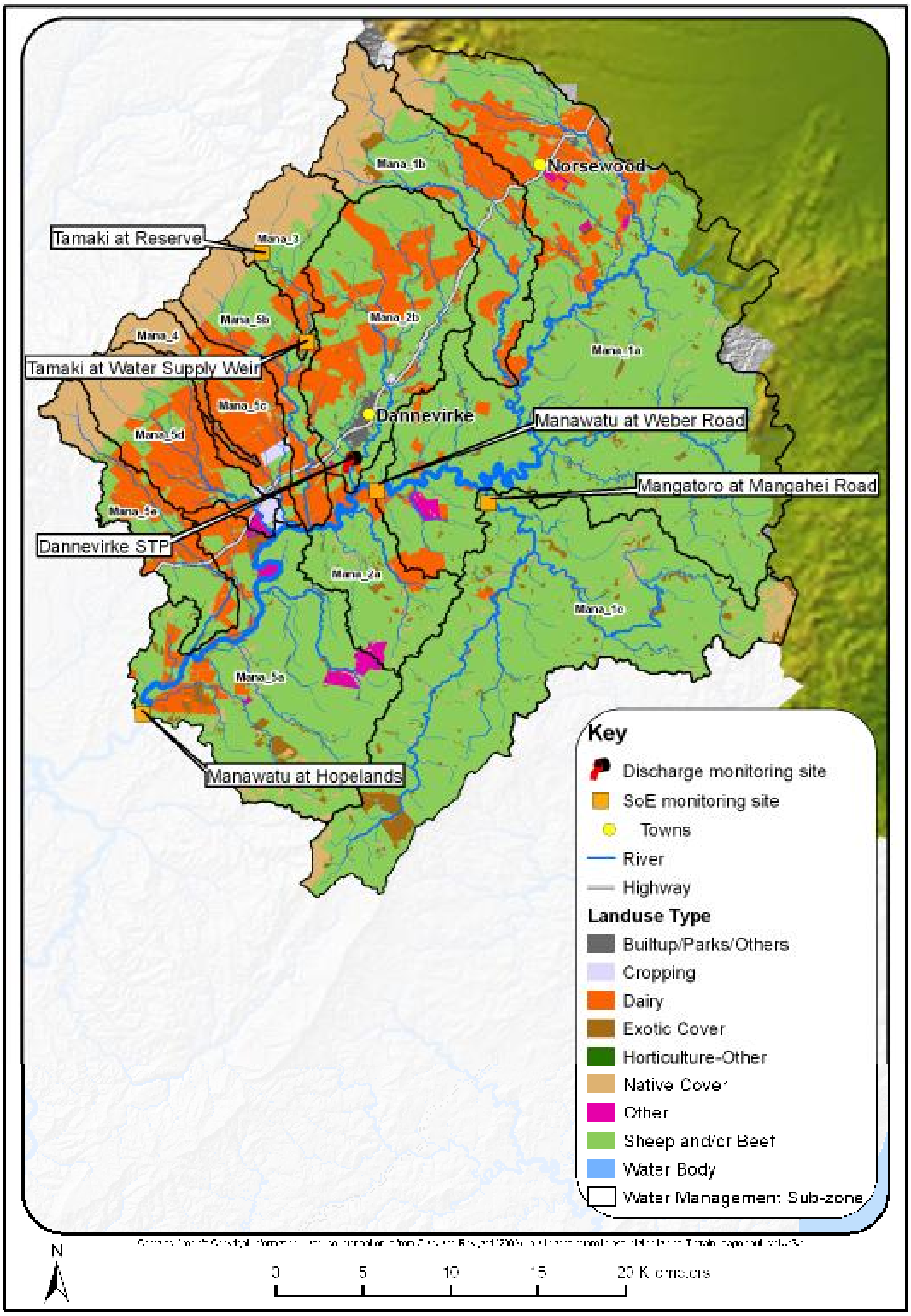
Section 2A: Target catchment summaries - upper Manawatu

56. The upper Manawatu target catchment encompasses all water management sub-zones upstream of the Manawatu at Hopelands monitoring site (Map 1). Detailed information on water quality in the upper Manawatu target catchment can be found in Chapter 9 of the s. 42A report of Kathryn McArthur (TEB v. 2 p. 744-851) and in the s. 42A report of Dr Roygard (TEB v. 1 p. 193-476).

57. The aquatic macroinvertebrate monitoring sites in the upper Manawatu target catchment are shown in Table 9 along with the analysis of the mean MCI against the One Plan targets. The key monitoring site in the upper Manawatu target catchment is the Manawatu at Hopelands site at the bottom of the water management zone. Of the thirteen years that aquatic macroinvertebrates have been sampled at this site the index has never met the One Plan MCI target of 120. The mean MCI score over all years of sampling is 97, corresponding to a degradation category of probable moderate pollution (Boothroyd and Stark, 2000).

58. The mean MCI score for the Manawatu at Weber site upstream, although better than the Hopelands site on average, also does not meet the target and has only achieved the target in one monitoring year out of five (Figure 4).

59. The other four sites in this target catchment are in tributaries draining the South Eastern Ruahine ranges. The Mangatera at Timber Bay has been monitored for thirteen years and on average does not meet the target. This site is affected by the Dannevirke STP discharge some kilometres upstream. Both the Tamaki and Oruakeretaki tributaries consistently meet the One Plan targets for MCI for each of the three years of sampling undertaken at these sites. The Tamaki catchment upstream of the Tamaki at Reserve site has more than 98% native cover. It is an ideal reference site as evidenced by the high mean MCI score of 140.



Map 1: Land use in the upper Manawatu catchment showing the locations of the monitoring sites modelled in this study, and their catchment areas. The location of point source monitoring sites are also shown. The Tamaki at Water Supply and weir site is included as flow information from this site was used for the Tamaki at Picnic reserve site.

Table 9: Aquatic macroinvertebrate sites in the upper Manawatu target catchment with mean MCI scores, comparison with One Plan MCI targets and number of years of sampling (*n*).

Site	Sub-zone	MCI target	*n*	Mean MCI	Meets MCI target	% samples meeting target
Manawatu at Weber	Upper Manawatu	120	5	106	No	20
Manawatu at Hopelands	Tamaki-Hopelands	120	13	97	No	0
Mangatera at Timber Bay	Mangatera	100	13	95	No	31
Oruakeretaki at SH2	Oruakeretaki	100	3	126	Yes	100
Tamaki at Reserve	Upper Tamaki	120	6	140	Yes	100
Tamaki at Stephensons	Lower Tamaki	100	3	125	Yes	100

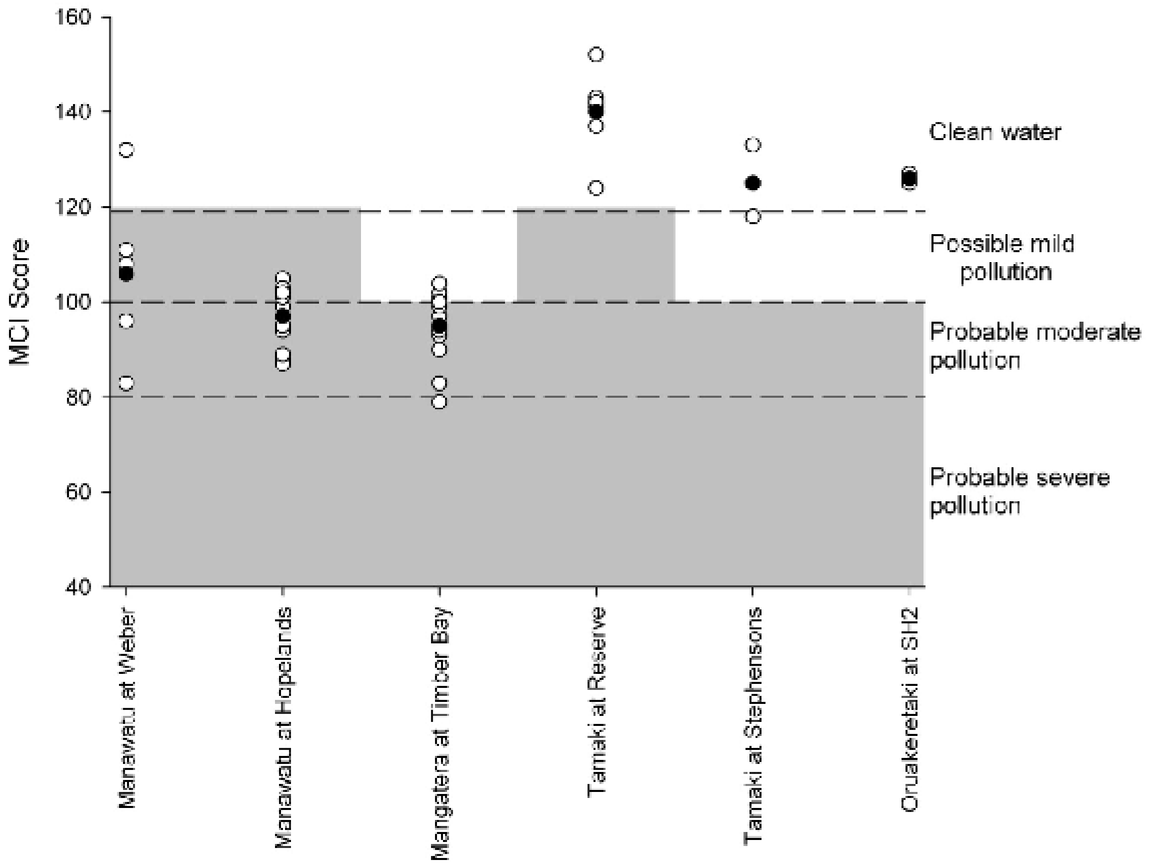


Figure 4: Macroinvertebrate community index (MCI) scores between 1999 and 2011 at six sites in the upper Manawatu target catchments. Open circles indicate individual MCI scores for each year of sampling, while closed circles indicate the mean MCI score for the site. Data points falling within the shaded area do not meet the Proposed One Plan MCI target. The water quality classes shown on the right axis of the graph are according to Boothroyd and Stark (2000).

60. Measures of periphyton in the upper Manawatu catchment exceed the One Plan targets some of the time at half of the sites. The Manawatu at Hopelands exceeds the periphyton targets most often (Table 10) and the annual maximums for chlorophyll *a* exceeds the target in every year (Figure 5), for two years out of three for the per cent cover of filamentous algae (Figure 6) and one year in three for mat algae (Figure 7).

61. The Manawatu at Weber Road exceeds the targets less often than the Hopelands site (Table 10). The annual maximum values exceed the targets for chlorophyll *a* (Figure 5) in one year out of three and the filamentous cover target in two years out of three (Figure 6).

Table 10: Summary of monthly periphyton observations in comparison with targets for per cent cover of filamentous algae (30% target), mat algae (60% target) and chlorophyll *a* (mg/m^2) for sites in the upper Manawatu target catchments monitored between Dec 2008 and Nov 2011. The within-year range of the number of observations exceeding the targets at each site is shown as the annual range (fils, mats and Chl *a*). *n* = number of monthly observations at each site.

Site	Sub-zone	*n*	No. above % cover target (fils)	Annual range (fils)	No. above % cover target (mats)	Annual range (mats)	No. above Chl *a* target	Annual range (Chl *a*)	Chl *a* target
Manawatu at Weber Rd	Upper Manawatu	34	5	0-4	0	0	1	0-1	120
Manawatu at Hopelands	Tamaki-Hopelands	36	4	0-3	2	0-2	8	0-3	120
Mangatera u/s Dannevirke STP	Mangatera	36	0	0	0	0	0	0	120
Mangatera d/s Dannevirke STP	Mangatera	36	5	0-4	0	0	1	0-1	120
Kumeti at Te Rehunga	Upper Kumeti	36	0	0	0	0	0	0	50
Tamaki at Reserve	Upper Tamaki	36	2	0-1	0	0	0	0	50
Tamaki at Stephensons	Lower Tamaki	36	0	0	0	0	1	0-1	120
Oruakeretaki at SH2	Oruakeretaki	36	0	0	0	0	0	0	120

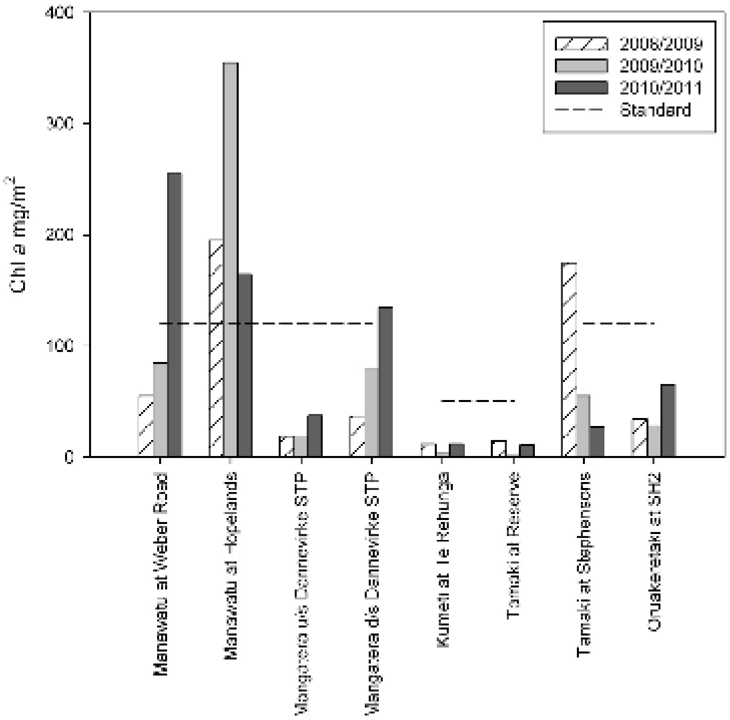


Figure 5: Annual maximum chlorophyll *a* concentration at sites in the upper Manawatu target catchment for three years of periphyton monitoring in comparison with Proposed One Plan targets for each site.

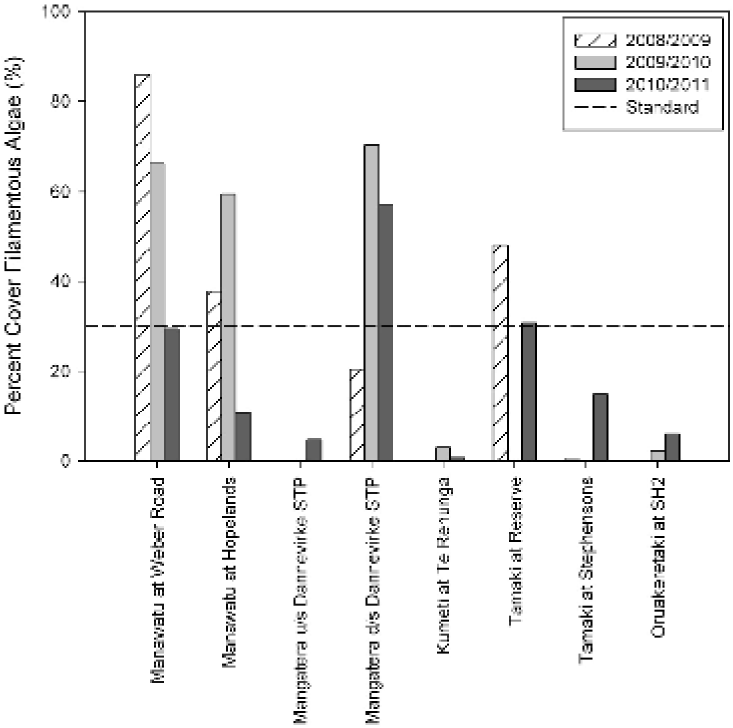


Figure 6: Annual maximum per cent cover by filamentous algae at sites in the upper Manawatu target catchment for three years of periphyton monitoring in comparison with Proposed One Plan targets for each site.

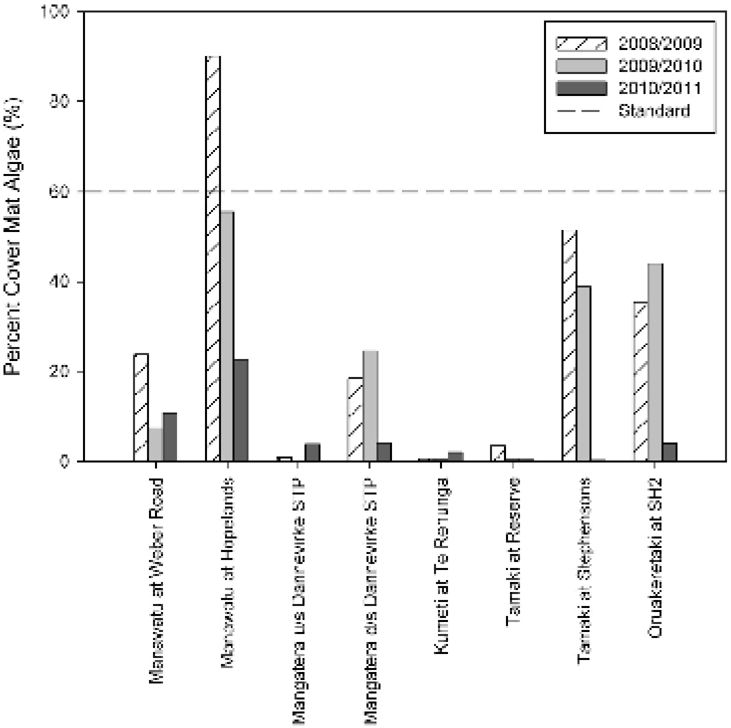


Figure 7: Annual maximum per cent cover by mat algae at sites in the upper Manawatu target catchment for three years of periphyton monitoring in comparison with Proposed One Plan targets for each site.

62. Plots of soluble nitrogen and phosphorus concentrations are presented below to show the state of water quality at the two Manawatu River mainstem monitoring sites that are within the target catchment area. Concentration plots of this type can indicate potential nutrient limitations to periphyton growth (McArthur et al. 2010; Appendix 4). The proposed One Plan nitrogen and phosphorus targets at each site are founded on the assumption that limiting nutrient to these levels will sufficiently constrain periphyton growth (other environmental conditions being ideal). Therefore the depicted thresholds for determining the limitation status in the plots below are the same as the Proposed One Plan nitrogen and phosphorus targets.

63. Figure 8 shows the potential nutrient limitation status for the Manawatu at Weber Rd monitoring site under all flow conditions and the concentrations of soluble nitrogen and phosphorus in relation to the targets for that site. The concentrations of nitrogen and phosphorus often exceed both targets, particularly at higher flows (Figure 9), implying that there is often no nutrient limitation to

periphyton growth at this site under these flow conditions. At lower flows, periphyton at this site is more likely to be nitrogen limited than phosphorus limited.

64. Figure 10 shows the nitrogen against phosphorus plots for the Manawatu at Hopelands at all flows. The higher target for nitrogen means more observations fall within the nitrogen limited category. Again, there are a high number samples with concentrations that are unlikely to cause any limitation to periphyton growth. Under the different flow scenarios (Figure 11) this site also becomes more nitrogen limited as flows drop.

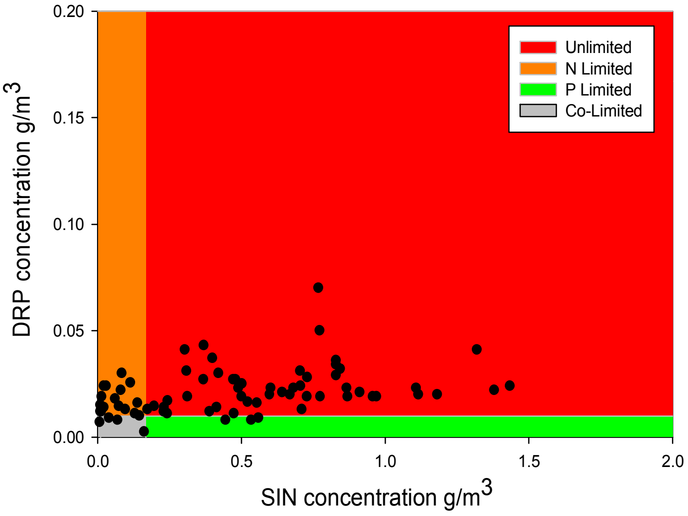
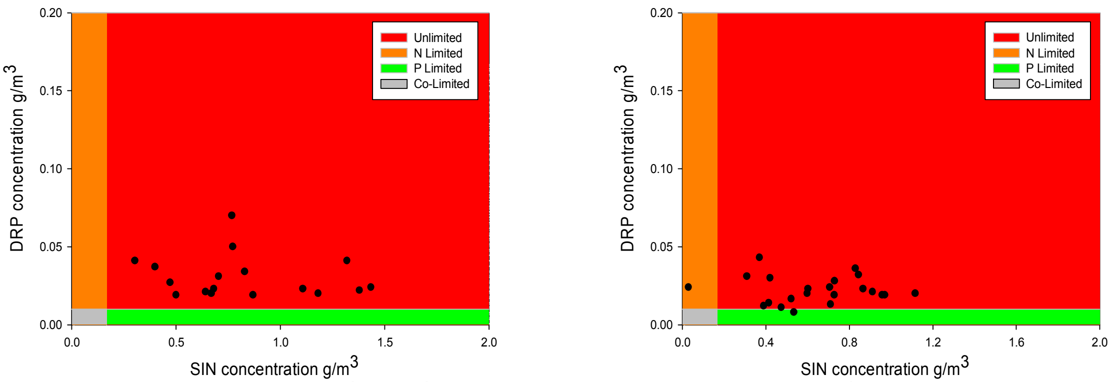


Figure 8: Soluble inorganic nitrogen (SIN) plotted against dissolved reactive phosphorus (DRP) concentrations for the Manawatu at Weber Road monitoring site (Jul 2005 – Aug 2011) under all flow conditions. Coloured boxes indicate potential nutrient limitation status based on the Proposed One Plan targets for SIN and DRP.



a) High flow (0-20th %ile)

b) Above median flow (50th – 20th %iles)

c) Below median flow (80th – 50th %iles)

d) Low flow (>80th %ile)

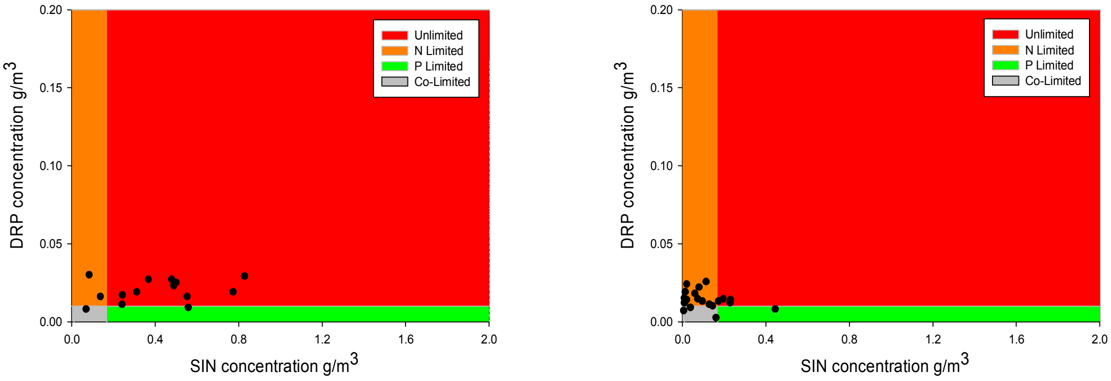


Figure 9: Soluble inorganic nitrogen (SIN) plotted against dissolved reactive phosphorus (DRP) concentrations for the Manawatu at Weber Road monitoring site (Jul 2005 – Aug 2011) under various flow scenarios (a-d). Coloured boxes indicate potential nutrient limitation status based on the Proposed One Plan targets for SIN and DRP.

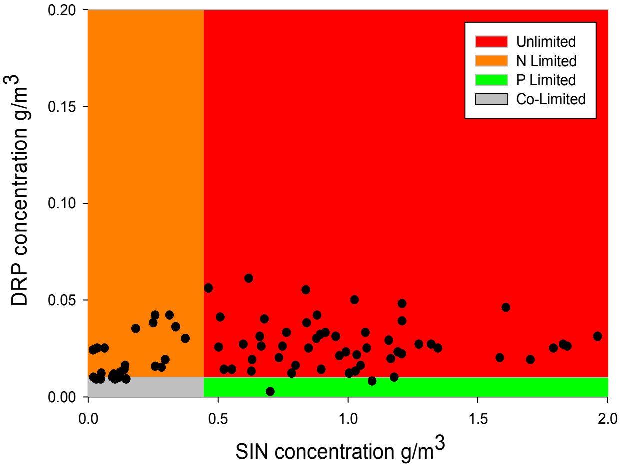
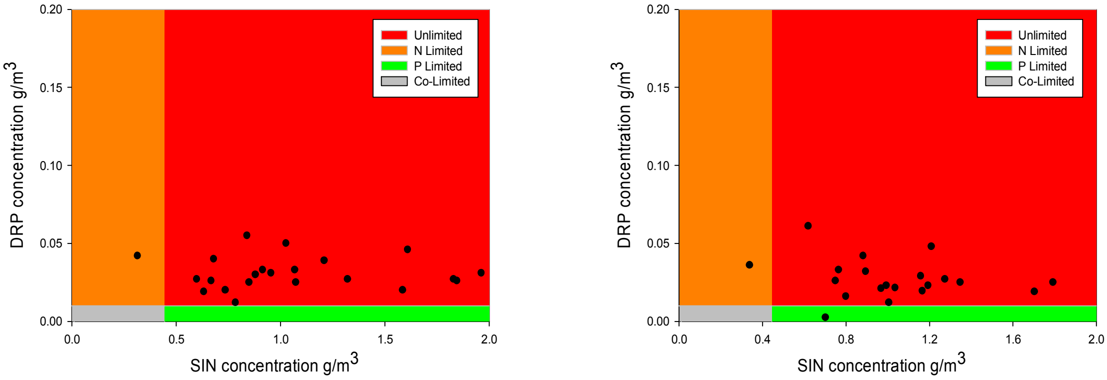


Figure 10: Soluble inorganic nitrogen (SIN) plotted against dissolved reactive phosphorus (DRP) concentrations for the Manawatu at Hopelands monitoring site (Jul 2005 – Aug 2011) under all flow conditions. Coloured boxes indicate potential nutrient limitation status based on the Proposed One Plan targets for SIN and DRP.

a) High flow (0-20th %ile)

b) Above median flow (50th – 20th %iles)



c) Below median flow (80th – 50th %iles)

d) Low flow (>80th %ile)

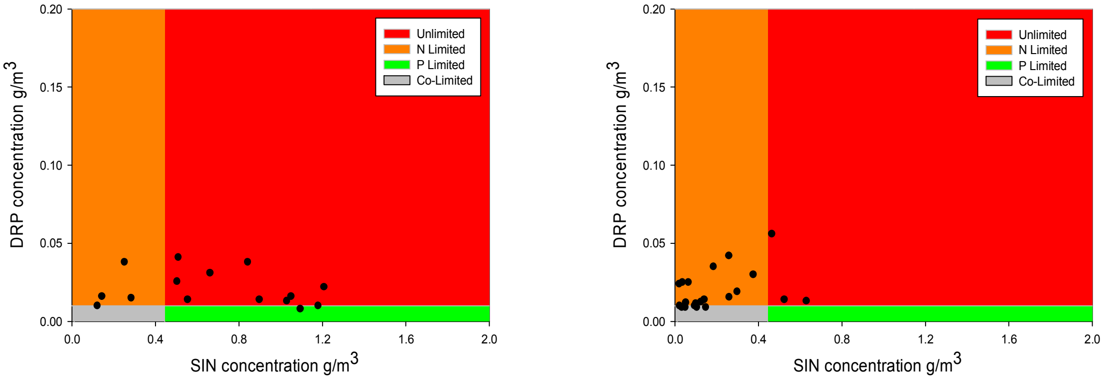


Figure 11: Soluble inorganic nitrogen (SIN) plotted against dissolved reactive phosphorus (DRP) concentrations for the Manawatu at Hopelands monitoring site (Jul 2005 – Aug 2011) under various flow scenarios (a-d). Coloured boxes indicate potential nutrient limitation status based on the Proposed One Plan targets for SIN and DRP.

65. A comparison of Measured and Target Loads (Table 11), along with the loads calculated for the predominant sources of nitrogen and phosphorus contamination, shows that when nutrient concentrations are converted to loads, targets are considerably exceeded (with the exception of the Tamaki at Reserve reference site). The exceedence is the result of non-point sourced inputs.

Table 11: Annual average nutrient loads for four sites in the upper Manawatu target catchment expressed as tonnes per year (T/yr). SIN = soluble inorganic nitrogen, DRP = dissolved reactive phosphorus. Shaded sites exceed the annual average SIN or DRP Target Loads. Sites in bold exceed either the SIN or DRP Target Load by more than 50% as a result of non-point sourced inputs.

Site	SIN (T/yr)				DRP (T/yr)			
	Target Load	Measured Load	Point Source (PS) Load	Non-Point Source (NPS) Load	Target Load	Measured Load	Point Source (PS) Load	Non-Point Source (NPS) Load
Manawatu at Weber Rd	**69.6**	**296.5**	**0**	**296.5**	**4.2**	**11.18**	**0**	**11.18**
Tamaki at Reserve[1]	1.6	2.08	0	2.08	**0.1**	**0.26**	**0**	**0.26**
Mangatoro at Mangahei Rd	**18.8**	**111.16**	**0**	**111.16**	**1.7**	**5.01**	**0**	**5.01**
Manawatu at Hopelands	**364.3**	**786.51**	**24.15**	**762.36**	**8.2**	**23.14**	**5.84**	**17.30**

66. The results of scenario modelling for non-point sourced contamination undertaken in the Upper Manawatu catchment following a number of different approaches has shown that:

a. Of the LUC approaches to managing nitrogen, improvements will generally only come about if limits were to apply equally to existing dairy farms as well as new conversions.

b. If the limits were applied to new conversions only, slight but continued degradation can be expected.

c. Of the Single Number Limit approaches it may be expected that limiting loss rates to 24 kgN/ha/yr or less will maintain or enhance water quality, with large improvements to be generally expected if limits were set less than 21 kgN/ha/yr. Continued degradation can be expected if the limits were set above 27 kgN/ha/yr.

d. Setting the limit based on the regional average may have slight gains, but averging limits by site is unlikely to offer any improvement.

e. Doing nothing is not going to maintain or enhance water quality.

Upper Manawatu target catchment summary

67. **Aquatic macroinvertebrates and periphyton at the mainstem monitoring sites in the upper Manawatu catchment often do not meet One Plan targets for MCI or periphyton biomass (chlorophyll *a*) and cover.** Generally, the Manawatu at Hopelands is the most degraded site when these biological indicators are considered; however, the aquatic communities of the Manawatu at Weber also show signs of degradation. Values such as life-supporting capacity, trout fishery, aesthetics and contact recreation are negatively affected by the degraded state of the catchment.

68. **The state of the tributaries is somewhat better than the mainstem sites, with the exception of the Mangatera Stream which is affected by the sewage discharge from Dannevirke.** Periphyton growth and aquatic macroinvertebrate habitat in the tributary streams may be influenced by the small size of these streams and the higher potential for limitations of nuisance algal growth through shading. However, the nutrient enrichment of the tributaries cumulatively contributes to the degradation of the mainstem sites.

69. **Nutrient concentrations at Weber Rd and Hopelands regularly exceed the nitrogen and phosphorus targets, particularly at higher flows.** At the lowest flows there is potential for both sites to be nitrogen limited more often than phosphorus limited.

70. **Measured Loads are approximately twice the Target Loads at Hopelands and four times the target at Weber Rd. The predominant source of contaminants is diffuse (non-point sourced).**

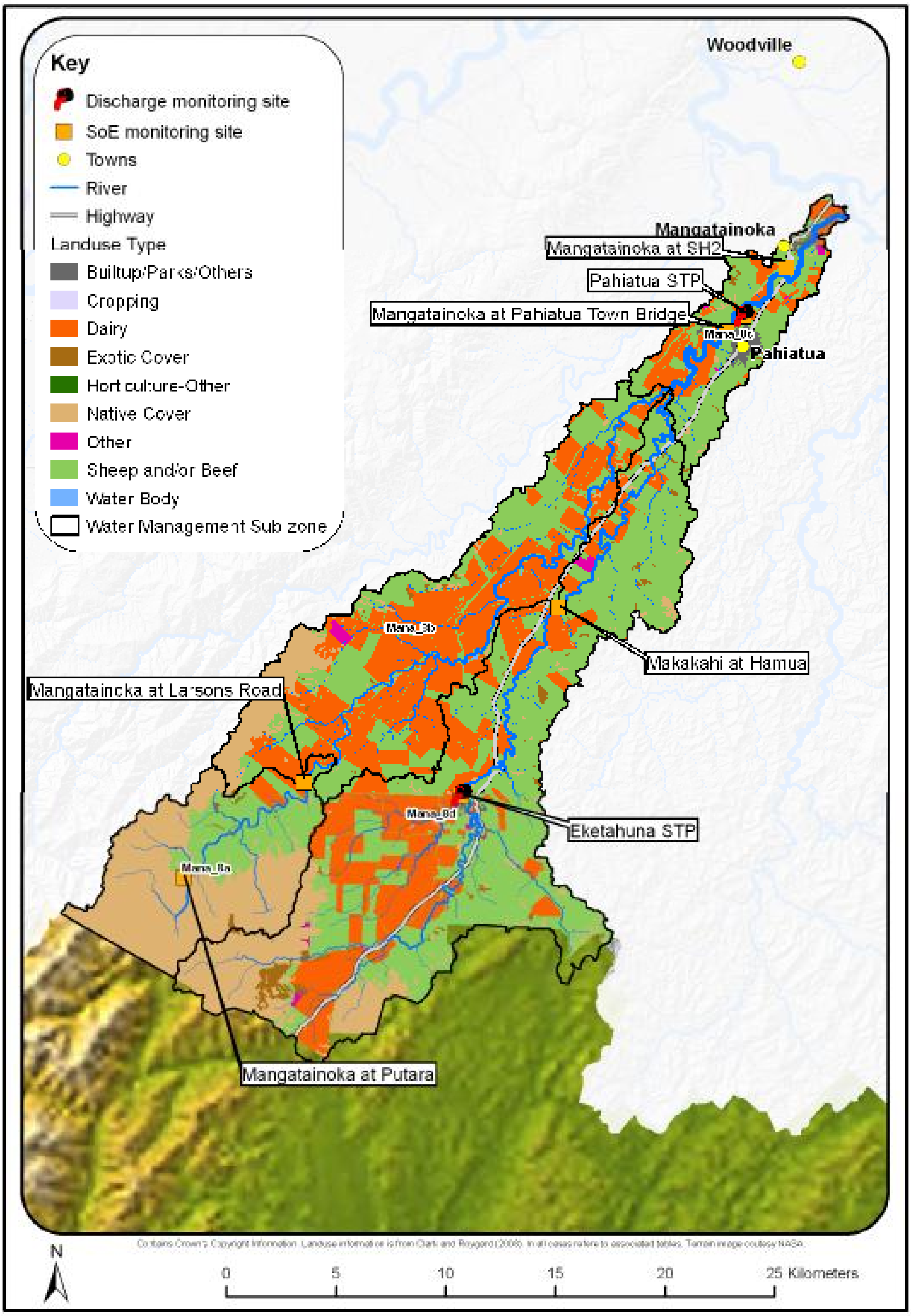
71. **The scenarios show that Doing nothing is not going to maintain or enhance water quality and of the LUC approaches to managing nitrogen, improvements will general only occur if loss limits were applied to existing farms as well as new conversions.**

Section 2B: Target catchment summaries - Mangatainoka

72. The Mangatainoka target catchment (Map 2) is a major tributary of the Manawatu River, joining the Tiraumea River just upstream of its confluence with the Manawatu at the Ngawapurua Bridge. This target catchment includes the sub-zones of the Mangatainoka (upper, middle and lower) and the Makakahi. Detailed information on water quality in the Mangatainoka target catchment can be found in Chapter 9 of the s. 42A report of Kathryn McArthur (TEB v. 2 p. 744-851) and in the s. 42A report of Dr Roygard (TEB v. 1 p. 193-476).

73. Results of aquatic macroinvertebrate monitoring using the mean and annual MCI scores for sites in the Mangatainoka (Table 12) show that the MCI targets are not met with the exception of the upper Mangatainoka site at Putara. The Mangatainoka at Putara is a reference site with more than 99% native forested catchment upstream, hence the high mean MCI score indicating clean water (Figure 12). The mean MCI score for Mangatainoka at SH2 indicates probable moderate pollution at the site, as does the mean MCI for the site midway up the tributary catchment of the Makakahi. The significant change in MCI score between the upper and lower Mangatainoka sites shows a clear negative change in aquatic macroinvertebrate community health.

74. Point source discharges from the Eketahuna sewage treatment plant, Fonterra Pahiatua condensate, Pahiatua sewage treatment plant and the DB Breweries clarifier discharge also contribute to the degradation of the aquatic communities.



Map 2: Landuse in the Mangatainoka catchment showing the locations of the SoE and Point-source monitoring sites modelled in this study.

Table 12: Aquatic macroinvertebrate sites in the Mangatainoka target catchment with mean MCI scores, comparison with One Plan MCI targets and years of sampling (*n*).

Site	Sub-zone	MCI target	*n*	Mean MCI	Meets the target	% samples meeting target
Makakahi at Hamua	Makakahi	120	6	98	No	0
Mangatainoka at Putara	Upper Mangatainoka	120	6	139	Yes	100
Mangatainoka at SH2	Lower Mangatainoka	120	13	95	No	0
Mangatainoka u/s Tiraumea	Lower Mangatainoka	120	1	107	No	0

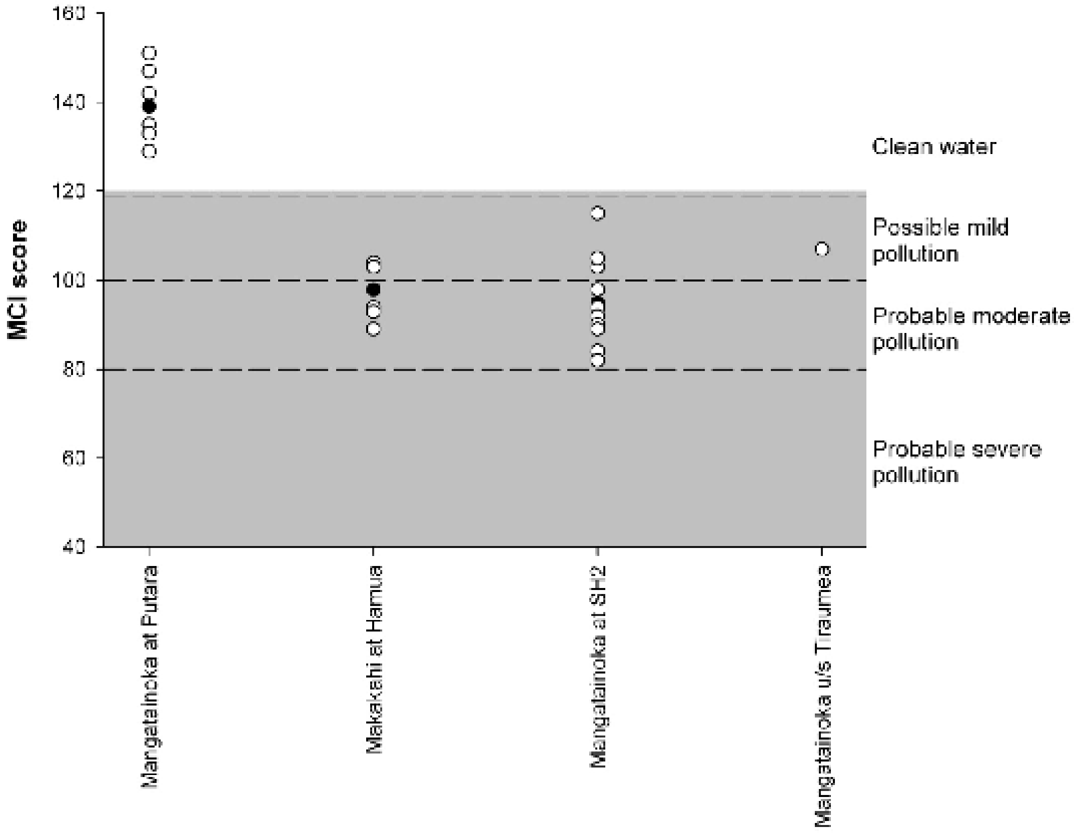


Figure 12: Macroinvertebrate community index (MCI) scores between 1999 and 2011 at four sites in the Mangatainoka target catchment. Open circles indicate individual MCI scores for each year of sampling, while closed circles indicate the mean MCI score for the site. Data points falling within the shaded area do not meet the Proposed One Plan MCI target. The water quality classes shown on the right axis of the graph are according to Boothroyd and Stark (2000).

75. Periphyton in the Mangatainoka target catchment exceeds the One Plan targets some of the time at all sites except Putara (Table 13). Generally, sites downstream of point source discharges exceed the targets more often than sites upstream, particularly for the Pahiatua sewage discharge. The annual maximums for each site also often exceed the chlorophyll *a* (Figure 13), filamentous (Figure 14) and mat algal cover targets (Figure 15) over the three years of sampling.

The percentage of mat algae cover at sites in the lower Mangatainoka is considerably higher than in the upper Manawatu, reflecting the common occurrence of toxic cyanobacteria at alert levels in this catchment (Wood and Young 2011).

Table 13: Summary of monthly periphyton observations in comparison with targets for percent cover of filamentous algae (30% target), mat algae (60% target) and chlorophyll *a* (mg/m^2) for sites in the Mangatainoka target catchments monitored between Dec 2008 and Nov 2011. The within-year range of the number of observations exceeding the targets at each site is shown as the annual range (fils, mats and Chl *a*). *n* = number of monthly observations at each site.

Site	Sub-zone	*n*	No. above % cover target (fils)	Annual range (fils)	No. above % cover target (mats)	Annual range (mats)	No. above Chl *a* target	Annual range (Chl *a*)	Chl *a* target
Makakahi at Hamua	Makakahi	35	2	0-1	1	0-1	0	0	120
Mangatainoka at Putara	Upper Mangatainoka	35	0	0	0	0	0	0	50
Mangatainoka u/s Pahiatua STP	Lower Mangatainoka	36	2	0-2	2	0-2	1	0-1	120
Mangatainoka d/s Pahiatua STP	Lower Mangatainoka	35	7	0-6	2	0-2	3	0-2	120
Mangatainoka at SH2	Lower Mangatainoka	36	4	0-2	1	0-1	1	0-1	120
Mangatainoka d/s DB Breweries	Lower Mangatainoka	36	4	0-2	1	0-1	2	0-2	120
Mangatainoka u/s Tiraumea confluence	Lower Mangatainoka	11	0	0	1	0-1	1	0-1	120

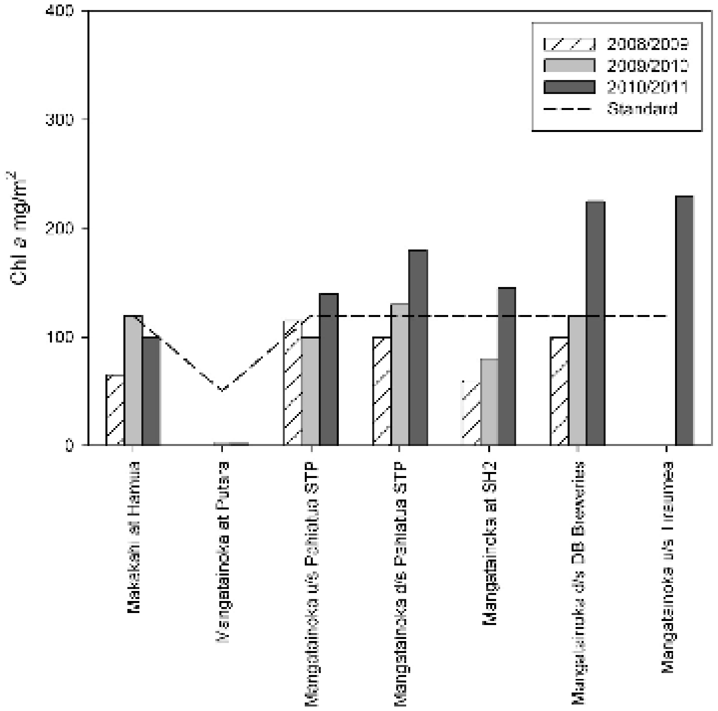


Figure 13: Annual maximum chlorophyll *a* concentration at sites in the Mangatainoka target catchment for three years of periphyton monitoring in comparison with Proposed One Plan targets for each site.

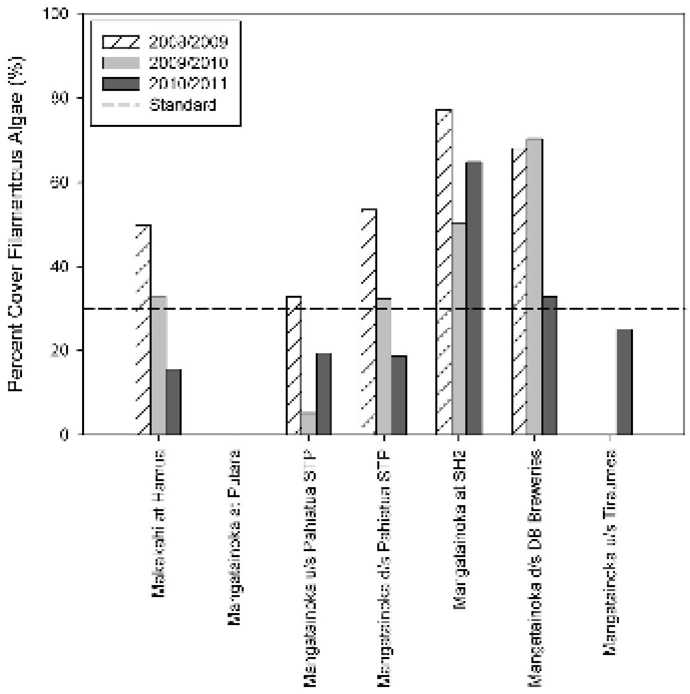


Figure 14: Annual maximum per cent cover by filamentous algae at sites in the Mangatainoka target catchment for three years of periphyton monitoring in comparison with Proposed One Plan targets for each site.

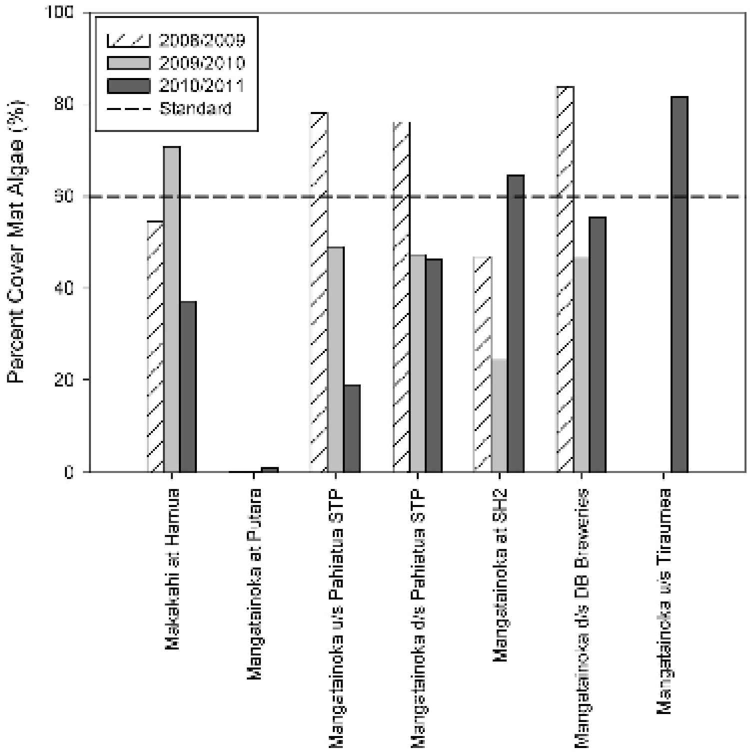


Figure 15: Annual maximum per cent cover by mat algae at sites in the Mangatainoka target catchment for three years of periphyton monitoring in comparison with Proposed One Plan targets for each site.

76. Soluble nutrient concentrations show the water quality at the Mangatainoka at Larsons site in the middle to upper catchment rarely exceeds DV POP targets under all flows (Figure 16). Samples collected at the lowest flows are almost always within the targets for nitrogen and phosphorus (Figure 17).

77. For the Mangatainoka at SH2 (Figure 18) and Makakahi at Hamua (Figure 20) sites, many samples fall within the unlimited category with the remainder potentially indicating phosphorus limitation. As flows drop, the Mangatainoka at SH2 site maintains high nitrogen concentrations (Figure 19), whereas the concentrations for the Makakahi at Hamua site tend to fall more often within the targets for both nutrients when flows are lower (Figure 21).

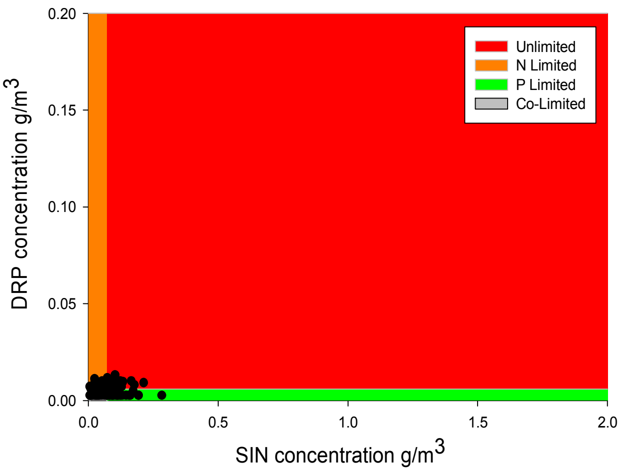
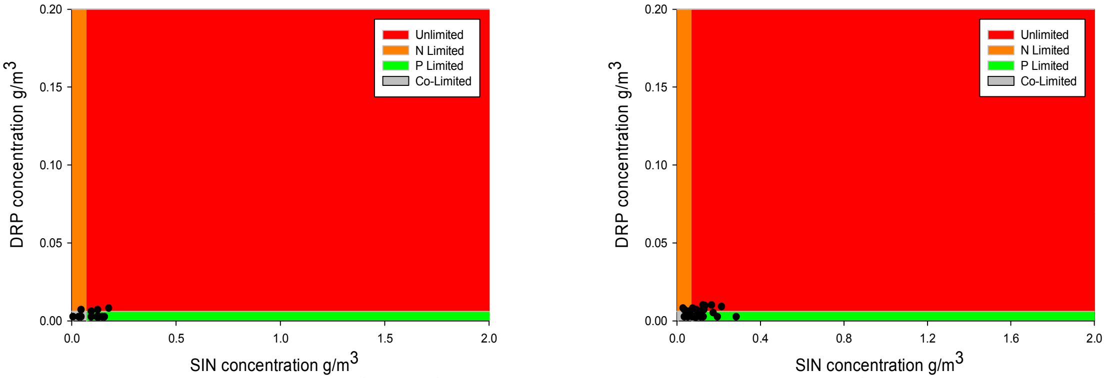
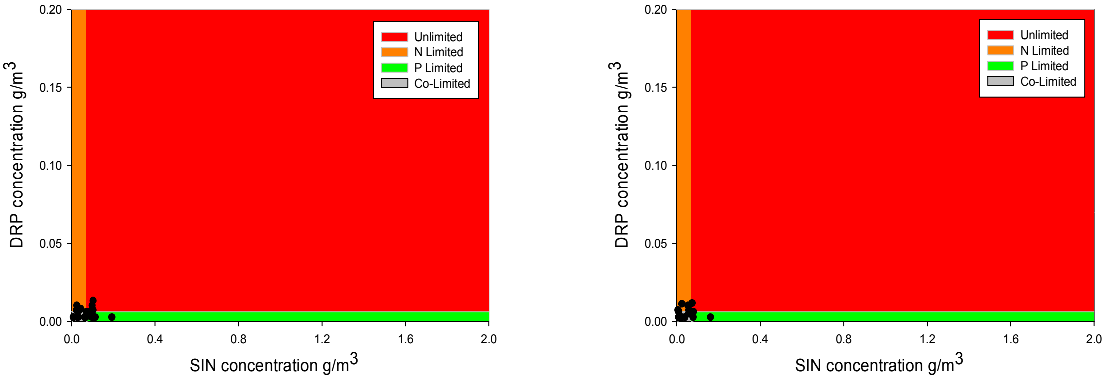


Figure 16: Soluble inorganic nitrogen (SIN) plotted against dissolved reactive phosphorus (DRP) concentrations for the Mangatainoka at Larsons monitoring site (Jul 2005 – Aug 2011) under all flow conditions. Coloured boxes indicate potential nutrient limitation status based on the Proposed One Plan targets for SIN and DRP.


a) High flow (0-20th %ile)

b) Above median flow (50th – 20th %iles)


c) Below median flow (80th – 50th %iles)

d) Low flow (>80th %ile)

Figure 17: Soluble inorganic nitrogen (SIN) plotted against dissolved reactive phosphorus (DRP) concentrations for the Mangatainoka at Larsons monitoring site (Jul 2005 – Aug 2011) under various flow scenarios (a-d). Coloured boxes indicate potential nutrient limitation status based on the Proposed One Plan targets for SIN and DRP.

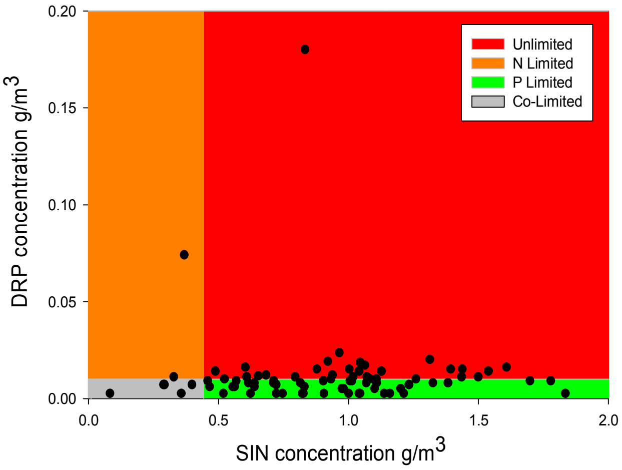
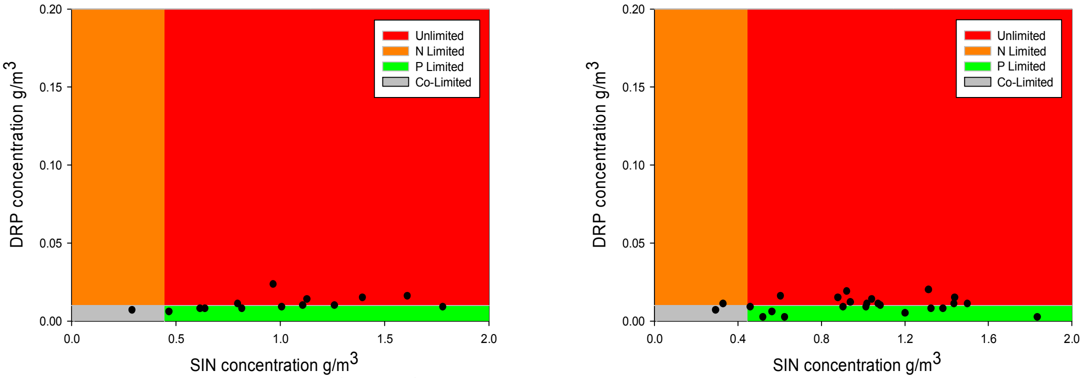
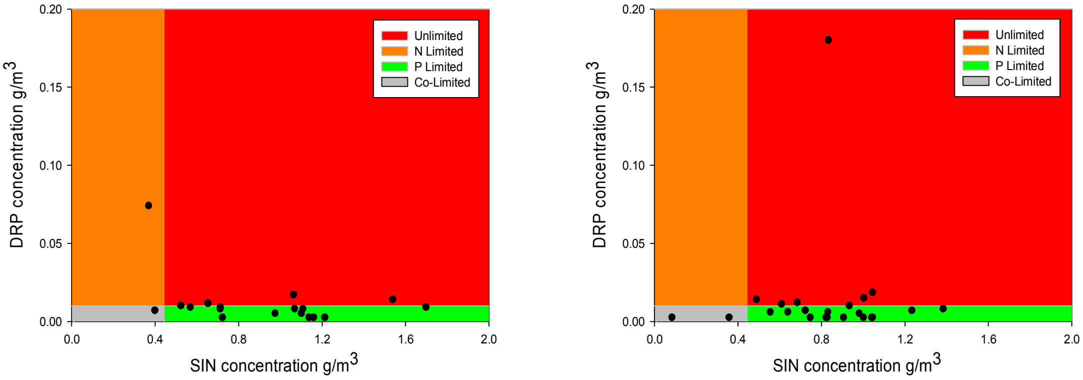


Figure 18: Soluble inorganic nitrogen (SIN) plotted against dissolved reactive phosphorus (DRP) concentrations for the Mangatainoka at SH2 monitoring site (Jul 2005 – Aug 2011) under all flow conditions. Coloured boxes indicate potential nutrient limitation status based on the Proposed One Plan targets for SIN and DRP.



a) High flow (0-20th %ile)

b) Above median flow (50th – 20th %iles)



c) Below median flow (80th – 50th %iles)

d) Low flow (>80th %ile)

Figure 19: Soluble inorganic nitrogen (SIN) plotted against dissolved reactive phosphorus (DRP) concentrations for the Mangatainoka at SH2 monitoring site (Jul 2005 – Aug 2011) under various flow scenarios (a-d). Coloured boxes indicate potential nutrient limitation status based on the Proposed One Plan targets for SIN and DRP.

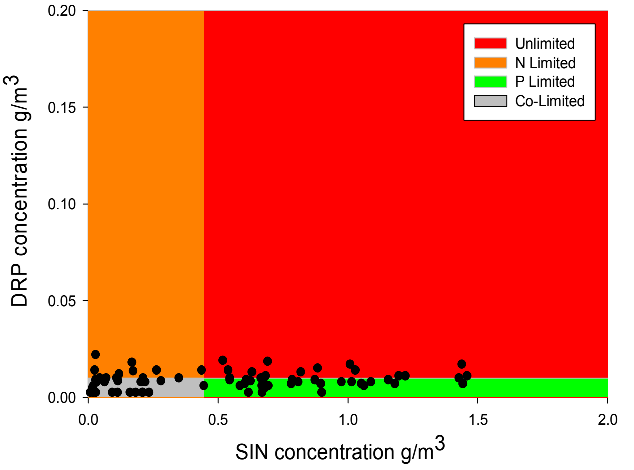
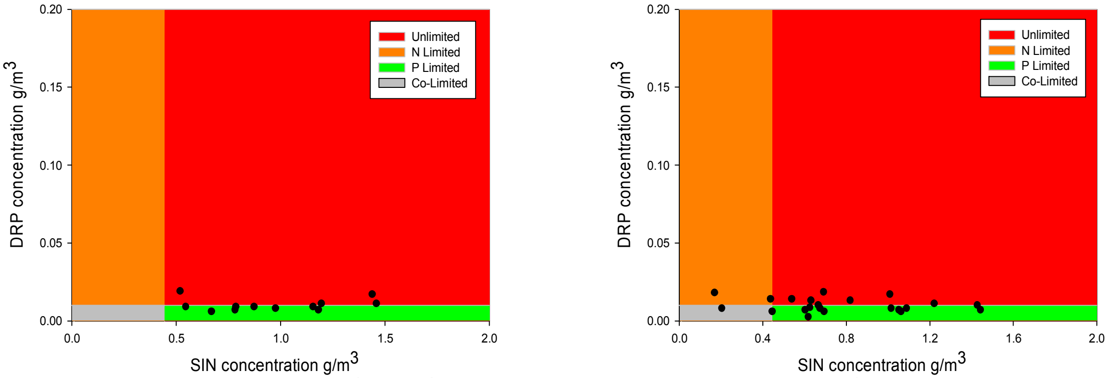


Figure 20: Soluble inorganic nitrogen (SIN) plotted against dissolved reactive phosphorus (DRP) concentrations for the Makakahi at Hamua monitoring site (Aug 2005 – Jul 2011) under all flow conditions. Coloured boxes indicate potential nutrient limitation status based on the Proposed One Plan targets for SIN and DRP.



a) High flow (0-20th %ile)

b) Above median flow (50th – 20th %iles)

c) Below median flow (80th – 50th %iles)

d) Low flow (>80th %ile)

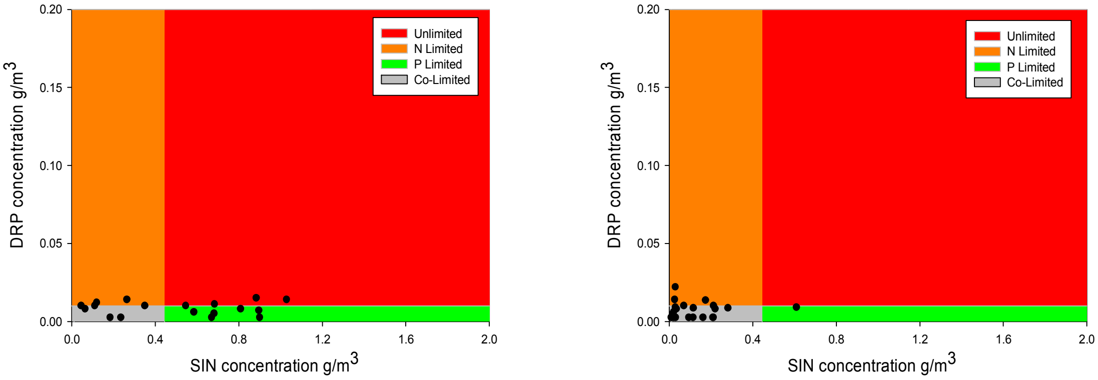


Figure 21: Soluble inorganic nitrogen (SIN) plotted against dissolved reactive phosphorus (DRP) concentrations for the Makakahi at Hamua monitoring site (Aug 2005 – Jul 2011) under various flow scenarios (a-d). Coloured boxes indicate potential nutrient limitation status based on the Proposed One Plan targets for SIN and DRP.

78. Measured Loads significantly exceed Target Loads for nitrogen at the Makakahi at Hamua and Mangatainoka at SH2 sites (Table 14). Nitrogen loads are considerably lower at the Larsons site which is higher up in the catchment and at the Putara reference site just downstream of the boundary of the Tararua Forest Park, exemplifying the pattern of downstream degradation. Measured Loads for phosphorus are largely within Target loads at all sites except the Mangatainoka at SH2, which marginally exceeds the Target Load limit.

Table 14: Annual average nutrient loads for four sites in the Mangatainoka target catchment expressed as tonnes per year (T/yr). SIN = soluble inorganic nitrogen, DRP = dissolved reactive phosphorus. Shaded sites exceed the annual average SIN or DRP Target Loads. Sites in bold exceed either the SIN or DRP Target Load by more than 50% as a result of non-point sourced inputs.

Site	SIN (T/yr)				DRP (T/yr)			
	Target Load	Measured Load	Point Source (PS) Load	Non-Point Source (NPS) Load	Target Load	Measured Load	Point Source (PS) Load	Non-Point Source (NPS) Load
Mangatainoka at Putara[2]	3.2	1.26	0	1.26	0.3	0.21	0	0.21
Mangatainoka at Larsons Rd	11.6	15.16	0	15.16	1.0	0.68	0	0.68
Makakahi at Hamua	**91.1**	**168.05**	**0.47**	**167.58**	2.1	2.1	0.16	1.94
Mangatainoka at SH2	**264.3**	**542.33**	**4.04**	**538.29**	6.0	6.17	1.12	5.05

79. The results of scenario modelling for non-point sourced contamination undertaken in the Mangatainoka catchment following a number of different approaches has shown that:

    a. Of the LUC approaches to managing nitrogen, some improvement may be gained from applying limits to new conversions only, though continued degradation may be seen at the Larsons site. Large improvements will generally only come about if limits were to apply equally to existing dairy farms as well as new conversions.

    b. Of the Single Number Limit approaches it may be expected that limiting loss rates to 24 kgN/ha/yr or less will maintain or enhance water quality, with the exception of Mangatainkoa at Larsons which would continue to show degradation unless the limit was set at 21 kg/N/ha/yr. Large improvements to be generally expected if limits were set less than 18 kgN/ha/yr. Continued degradation can be expected if the limits were set above 27 kgN/ha/yr.

    c. Setting the limit based on the regional average may have slight gains.

    d. Doing nothing is not going to maintain or enhance water quality.

---

[2] Reference site: very low proportions of pastoral land use in the upstream catchment. Concentration-based nutrient targets may be exceeded as Schedule D of the DV POP allows for natural levels to exceed the target.

Mangatainoka target catchment summary

80. **Aquatic macroinvertebrates at the lower Mangatainoka and Makakahi sites do not meet One Plan targets for MCI and sometimes exceed targets for periphyton biomass (chlorophyll *a*) and cover.** Generally, the Mangatainoka at SH2 is the most degraded site when these biological indicators are considered, although the aquatic communities of the Makakahi at Hamua also show signs of degradation. Values such as life-supporting capacity, trout fishery, aesthetics and contact recreation are negatively affected by the degraded state of the catchment.

81. **The state of the upper Mangatainoka is significantly better than the other sites.** Periphyton growth and aquatic macroinvertebrate habitat in the upper catchment are influenced by the large proportion of native forestry which provides better habitat, low nutrient concentrations and stream shading from riparian vegetation.

82. **Nutrient concentrations at Hamua and SH2 regularly exceed the nitrogen and phosphorus targets, particularly at higher flows.** At the lowest flows there is potential for the SH2 site to be phosphorus limited more often than nitrogen limited due to the high concentrations of nitrogen that occur under all flows. The Mangatainoka at Larsons Road site in the upper to middle catchment has considerably better water quality with low nutrient concentrations under most flows.

83. **Nitrogen loads in the middle to lower Makakahi and Mangatainoka catchments are approximately twice the Target Loads.** Phosphorus is largely within Target Loads.

84. **The scenarios show that Doing nothing is not going to maintain or enhance water quality and of the LUC approaches to managing nitrogen, the biggest improvements will occur if loss limits were applied to existing farms as well as new conversions.**

Section 2C: Target catchment summaries - upper Gorge

85. The upper Gorge target catchment on the Manawatu River includes the sub-zones of the Mangapapa and Mangaatua Streams. Detailed information on water quality in the upper Gorge target catchment can be found in Chapter 9 of the s. 42A report of Kathryn McArthur (TEB v. 2 p. 744-851) and in the s. 42A report of Dr Roygard (TEB v. 1 p. 193-476).

86. Aquatic macroinvertebrate and periphyton is limited to two sites in the upper Gorge target catchment. Mean MCI scores meet the One Plan targets and the annual scores are within targets more than 70% of the time (Table 15 and Figure 22). In contrast to these results, aquatic macroinvertebrate sampling associated with baseline information for the Clean Streams Accord (Clark et al. 2007) showed five out of twelve sites in the Mangapapa catchment were below the MCI target.

Table 15: Aquatic macroinvertebrate sites in the upper Gorge target catchment with mean MCI scores, comparison with One Plan MCI targets and years of sampling (*n*).

Site	Sub-zone	MCI target	*n*	Mean MCI	Meets the target	% samples meeting target
Manawatu at Upper Gorge	Upper Gorge	100	7	104	Yes	71
Mangapapa at Troup Rd	Mangapapa	100	4	115	Yes	75

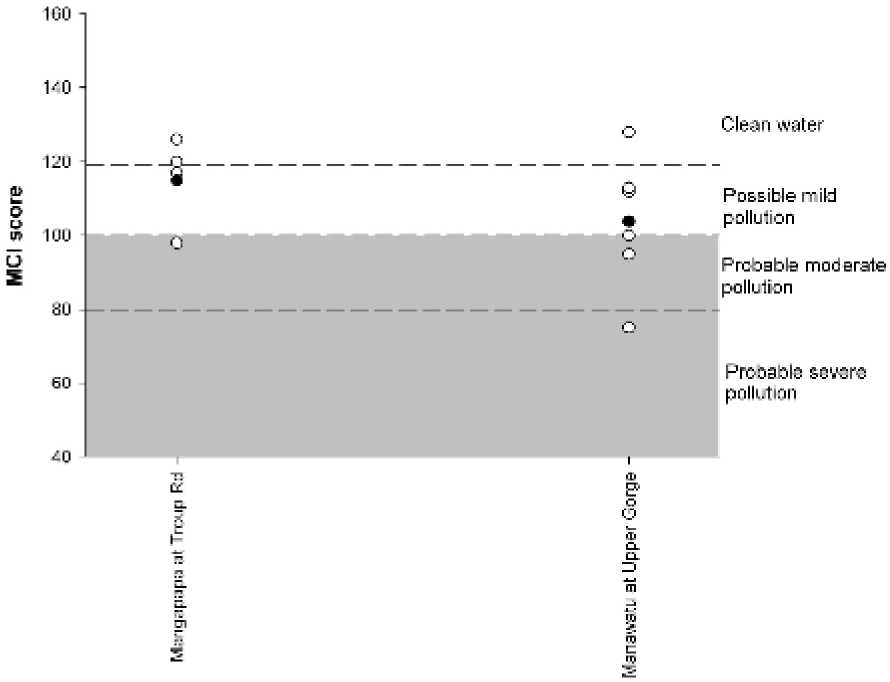


Figure 22: Macroinvertebrate community index (MCI) scores between 1999 and 2011 at two sites in the upper Gorge target catchment. Open circles indicate individual MCI scores for each year of sampling, while closed circles indicate the mean MCI score for the site. Data points falling within the shaded area do not meet the Proposed One Plan MCI target. The water quality classes shown on the right axis of the graph are according to Boothroyd and Stark (2000).

87. Periphyton was within the targets at all sites (Table 16, Figure 23 Figure 25) apart from one observation in the Mangaatua that exceeded the annual maximum for filamentous cover on one occasion (Figure 24). Clark et al. (2007) found one site in the upper Mangapapa catchment significantly exceeded the chlorophyll *a* target during the Clean Streams Accord baseline monitoring in 2007. The Manawatu at upper Gorge site has also been subject to severe cyanobacterial blooms, particularly during the summers of 2008 and 2009 when the recreational area was closed due to the cover of *Phormidium sp.* Cyanobacteria (personal observation).

Table 16: Summary of monthly periphyton observations in comparison with targets for per cent cover of filamentous algae (30% target), mat algae (60% target) and chlorophyll *a* (mg/m^2) for sites in the upper Gorge target catchments monitored between Dec 2008 and Nov 2011. The within-year range of the number of observations exceeding the targets at each site is shown as the annual range (fils, mats and Chl *a*). *n* = number of monthly observations at each site.

Site	Sub-zone	*n*	No. above % cover target (fils)	Annual range (fils)	No. above % cover target (mats)	Annual range (mats)	No. above Chl *a* target	Annual range (Chl *a*)	Chl *a* target
Mangapapa at Troup Rd	Mangapapa	36	0	0	0	0	0	0	120
Mangaatua u/s Woodville STP	Mangaatua	14	1	0-1	0	0	0	0	120
Mangaatua d/s Woodville STP	Mangaatua	14	0	0	0	0	0	0	120
Manawatu at Upper Gorge	Upper Gorge	34	0	0	0	0	0	0	120

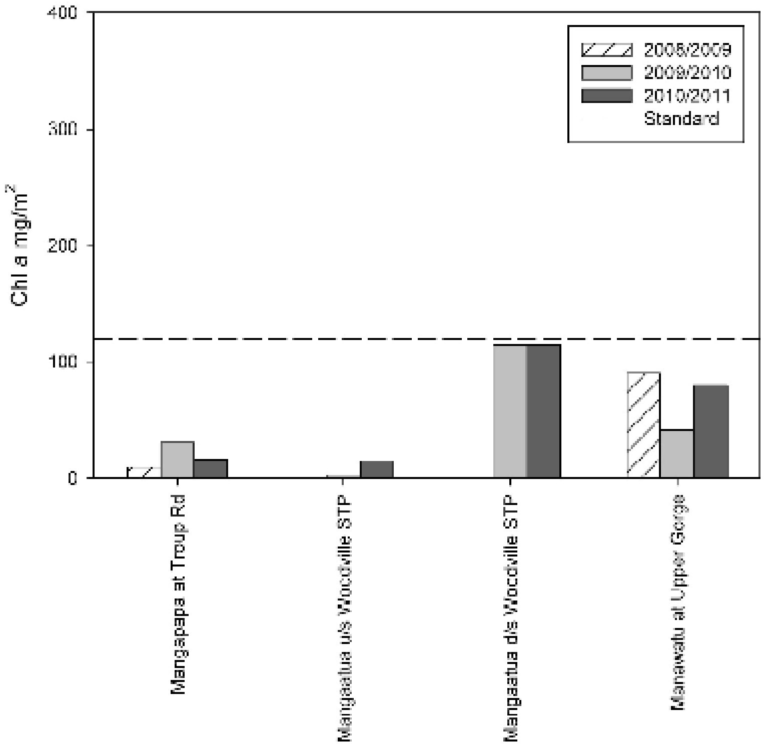


Figure 23: Annual maximum chlorophyll *a* concentration at sites in the upper Gorge target catchment for three years of periphyton monitoring in comparison with Proposed One Plan target for each site.

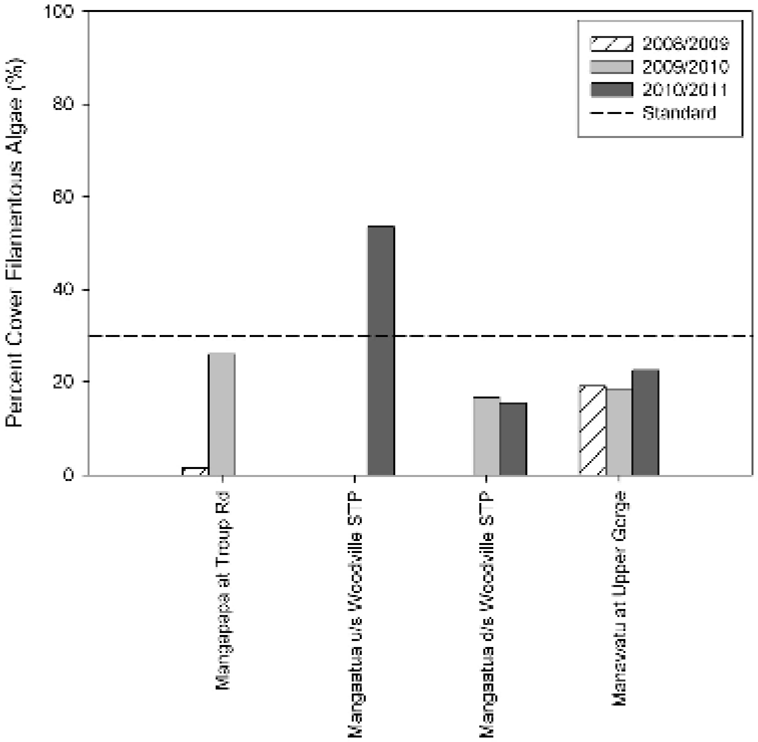


Figure 24: Annual maximum per cent cover by filamentous algae at sites in the upper Gorge target catchment for three years of periphyton monitoring in comparison with Proposed One Plan target for each site.

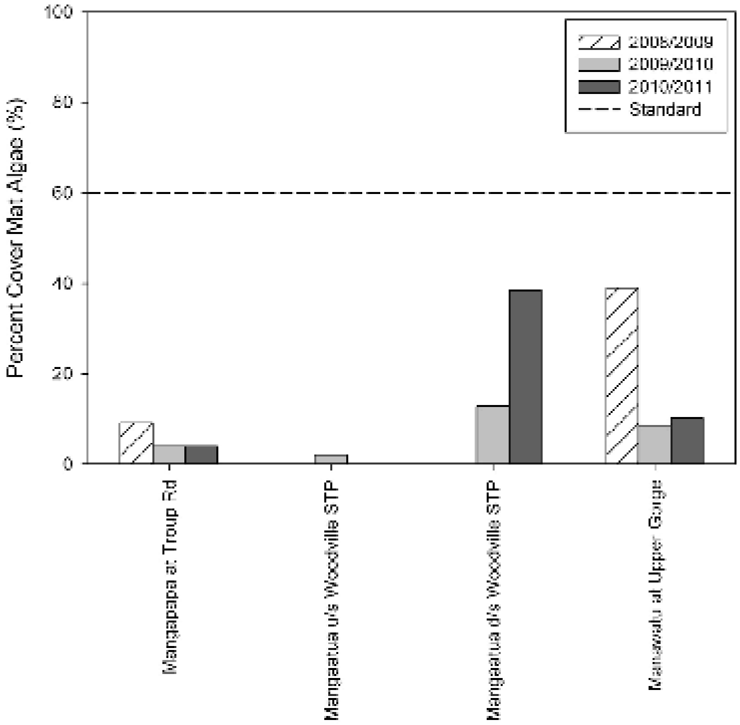


Figure 25: Annual maximum per cent cover by mat algae at sites in the upper Gorge target catchment for three years of periphyton monitoring in comparison with Proposed One Plan target for each site.

88. Soluble nutrient concentrations show the water quality at the Manawatu at upper Gorge site at the bottom of the target catchment often exceeds One Plan targets under all flows (Figure 26). As flows reduce there is the potential for the site to be phosphorus limited at flows less than median but greater than the 80th percentile of flows and at low flows most samples are within the targets (Figure 27).

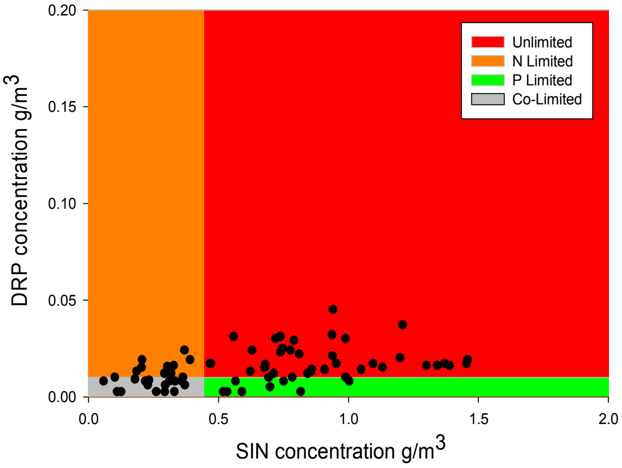
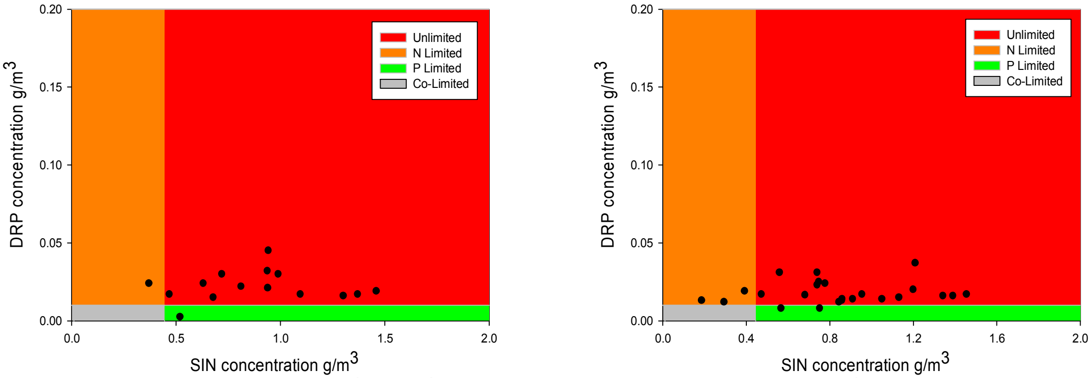
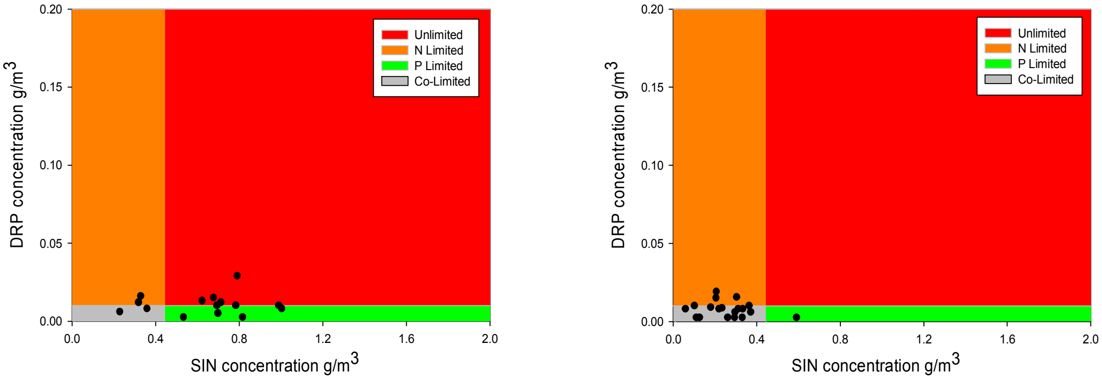


Figure 26: Soluble inorganic nitrogen (SIN) plotted against dissolved reactive phosphorus (DRP) concentrations for the Manawatu at upper Gorge monitoring site (Jul 2005 – Aug 2011) under all flow conditions. Coloured boxes indicate potential nutrient limitation status based on the Proposed One Plan targets for SIN and DRP.



a) High flow (0-20th %ile)

b) Above median flow (50th – 20th %iles)



c) Below median flow (80th – 50th %iles)

d) Low flow (>80th %ile)

Figure 27: Soluble inorganic nitrogen (SIN) plotted against dissolved reactive phosphorus (DRP) concentrations for the Manawatu at upper Gorge monitoring site (Jul 2005 – Aug 2011) under various flow scenarios (a-d). Coloured boxes indicate potential nutrient limitation status based on the Proposed One Plan targets for SIN and DRP.

89. The Measured Load is approximately twice the Target Load at the upper Gorge site (Table 17) for both nitrogen and phosphorus. Loads at this site are the cumulative product of contaminants input to the upstream catchment areas (both target and non-target catchments areas) and from the land use in the capture area of the site itself. The predominant sources of nutrient inputs are diffuse (non-point source).

Table 17: Annual average nutrient loads for the Manawatu at upper Gorge site expressed as tonnes per year (T/yr). SIN = soluble inorganic nitrogen, DRP = dissolved reactive phosphorus. Shaded areas exceed the annual average SIN or DRP Target Load. Bold indicates the site exceeds either the SIN or DRP Target Load by more than 50% as a result of non-point sourced inputs.

Site	SIN (T/yr)				DRP (T/yr)			
	Target Load	Measured Load	Point Source (PS) Load	Non-Point Source (NPS) Load	Target Load	Measured Load	Point Source (PS) Load	Non-Point Source (NPS) Load
Manawatu at Upper Gorge	**1193.5**	**2281.2**	**29.76**	**2251.48**	**26.9**	**54.87**	**7.20**	**47.67**

90. The results of scenario modelling for non-point sourced contamination undertaken in the Upper Gorge catchment following a number of different approaches has shown that:

a. Of the LUC approaches to managing nitrogen, improvements will generally only come about if limits were to apply equally to existing dairy farms as well as new conversions. If the limits were applied to new conversions only, slight but continued degradation can be expected.

b. Of the Single Number Limit approaches it may be expected that limiting loss rates to 24 kgN/ha/yr or less will maintain or enhance water quality, with large improvements to be generally expected if limits were set less than 21 kgN/ha/yr.

c. Continued degradation can be expected if the limits were set above 27 kgN/ha/yr. Setting the limit based on the regional average may have slight gains, but averging limits by site is unlikely to offer any improvement.

d. Doing nothing is not going to maintain or enhance water quality.

Upper Gorge target catchment summary

91. **Aquatic macroinvertebrates and periphyton at sites in the upper Gorge target catchment generally meet the One Plan targets for MCI and periphyton.** However, severe cyanobacterial blooms that have resulted in river closure have commonly been observed at the upper Gorge Reserve.

92. **Nutrient concentrations in the Manawatu at upper Gorge regularly exceed the nitrogen and phosphorus targets, particularly at higher flows.** At the lowest flows there is potential for the upper Gorge site to be phosphorus limited more often than nitrogen limited but as flows drop to the lowest 20% of flows the concentrations of nitrogen and phosphorus are generally within the One Plan targets.

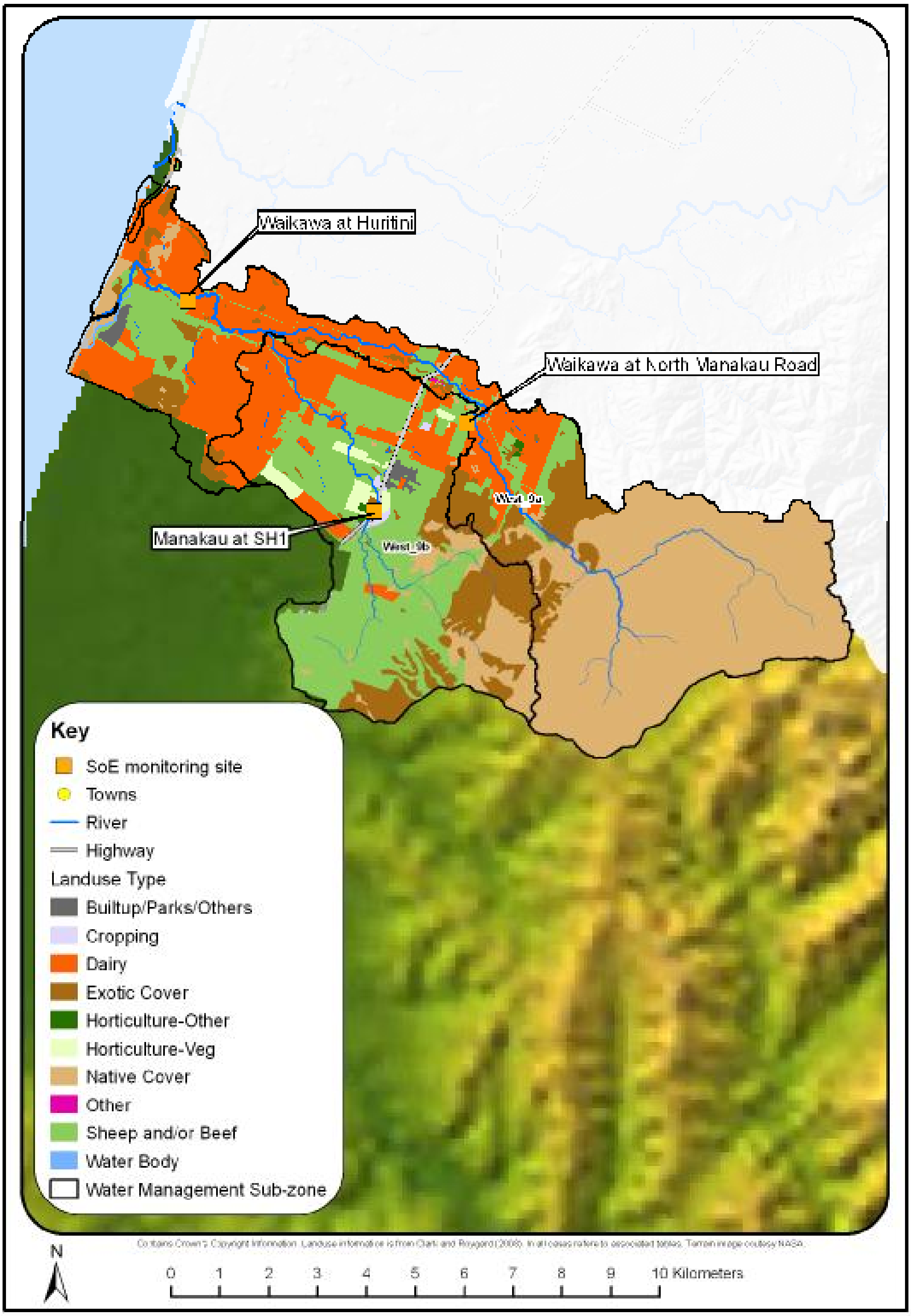
93. **Measured nitrogen and phosphorus loads for the Manawatu at upper Gorge site are approximately twice the Target Loads and the contaminant inputs are predominantly non-point sourced, both within the target catchment and from the upstream inflows from the contributing land areas.**

94. **The scenarios show that Doing nothing is not going to maintain or enhance water quality and of the LUC approaches to managing nitrogen, improvements will generally only occur if loss limits were applied to existing farms as well as new conversions.**

Section 2D: Target catchment summaries - Waikawa

95. The Waikawa target catchment includes the sub-zones of the Waikawa and Manakau streams (Map 3). This catchment is recognised for the significant contribution it makes to regional aquatic biodiversity due to the native fish communities found in the forested upper catchment. More detailed information on water quality in the Waikawa target catchment can be found in Chapter 9 of the s. 42A report of Kathryn McArthur (TEB v. 2 p. 744-851) and in the s. 42A report of Dr Roygard (TEB v. 1 p. 193-476).

96. The only biomonitoring site in the Waikawa catchment is a reference site that is largely forested upstream (both exotic and native). The minimal negative effect that this land use has on water quality is reflected in the mean MCI score of 135 (Table 18). There is no downstream biomonitoring site to compare changes in the aquatic macroinvertebrate community resulting from pastoral land use and other impacts because the lower river (Waikawa at Huritini) is soft-bottomed and not suitable for biomonitoring using the same protocols as the upstream site. Inclusion of the soft-bottomed variant of the MCI in Schedule D of the DV POP means the site can be monitored using the soft-bottomed protocols in future.



Contains Crown's Copyright Information. Landuse information is from Clark and Roygard (2008). In all cases refer to associated tables. Terrain image courtesy NASA.

Map 3: Map of land use in the Waikawa catchment showing the locations of the monitoring sites modelled in this study, including point source monitoring sites.

Table 18: Aquatic macroinvertebrate sites in the Waikawa target catchment with mean MCI score, comparison with One Plan MCI targets and years of sampling (*n*).

Site	Sub-zone	MCI target	*n*	Mean MCI	Meets the target	% samples meeting target
Waikawa at Nth Manakau Rd	Waikawa	100	3	135	Yes	100

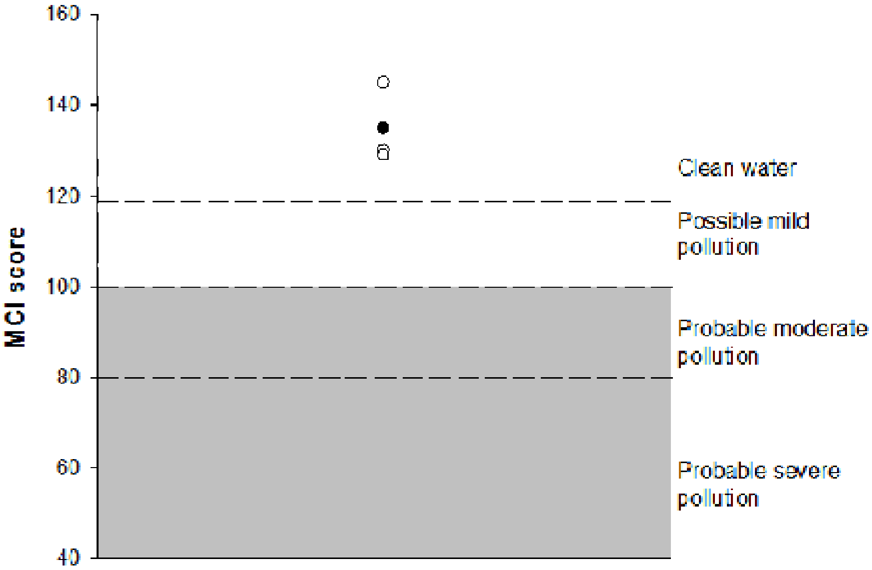
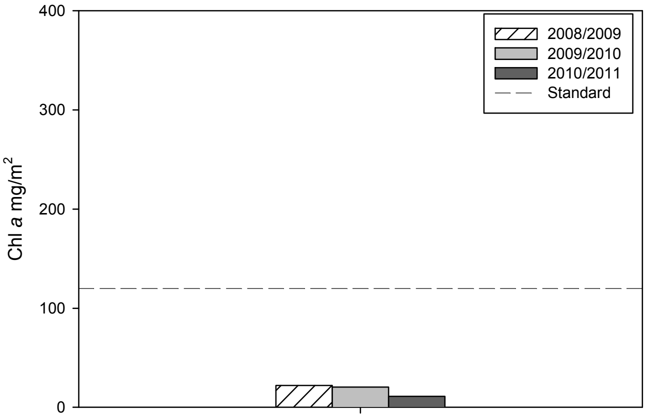


Figure 28: Macroinvertebrate community index (MCI) scores between 1999 and 2011 at the Waikawa at North Manakau Rd site. Open circles indicate individual MCI scores for each year of sampling, while closed circles indicate the mean MCI score for the site. Data points falling within the shaded area do not meet the Proposed One Plan MCI target. The water quality classes shown on the right axis of the graph are according to Boothroyd and Stark (2000).

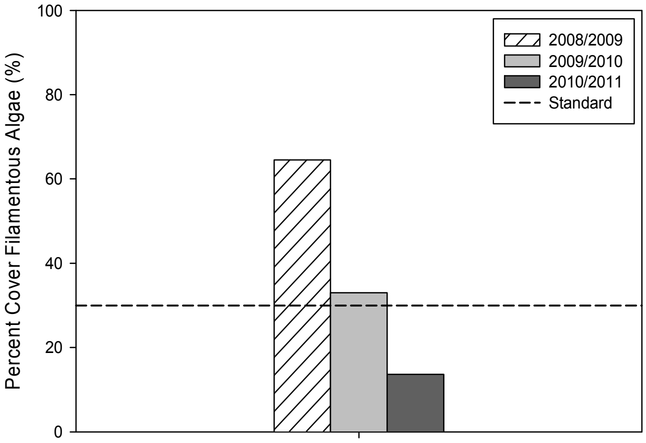
97. Periphyton at the site has exceeded One Plan targets at times (Table 19) for the annual maximum cover by filamentous algae (Figure 29).

Table 19: Summary of monthly periphyton observations in comparison with targets for percent cover of filamentous algae (30% target), mat algae (60% target) and chlorophyll *a* (mg/m^2) for the Waikawa target catchment monitored between Dec 2008 and Nov 2011. The within-year range of the number of observations exceeding the targets at each site is shown as the annual range (fils, mats and Chl *a*). *n* = number of monthly observations at each site.

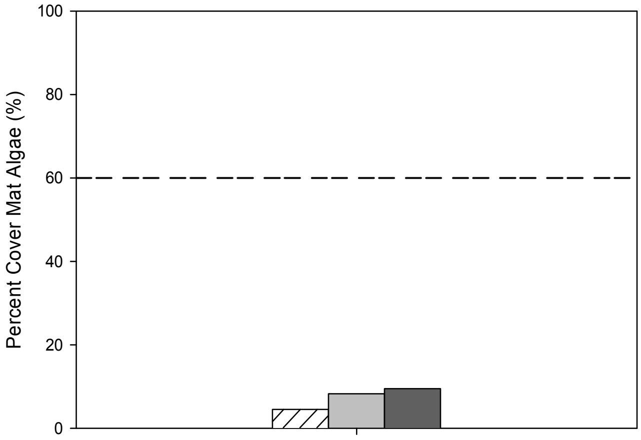
Site	Sub-zone	*n*	No. above % cover target (fils)	Annual range (fils)	No. above % cover target (mats)	Annual range (mats)	No. above Chl *a* target	Annual range (Chl *a*)	Chl *a* target
Waikawa at Nth Manakau Rd	Waikawa	36	4	0-2	0	0	0	0	120



a)



b)



c)

Figure 29: Annual maximum a) chlorophyll *a*; b) per cent cover by filamentous algae; and c) per cent cover by mat algae at the Waikawa at North Manakau Rd site for three years of periphyton monitoring in comparison with Proposed One Plan targets for each site.

98. The effects of land use and nutrient enrichment are difficult to quantify using biological indicators because of the lack of comparison between the reference/clean upstream condition and a comparable downstream monitoring site. However biological monitoring within the Waikawa Estuary may be used to infer the effects of upstream land use and nutrient enrichment. Because of the short river length of the Waikawa, the enrichment effects of elevated nutrient concentrations have less chance of being mitigated through uptake by periphyton on the river bed before reaching the coastal environment.

99. Suspended algae measured as chlorophyll *a* in mg/litre have been collected monthly throughout 2011 as part of Horizons newly instigated coastal and estuarine monitoring programme. The DV POP target in Schedule H for chlorophyll *a* in the Waikawa Estuary sub-zone is an annual average of 0.004 mg/L. The Waikawa Estuary is the only estuary to exceed this limit in the 2011 monitoring (Figure 30).

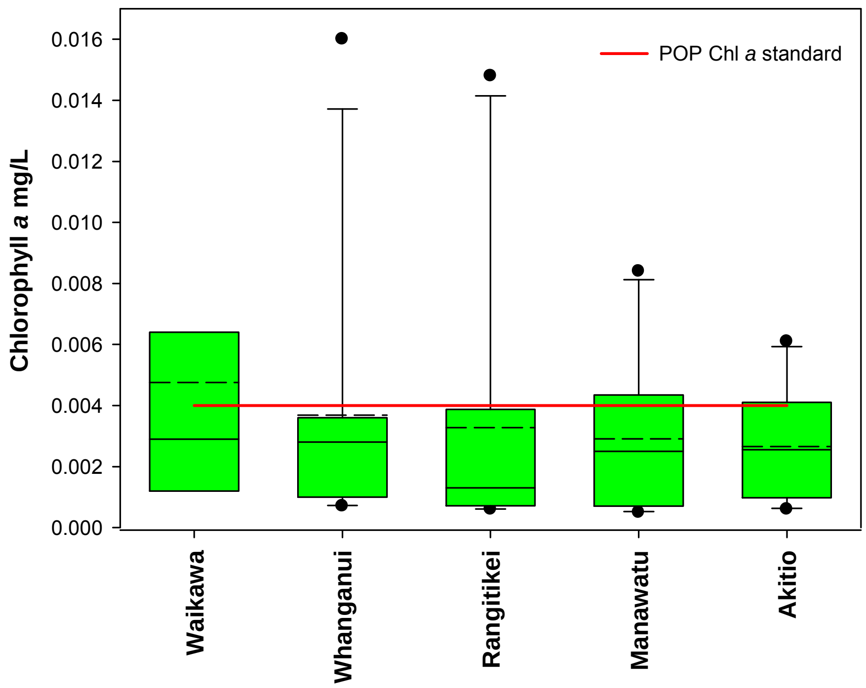


Figure 30: Estuarine chlorophyll *a* concentrations (mg/L) collected monthly between January and December 2011 from Horizons estuarine monitoring sites. Boxes represent upper and lower quartiles with median (straight) and mean (dashed) mid-point lines, whiskers are 10th (lowest) and 90th (highest) percentiles of the data and black dots are outlying observations. The red line represents the Proposed One Plan Chlorophyll *a* target for the estuary water management sub-zones (Schedule H DV POP).

100. Despite the small amount of sheep and beef and dairying upstream of the Waikawa at North Manakau Rd site, the site has relatively good water quality with Measured Loads of nitrogen and phosphorus being within the Target concentrations and subsequently Target Loads for this site (Figure 31 and Table 20). The measured nitrogen loads at the site Manakau at SH1 show that the Manakau Stream is subject to some contaminant inputs from non-point sources. The lower Waikawa monitoring site (Waikawa at Huritini) located downstream of the Manakau Stream confluence shows even greater degradation. In the absence of any know point source the contaminants can only be assumed to be derived from landuse.

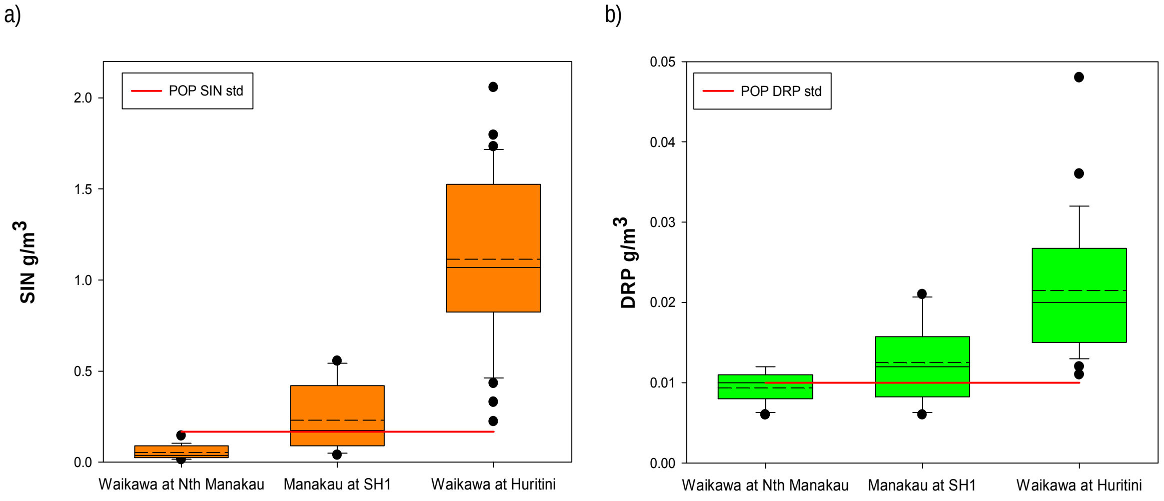


Figure 31: a) Soluble inorganic nitrogen (SIN) and b) dissolved reactive phosphorus (DRP) concentrations at three sites in the Waikawa target catchment. *Reproduced from s. 42A report of Kate McArthur page 208 (TEB v. 2 p. 800).*

Table 20: Annual average nutrient loads for two sites in the Waikawa target catchment expressed as tonnes per year (T/yr). SIN = soluble inorganic nitrogen, DRP = dissolved reactive phosphorus. Shaded sites exceed the annual average SIN or DRP Target Loads. Sites in bold exceed either the SIN or DRP Target Load by more than 50% as a result of non-point sourced inputs.

Site	SIN (T/yr)				DRP (T/yr)			
	Target Load	Measured Load	Point Source (PS) Load	Non-Point Source (NPS) Load	Target Load	Measured Load	Point Source (PS) Load	Non-Point Source (NPS) Load
Waikawa at Nth Manakau Rd[1]	8.1	4.48	0	4.48	0.5	0.48	0	0.48
Manakau at SH1	**2.0**	**5.57**	**0**	**5.57**	0.1	0.15	0	0.15
Waikawa at Huritini	**10.0**	**43.7**	**0**	**43.7**	**0.6**	**1.2**	**0**	**1.2**

101. The results of scenario modelling for non-point sourced contamination undertaken in the Waikawa catchment following a number of different approaches has shown that the only scenario that offers to maintain or improve water quality in the Waikawa Catchment is for losses to be limited to the average loss at Huritini or to be limited to less than 15kgn/ha/yr. Even under these scenarios, continued degradation of Waikawa at North Manakau site can be expected if the number of dairy farms continues to expand.

Waikawa target catchment summary

102. **Aquatic macroinvertebrates in the upper Waikawa target catchment generally always meet the DV POP targets for MCI. Periphyton is occasionally above the per cent cover for filamentous algae target.** This site is a reference site with a large proportion of the upstream catchment in native forest. The Waikawa has very high aquatic biodiversity values for native fish communities.

103. **Nutrient enrichment in the Waikawa has an adverse effect on suspended algae in the Waikawa Estuary. This estuary was the only one to exceed the DV POP targets in 2011.**

104. **Measured nutrient loads in the upper catchment reference site are within the Target Loads. Some degradation occurs further downstream within the Manakau tributary catchment, particularly in relation to nitrogen loads**. Nitrogen and phosphorus concentrations are known to significantly increase in relation to the proportion of dairying land use between the upstream and lower catchment sites.

105. **The only scenario that offers to maintain or improve water quality in the Waikawa Catchment is for losses to be limited to the average loss at Huritini or to be limited to less than 15 KgN/ha/yr. Even under these scenarios, continued degredation of Waikawa at North Manakau site can be expected if the area of dairy farms continue to expand.**

Section 2E: Target catchment summaries - Northern Manawatu Lakes

106. The Northern Manawatu Lakes target catchment (insert map here) includes a number of internationally important wetlands and lakes that are connected by surface water drains and groundwater (ie. Pukepuke Lagoon and Lakes Kaikokopu and Koputara; Cromarty and Scott 1995). The numerous dune lakes and wetlands in this water management zones are regionally significant for their biodiversity value. Further information on the Northern Manawatu Lakes target catchment can be found in paragraph 452 and Chapter 9 of the s. 42A report of Kathryn McArthur (TEB v. 2 p. 822; v. 2 p. 744-851) and appendix 5 of the end of hearing report (TEB v. 9 p. 4396-4402).

107. Surface water quality data the Northern Manawatu Lakes water management zone is sparse and further monitoring of water bodies within this zone has not been undertaken since the information presented at the water hearing. With the exception of contact recreation monitoring, the only surface water quality data for the zone is from the Kaikokopu Stream (Lake Kaikokopu oulet) where it flows onto Himatangi Beach. The data was collected over the 2007 to 2008 summer and shows elevated nutrient concentrations, in particular ammonia and phosphorus, that indicate nutrient enrichment is affecting the stream within the catchment area of the stream and/or lake.

108. Given that the degree of pastoral land cover is almost 80% and that dairying comprises 50% of the catchment land area, the likelihood of water quality and aquatic ecosystem health being affected by nutrient enrichment is high. In a recent study of lake water quality status and trends in New Zealand, on behalf of the Ministry for the Environment, Verberg et al. (2010) concluded that their most significant finding is that pastoral land use in New Zealand is associated with lake eutrophication and ecological deterioration.

109. As noted in Kathryn McArthur's s. 42A report (TEB v. 2 p. 591-878), the hydrological relationship between the lakes in the Northern Manawatu zone and the sources of contaminants that cause lake eutrophication are highly complex and largely unknown, although it is suspected that the surface water quality is influenced strongly by both surface water runoff and delivery of nutrients from

contaminated groundwater. According to Winter et al. (2003) the expression of the quality of the groundwater at the land surface (which characterises the coastal lakes and wetlands in this zone) can range from locally sourced groundwater to reflecting the groundwater quality at a wider regional level.

110. Other than the surface expression of the groundwater as dune lakes and wetlands the predominant groundwater flow in this area is westerly and to the coast (Zarour 2008). Inshore coastal water quality can be affected by the quality of water discharging from major rivers and from the groundwater flowing to the coast. Coastal monitoring is undertaken at Himatangi Beach, approximately halfway down the coast of the Northern Manawatu Lakes zone. The predominant current carrying water discharged from the major rivers flowing to the West Coast is along shore to the South. Himatangi Beach is downstream of the discharge from the Rangitikei River Estuary and the water quality is therefore likely to reflect influences from the Rangitikei River. However, there is considerable distance between the Rangitikei Estuary and Himatangi Beach and so it is likely that the water quality at the Himitangi Beach is also influenced by the groundwater quality flowing from beneath the land surface to the coast.

111. Water quality monitoring results collected from the Himatangi Beach site in the summer monitoring of 2007 to 2008 show average total nitrogen and phosphorus concentrations were elevated above DV POP targets at (see section 7.4 of Kate McArthur's section 42A TEB v. 2 p. 716-717).

112. Chlorophyll *a* concentrations have also been collected from this site over the last twelve months as part of the coastal and estuary monitoring programme. Annual average concentrations significantly exceed the One Plan target(Figure 32). The degree to which the Himatangi site exceeds the target is more easily seen on a log transformed plot of the data (Figure 33).

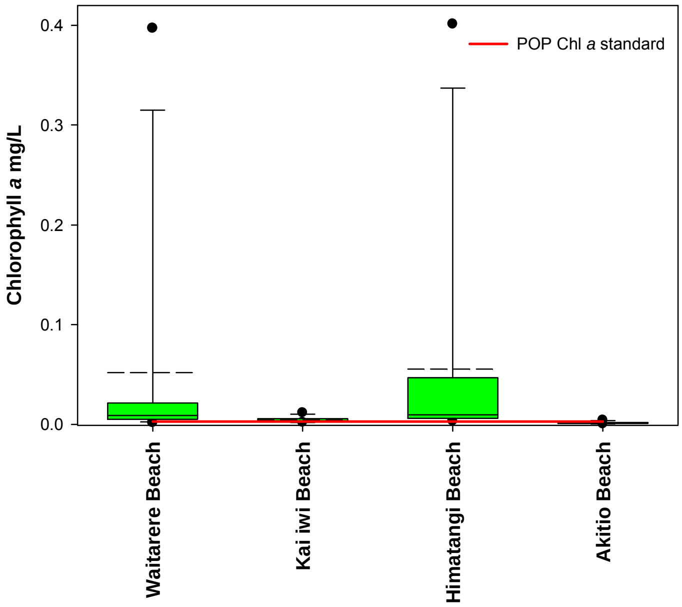


Figure 32: Seawater chlorophyll *a* concentrations (mg/L) collected monthly between January and December 2011 from Horizons coastal monitoring sites. Boxes represent upper and lower quartiles with median (straight) and mean (dashed) mid-point lines, whiskers are 10th (lowest) and 90th (highest) percentiles of the data and black dots are outlying observations. The red line represents the Proposed One Plan Chlorophyll *a* target for the seawater management zone (Schedule H).

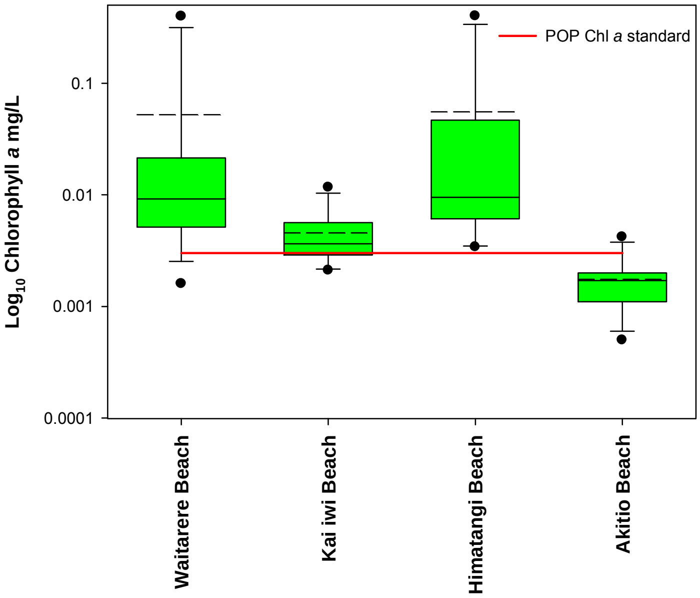


Figure 33: Log_{10} seawater chlorophyll *a* concentrations (mg/L) collected monthly between January and December 2011 from Horizons coastal monitoring sites. Boxes represent upper and lower quartiles with median (straight) and mean (dashed) mid-point lines, whiskers are 10th (lowest) and 90th (highest) percentiles of the data and black dots are outlying observations. The red line represents the Proposed One Plan Chlorophyll *a* target for the seawater management zone (Schedule H).

113. High concentrations of suspended algae in near-shore coastal waters have the potential to adversely impact on ecological and recreational values at the coast. Algal blooms are commonly reported at Himatangi, Foxton and Waitarere beaches and complaints from the public about nuisance algae at these sites are fielded by Council staff most years (Photo 1).

Photo 1: Surf algal bloom at Waitarere Beach in September 2009 a) affecting coastal water quality and recreational use of the beach and b) washing up as a scum on the shore.

Northern Manawatu Lakes target catchment summary

114. **The Northern Manawatu Lakes target catchment contains a numerous regionally significant and internationally important wetlands and lakes.**

115. **Surface water quality data is sparse for the Northern Manawatu Lakes target catchment. Seawater data shows enriched coastal waters and ecological and recreational values are known to be adversely affected by algal blooms adjacent to the target catchment.** Measured enrichment has the potential to be associated with ground and surface water carrying elevated nutrient concentrations to the coast resulting from land use in the area. The relationship between land use and ground and surface water quality is difficult to quantify and requires specialist intensive study to establish to a higher degree of certainty.

116. **Although the water quality data is uncertain, the high proportion of pastoral and intensive dairying in the catchment puts significant wetland and lake waters at considerable risk of accelerated eutrophication, adversely impacting on aquatic and terrestrial biodiversity.**

Jon Roygard
SCIENCE MANAGER

Kate McArthur
ENVIRONMENTAL SCIENTIST WATER QUALITY

Maree Clark
ENVIRONMENTAL SCIENTIST WATER

References

Ausseil, O., & Clark, M., (2007) *Recommended Water Quality Targets for the Manawatu-Wanganui Region: Technical Report to Support Policy Development* (Report 2007/EXT/806). Palmerston North, New Zealand: Horizons Regional Council.

Ballantine, D.J., & Davies-Colley, R.J., (2009) *Water quality State and Trends in the Horizons Region.* (Report HAM2009-090). Hamilton, New Zealand: NIWA.

Ballantine, D.J., & Davis-Colley, R.J., (2010) *Water quality trends at National River Water Quality Network sites for 1989–2007* (2nd ed). (Report: HAM2009-026). Hamilton, New Zealand: NIWA.

Boothroyd, I., & Stark, J., (2000). Use of invertebrates in monitoring. In: Collier KJ, Winterbourn MJ (eds), *New Zealand stream invertebrate ecology and implications for management.* (pp.344-373). Christchurch, New Zealand: New Zealand Limnological Society.

Clark, M.E., McArthur, K.J., Death F. & Roygard, J.K.F. (2007*) Baseline Monitoring Report Mangapapa Stream: Tier 2 Clean Streams Accord Monitoring Technical Report to the Ministry for the Environment.* (Report: 2007/EXT/247) Palmerston North, New Zealand: Horizons Regional Council.

Clark, M.E. & Roygard, J.K.F. (2008) *Land use and land use capability in the Manawatu-Wanganui Region: Internal report to support policy development.* (Report: 2008/INT/616) Palmerston North, New Zealand: Horizons Regional Council.

Cromarty, P. & Scott, D.A. (1995). A directory of wetlands in New Zealand. Department of Conservation, Wellington, New Zealand.

Davies-Colley, R.J., Smith, D.G., Ward, R.C., Bryers, G.G., McBride, G.B., Quinn, J.M. & Scarsbrook, M.R. (2011) Twenty years of New Zealand's national rivers water quality network: benefits of careful design and consistent operation. *Journal of the American Water Resources Association (JAWRA) 47*(4):750-771.

Hay, J., Hayes, J. & Young, R. (2006) *Water Quality Guidelines to Protect Trout Fishery Values.* (Report 1205) Nelson, New Zealand: Cawthron Institute.

Kilroy, C., Biggs, B. & Death, R. (2008) *A periphyton monitoring plan for the Manawatu-Wanganui Region.* (Report CHC2008-03) Christchurch, New Zealand: NIWA.

McArthur, K., Roygard, J. & Clark, M. (2010). Understanding the variation in limiting nutrient status of rivers in the Horizons region. *Journal of Hydrology (NZ), 49* (2), 15-33.

Roygard et al (in press), Soluble nutrients in two sub-catchments of the Manawatu River. *New Zealand Journal of Marine and Freshwater Sciences.*

Scarsbrook, M.R. (2006) *State and trends in the National River Water Quality Network (1989-2005).* (Report ME: 778) Hamilton, New Zealand: NIWA.

Stark, J.D. (1985) A macroinvertebrate community index of water quality for stoney streams. *(Water & soil miscellaneous publication 87).* Wellington, New Zealand: National Water and Soil Conservation Authority.

Stark, J.D. (1993) Performance of the Macroinvertebrate Community Index: Effects of sampling method, sample replication, water depth, current velocity and substratum on index values. *New Zealand Journal of marine and freshwater research 27*: 463-478.

Stark, J.D. (1998) SQMCI: a biotic index for freshwater macroinvertebrate coded abundance data*. New Zealand journal of marine and freshwater research 27*: 463-478.

Stark, J.D. & Maxted, J.R. (2007) *A User Guide to the Macroinvertebrate Community Index.* (Report 1166) Nelson, New Zealand: Cawthron Institute.

Stark. J.D. (2011) Aquatic invertebrate communities of the Manawatu-Wanganui Region – 2011 State of the Environment Report. (Report 2001/EXT/1210) Nelson, New Zealand: Stark Environmental.

Verberg, P. et al. (2010) *Lake water quality in New Zealand 2010: Status and trends.* (Report HAM2010-107) Hamilton, New Zealand: NIWA.

Winter, T.C., Rosenberry, D.O. & LaBaugh, J.W. (2003). Where does the groundwater in small watersheds come from? *Ground Water 41*(7), 989-1000.

Wood, S. & Young, R. (2011) Benthic Cyanobacteria and Toxin Production in the Manawatu-Wanganui Region (Report 2001/EXT/1157) Nelson, New Zealand: Cawthron Institute.

Zarour, H. (2008) *Groundwater Resources in the Manawatu-Wanganui Region: Technical report to support policy development* (Report 2008/EXT/948). Palmerston North, New Zealand: Horizons Regional Council.

Appendix 1: Regional water quality summary data from LAWNZ

Table 21: Summary water quality data for eighty-eight sites in the Manawatu-Wanganui Region in relation to national quartiles of water quality data from 891 sites (data sourced from Land and Water New Zealand (LAWNZ).

Sub-zone	**Site**	**Visual Clarity**		**Dissolved Reactive Phosphorus**		***E. coli***		**Ammoniacal Nitrogen**		**Total oxidised nitrogen**	
		Median value	National Quartile	Median value	National Quartile	Median value	National Quartile	Median value	National Quartile	Median value	National Quartile
Mana_1a	Manawatu at Weber Road	1.6	2	0.011	3	326	4	0.014	3	0.41	3
Mana_1a	Mangarangiora tributary u/s Norsewood STP	1.4	3	0.008	2	814.5	4	0.0205	4	0.727	4
Mana_1c	Mangatoro at Mangahei Rd	1.25	3	0.015	3	240	3	0.009	2	0.587	3
Mana_2b	Mangatera confluence at Timber Bay	1	3	0.0165	3	630	4	0.16	4	0.945	4
Mana_2b	Mangatera u/s Dannevirke STP	1.8	2	0.014	3	491.1	4	0.023	4	0.661	4
Mana_3	Tamaki at Reserve	3.35	1	0.057	4	10	1	0.005	2	0.1	2
Mana_4	Kumeti at Te Rehunga	2.85	1	0.00375	1	210.3	3	0.007	2	0.529	3
Mana_5a	Manawatu at Hopelands	1.4	3	0.008	2	248.1	3	0.014	3	0.712	4
Mana_5b	Tamaki at Stephensons	3.2	1	0.049	4	260	3	0.007	2	0.236	3
Mana_5d	Oruakeretaki at SH2	3.8	1	0.0265	4	229	3	0.01	2	0.6575	4
Mana_5e	Raparapawai at Jacksons Rd	2.05	2	0.165	4	440	4	0.008	2	0.352	3
Mana_6	Manawatu at Ngawapurua Bridge	0.95	3	0.0065	2	228.65	3	0.0145	3	0.5535	3
Mana_7a	Tiraumea at Ngaturi	0.95	3	0.0235	4	292	3	0.0195	4	0.597	4
Mana_7b	Tiraumea at Haukopua Reserve	0.5	4	0.022	4	318	4	0.0215	4	0.518	3
Mana_7b	Tiraumea u/s Manawatu confluence	1.1	3	0.0245	4	191.55	3	0.013	3	0.6175	4

Sub-zone	**Site**	**Visual Clarity**		**Dissolved Reactive Phosphorus**		***E. coli***		**Ammoniacal Nitrogen**		**Total oxidised nitrogen**	
		Median value	National Quartile	Median value	National Quartile	Median value	National Quartile	Median value	National Quartile	Median value	National Quartile
Mana_7d	Makuri at Tuscan Hills	1.6	2	0.0095	2	183	3	0.008	2	0.883	4
Mana_8a	Mangatainoka at Larsons Rd	3.5	1	0.0125	3	48	2	0.005	2	0.0715	1
Mana_8a	Mangatainoka at Putara	3	1	0.017	3	5	1	0.0025	1	0.0095	1
Mana_8c	Brechin u/s Fonterra Pahiatua	1.85	2	0.0195	3	85	2	0.01	2	1.534	4
Mana_8c	Mangatainoka at Pahitua Town Bridge	2	2	0.0025	1	93	2	0.007	2	0.857	4
Mana_8c	Mangatainoka at SH2	1.8	2	0.013	3	100	2	0.011	3	0.974	4
Mana_8c	Mangatainoka u/s Pahiatua STP	1.75	2	0.011	3	120	3	0.009	2	0.8965	4
Mana_8d	Makakahi at Hamua	1.9	2	0.007	2	312.5	4	0.01	2	0.592	4
Mana_8d	Makakahi u/s Eketahuna STP	1.9	2	0.009	2	198.95	3	0.006	2	0.281	3
Mana_9a	Manawatu at Upper Gorge	0.75	4	0.009	2	230.5	3	0.0115	3	0.6605	4
Mana_9b	Mangapapa at Troup Rd Bridge	2.175	2	0.012	3	310	4	0.01	2	0.637	4
Mana_9c	Mangaatua u/s Woodville STP	1.54	3	0.007	2	342.5	4	0.0095	2	0.364	3
Mana_9d	Mangahao at Ballance	1.675	2	0.006	2	124.5	3	0.005	2	0.193	2
Mana_10a	Manawatu at Teachers College	0.7	4	0.005	2	131.5	3	0.006	2	0.318	3
Mana_10b	Pohangina at Piripiri	1.65	2	0.025	4	11	1	0.005	2	0.0405	1
Mana_10c	Pohangina at Mais Reach	1.32	3	0.024	4	85	2	0.005	2	0.09	2
Mana_11a	Manawatu at Opiki Bridge	0.9	4	0.0055	2	249	3	0.0755	4	0.415	3
Mana_11a	Manawatu u/s Fonterra and Longburn STP	0.9	4	0.011	3	305	4	0.083	4	0.378	3
Mana_11a	Manawatu u/s PNCC STP	0.9	4	0.011	3	208.95	3	0.0195	4	0.3895	3
Mana_11a	Oroua at Almadale	1	3	0.008	2	100	2	0.005	2	0.1125	2

Sub-zone	**Site**	**Visual Clarity**		**Dissolved Reactive Phosphorus**		***E. coli***		**Ammoniacal Nitrogen**		**Total oxidised nitrogen**	
		Median value	National Quartile	Median value	National Quartile	Median value	National Quartile	Median value	National Quartile	Median value	National Quartile
Mana_11a	Oroua at Apiti Gorge Bridge	5	1	0.0115	3	8.5	1	0.0025	1	0.055	1
Mana_11a	Oroua Tributary u/s Kimbolton STP	1.95	2	0.008	2	319	4	0.0185	3	0.945	4
Mana_11b	Oroua at Awahuri	0.7	4	0.0155	3	300	3	0.1165	4	0.4785	3
Mana_11b	Oroua u/s AFFCO Feilding	1.4	3	0.0155	3	213.3	3	0.018	3	0.1906	2
Mana_11b	Oroua u/s Feilding STP	1.3	3	0.0105	3	283.5	3	0.099	4	0.43	3
Mana_11c	Kahuterawa at Johnstons Rata	1.55	2	0.00375	1	55.5	2	0.007	2	0.1695	2
Mana_13a	Manawatu at Whirokino	0.31	4	0.007	2	289.25	3	0.055	4	0.475	3
Mana_13a	Manawatu u/s PPCS Shannon	0.5	4	0.008	2	276	3	0.06	4	0.42	3
Mana_13c	Tokomaru at Horseshoe Bend	3.15	1	0.026	4	95	2	0.005	2	0.09	2
Mana_13d	Mangaore u/s Shannon STP	0.8	4	0.0095	2	98	2	0.008	2	0.152	2
Rang_2a	Rangitikei at Pukeokahu	3	1	0.027	4	20.1	1	0.005	2	0.015	1
Rang_2b	Rangitikei at Mangaweka	1.265	3	0.011	3	40	2	0.005	2	0.0595	1
Rang_2f	Hautapu at Alabasters	1.1	3	0.0025	1	134	3	0.005	2	0.04485	1
Rang_2g	Hautapu u/s Rangitikei Confluence	0.8	4	0.009	2	210	3	0.008	2	0.11	2
Rang_3a	Rangitikei at Onepuhi	0.505	4	0.0255	4	108	2	0.006	2	0.0805	2
Rang_4a	Piakatutu u/s Sanson STP	0.15	4	0.0175	3	512	4	0.054	4	0.079	2
Rang_4a	Rangitawa Stream u/s Halcombe STP	1.4	3	0.085	4	348.55	4	0.033	4	0.2855	3
Rang_4a	Rangitikei at McKelvie	0.435	4	0.0265	4	110	2	0.005	2	0.089	2
Rang_4a	Rangitikei u/s Bulls STP	1.1	3	0.007	2	140.5	3	0.008	2	0.091	2
Rang_4c	Porewa at Onepuhi	1.6	2	0.005	2	400	4	0.013	3	0.096	2
Rang_4c	Porewa u/s Hunterville STP	1.1	3	0.009	2	1340	4	0.027	4	0.1565	2
Rang_4d	Tutaenui Stream u/s Marton STP	1.15	3	0.0445	4	623.5	4	0.02	4	0.6165	4

Sub-zone	Site	**Visual Clarity**		**Dissolved Reactive Phosphorus**		***E. coli***		**Ammoniacal Nitrogen**		**Total oxidised nitrogen**	
		Median value	National Quartile	Median value	National Quartile	Median value	National Quartile	Median value	National Quartile	Median value	National Quartile
Whai_2a	Whanganui at Cherry Grove	1.37	3	0.009	2	75	2	0.005	2	0.13	2
Whai_2g	Ongarue at Taringamotu	0.8	4	0.0075	2	225.5	3	0.0085	2	0.2765	3
Whai_3	Whanganui at Te Maire	0.885	4	0.009	2	157.5	3	0.008	2	0.225	2
Whai_4a	Whanganui d/s Retaruke Confluence	0.695	4	0.012	3	175	3	0.008	2	0.23	3
Whai_4b	Ohura at Tokorima	0.27	4	0.009	2	630	4	0.017	3	0.2	2
Whai_5a	Whanganui at Pipiriki	0.6	4	0.01	2	111	3	0.008	2	0.14	2
Whai_6	Whanganui at Te Rewa	0.8	4	0.013	3	56	2	0.007	2	0.0935	2
Whau_1a	Whangaehu u/s Winstone Pulp STP	0.51	4	0.021	4	0.5	1	0.07	4	0.04	1
Whau_1b	Waitangi u/s Waiouru STP	1.55	2	0.02	3	30	1	0.008	2	0.276	3
Whau_1c	Mangaehuehu u/s Rangataua STP	2.8	1	0.016	3	21.1	1	0.005	2	0.0695	1
Whau_1c	Tokiahuru U/s Whangaehu Confluence	0.965	3	0.0075	2	65	2	0.005	2	0.06985	1
Whau_3a	Whangaehu at Kauangaroa	0.15	4	0.033	4	161.5	3	0.016	3	0.1555	2
Whau_3b	Makotuku at SH49a	2.76	1	0.0025	1	131.5	3	0.00725	2	0.1965	2
Whau_3d	Mangawhero at DoC Headquarters	2.8	1	0.0055	2	11	1	0.006	2	0.014	1
Whau_3d	Mangawhero at Pakahi Rd Bridge	1.185	3	0.014	3	146	3	0.0155	3	0.25585	3
Whau_3d	Mangawhero u/s Ohakune STP	1.6	2	0.01	2	111.8	3	0.011	3	0.18	2
Whau_3e	Mangawhero at Raupiu Rd	0.4	4	0.011	3	159.9	3	0.0055	2	0.199	2
Whau_3f	Makotuku U/s Raetihi	1.8	2	0.008	2	192	3	0.0075	2	0.2915	3
Whau_3f	Makotuku u/s Raetihi STP	1.5	3	0.00325	1	366	4	0.0145	3	0.31745	3
Tura_1a	Turakina at Oneils Bridge	0.4	4	0.0195	3	137.5	3	0.0125	3	0.009	1
Tura_1c	Unnamed Tributary of Waipu Str	0.9	4	0.077	4	549.5	4	0.0315	4	0.024	1

Sub-zone	Site	Visual Clarity		Dissolved Reactive Phosphorus		*E. coli*		Ammoniacal Nitrogen		Total oxidised nitrogen	
		Median value	National Quartile	Median value	National Quartile	Median value	National Quartile	Median value	National Quartile	Median value	National Quartile
	upstream Ratana STP		🟥		🟥		🟥		🟥		🟩
Ohau_1a	Ohau at Gladstone Reserve	3.5	1	0.009	2	40	2	0.005	2	0.063	1
Ohau_1b	Ohau at Haines Property	2.6	2	0.0095	2	73	2	0.009	2	0.295	3
Owah_1	Owhanga at Branscombe Bridge	0.5	4	0.0025	1	213.5	3	0.01	2	0.013	1
West_9a	Waikawa at Huritini	0.6	4	0.014	3	336.7	4	0.03	4	0.8775	4
West_9a	Waikawa at Nth Manakau Rd	4.2	1	0.019	3	13	1	0.0025	1	0.057	1
West_9b	Manakau at SH1 Bridge	1.1	3	0.01	2	1200	4	0.012	3	0.184	2
Hoki_1a	Arawhata at Hokio Beach Rd	1.3	3	0.023	4	365	4	0.0325	4	12.547	4
Hoki_1a	Patiki at Kawiu Road	1.8	2	0.027	4	461	4	0.044	4	7.431	4
Hoki_1b	Hokio Stream Lake Outlet at Weir	0.75	4	0.021	4	118.5	3	0.032	4	0.541	3
Akit_1b	Pongaroa u/s Pongaroa STP	0.37	4	0.009	2	325.5	4	0.01	2	0.025	1

Appendix 2: Roygard et al. (2012 *in press*)

New Zealand Journal of Marine and Freshwater Research
Vol. 00, No. 00, Month 2011, 1–23

Taylor & Francis
Taylor & Francis Group

Diffuse contributions dominate over point sources of soluble nutrients in two sub-catchments of the Manawatu River, New Zealand

Jon KF Roygard*, Kate J McArthur and Maree E Clark

Horizons Regional Council, Palmerston North, New Zealand

(Received 20 May 2011; final version received 7 October 2011)

Nitrogen and phosphorus concentrations in the Manawatu River, New Zealand, are among the highest nationally. To target policies to address these nutrient levels effectively, this study sought information on relative contributions of soluble nutrients from point and diffuse (non-point) sources at various river flows and in relation to concentration-based regulatory targets using load calculations. In the upper Manawatu and Mangatainoka sub-catchments of the Manawatu River, measured nutrient loads were 55–154% greater than target nutrient loads. Measured loads were predominately from diffuse sources, which contributed 98% or more of the soluble inorganic nitrogen (SIN) and 84–88% of the dissolved reactive phosphorus (DRP) at all flows. At low flows, point source inputs contributed up to 64% of the DRP in the upper Manawatu sub-catchment. This study suggests policy to manage nutrient enrichment in these areas should target inputs from diffuse sources at all flows, along with management of point sources at low flows.

Keywords: water quality targets; nitrogen; phosphorus; nutrient loads; point source; non-point source; diffuse; river flow; load calculation; nutrient management policy

Introduction

In New Zealand, central government legislation (the Resource Management Act 1991) directs local government agencies, known as regional councils, to manage freshwater resources in their regions. To achieve this, regional council functions include the control of discharges into or onto land, or into water and control of land use for the purposes of maintaining and enhancing water quality. The policy guidance for implementing these controls is set by regional councils through regional policy statements and regional plans (Richmond et al. 2004). New central government legislation, the National Policy Statement for Freshwater Management (NPS 2011), directs regional councils to set water quality limits to provide for freshwater objectives, and that where these objectives are not met, time-bound targets for water quality are to be specified and policy and plans implemented to ensure these are met in the future.

Policy development to achieve these requirements can be informed by an understanding of how current water quality relates to the objectives, limits and targets and the relative contributions of the sources of contamination. This study aims to determine the relative contributions of point and diffuse sources to nutrient levels in relation to regulatory targets and flows in two sub-catchments of the Manawatu catchment. This information was sought by the Manawatu–Wanganui Regional Council as a part of policy development to update the existing Plans into an integrated planning document known as the 'One Plan' a combined regional and coastal policy statement and regional plan.

---

*Corresponding author. Email: jon.roygard@horizons.govt.nz

Management of nutrients in waterways of the Manawatu catchment is primarily to reduce nutrient concentrations to levels that decrease the proliferations of plant and algal material collectively known as periphyton. At nuisance levels, these proliferations adversely affect the ecological, recreational, aesthetic and cultural values of rivers and streams by changing the physicochemical properties of the water, reducing the availability and quality of aquatic habitat and covering the substrate with unsightly algal growths (Biggs 2000a, 2000b). In severe cases, periphyton-induced changes in physicochemical and habitat properties of a river can be lethal to invertebrates and fish (e.g. via lowering dissolved oxygen concentrations; Dean & Richardson 1999). Some forms of soluble nutrient are also managed in the Manawatu, as they can be toxic to freshwater water aquatic species at high concentrations, for example ammonia (Hickey & Vickers 1994; Richardson 1997; Richardson et al. 2001) and nitrate (Hickey & Martin 2009).

There are several mechanisms available to control the proliferation of periphyton. The primary control of maximum periphyton biomass in unshaded rivers is the frequency of flushing flows that reset the growth of periphyton through physical removal and scouring of the river bed (Biggs 1990, 1995, 2000a, 2000b) and this has been proven effective as a management tool (Biggs et al. 2008). River channel shading can also be a useful periphyton control for smaller tributary streams and rivers, slowing growth by reducing light inputs and lowering water temperatures (Davies-Colley & Quinn 1998; Boothroyd et al. 2004; Quinn et al. 2009). However, flow manipulation and shading are impractical for the management of periphyton in large, non flow-regulated channels like the main-stem of the Manawatu River. The primary mechanism for control of periphyton growth in the Manawatu River is limitation of the plant available nutrients, soluble inorganic nitrogen (SIN) and dissolved reactive phosphorus (DRP).

Several studies have determined the need to control both SIN and DRP to manage the growth of periphyton in New Zealand rivers (Biggs 2000a; Wilcock et al. 2007; McDowell & Larned 2008; Roygard & McArthur 2008; Roygard 2009; McArthur et al. 2010). For example, McDowell & Larned (2008) studied nutrient ratios (SIN:DRP) at 1100 regional council water quality sites and determined that 76% of sites were phosphorus limited, 12% nitrogen limited and 12% co-limited. They concluded that the prudent approach to nutrient management was to mitigate both nitrogen and phosphorus inputs. Subsequent studies in the Manawatu catchment found that the limiting nutrient can differ within a sub-catchment on the same day and that nutrient limitation at a particular site can change with time and flow (Roygard & McArthur 2008; Roygard 2009; McArthur et al. 2010). Studies also recommended management of SIN and DRP year round at flows below flood flows in the Manawatu–Wanganui and Hawkes Bay regions of New Zealand (Wilcock et al. 2007). Prior to these studies, the previous regional Plan that managed water quality in the Manawatu catchment, the Manawatu Catchment Water Quality Regional Plan (MCWQRP 1998) managed nutrient enrichment through limits on DRP concentrations at flows below the half the median flow for point sources. The concentration based targets in the One Plan for the two study sub-catchments of the Manawatu catchment discussed in this study were set at 0.444 g SIN/m^3 and 0.010 g DRP/m^3. These targets apply year round at all flows less than the 20th flow exceedance percentile (highest 20% of flows) with flows greater than this level defined as 'flood flows'. The 20th flow exceedance percentile threshold was selected as an approximation of the flushing flows required to remove periphyton (Roygard 2009; Kilroy et al. 2010; McArthur 2010).

Nutrient concentrations in the Manawatu catchment regularly exceed the One Plan targets and ANZECC (2000) trigger values and are ranked amongst the highest in New Zealand when compared with data from the National Rivers Water Quality Network (MfE 2007, 2009; Ballantine & Davies-Colley 2009a; Ballantine et al. 2010a). Nitrogen concentrations increased at all three National Network sites in the Manawatu catchment between 1991 and 2008, whereas phosphorus trends were more variable (Ballantine & Davies-Colley 2009a, 2009b; Ballantine et al. 2010a, 2010b). Overall, nutrient trends indicated degrading water quality at the Manawatu sites between 1991 and 2008 (Ballantine & Davies-Colley 2009a).

Nutrient trends in the Manawatu are consistent with the strong increasing trends in nitrogen and phosphorus reported nationally (Scarsbrook 2006; Ballantine & Davies-Colley; 2009b; Ballantine et al. 2010a, 2010c). Increasing national trends in nutrient concentration were attributed to the expansion and intensification of pastoral agriculture with all studies concluding that environmental gains in terms of reduced point source pollution of waters in New Zealand were being overshadowed by increasing diffuse source pollution (Scarsbrook 2006; Ballantine & Davies-Colley 2009b; Ballantine et al. 2010a, 2010c). These studies are supported by the findings of Elliot et al. (2005), who modelled nationwide loads of total nitrogen (TN) and total phosphorus (TP) from the New Zealand land mass to the sea and showed that 3% of the TN and 1.8% of the TP could be accounted for by known point sources. However, there is little data about the specific relative contributions from different sources of nutrient to rivers and lakes in New Zealand (PCE 2010). This is a critical information gap for policy makers seeking to address nutrient enrichment. The few studies that do exist are primarily for lakes and have focused on total nutrient concentrations rather than soluble nutrients, which are more important in river nutrient management.

Regulatory targets for nutrients are typically expressed as concentrations to limit nuisance plant growth and ensure ammonia and nitrate are not toxic to aquatic life. Management of nutrient concentrations can be informed by determining nutrient loadings that are the nutrient flux (concentration multiplied by the flow) over a period of time. Nutrient concentration outcomes can be achieved by managing the combined loads from point and diffuse sources. For example, point sources are often managed by daily limits on discharge volume, contaminant load or concentration. Diffuse sources are more typically managed over annual time scales using nutrient budgeting tools that estimate losses from farming systems. Relating the annual losses determined by these tools to nutrient loadings and concentrations in waterways requires knowledge of the areas of different land uses and the total nutrient losses from each of these land uses accounting for any nutrient losses and timing delays as the nutrient moves from the area of the land use to waterways (Roygard 2009). Management of losses from farming systems via annual nutrient budgets has been incorporated into regulatory water quality management approaches for lakes in New Zealand (Ledgard et al. 2001; Quinn et al. 2009). These approaches have utilised the OVERSEER™ model that predicts long-term average annual nutrient losses from farming systems (Wheeler et al. 2003, 2006) and is the most commonly used tool to assist farmers to meet voluntary dairy-industry nutrient budgeting requirements and for fertiliser recommendations on sheep, beef and dairy farms (Ledgard et al. 1999; Wheeler et al. 2007). AQ1

A first step to achieve the regulatory target concentrations in rivers is to determine the relative contributions from point and diffuse sources at a range of flows. This is complicated by the regulatory targets applying only at certain flows. To provide answers relevant to the varying mechanisms of contamination (point and diffuse sources) and the management of these, this study sought to develop and apply a calculation framework to two sub-catchments of the Manawatu catchment to determine:

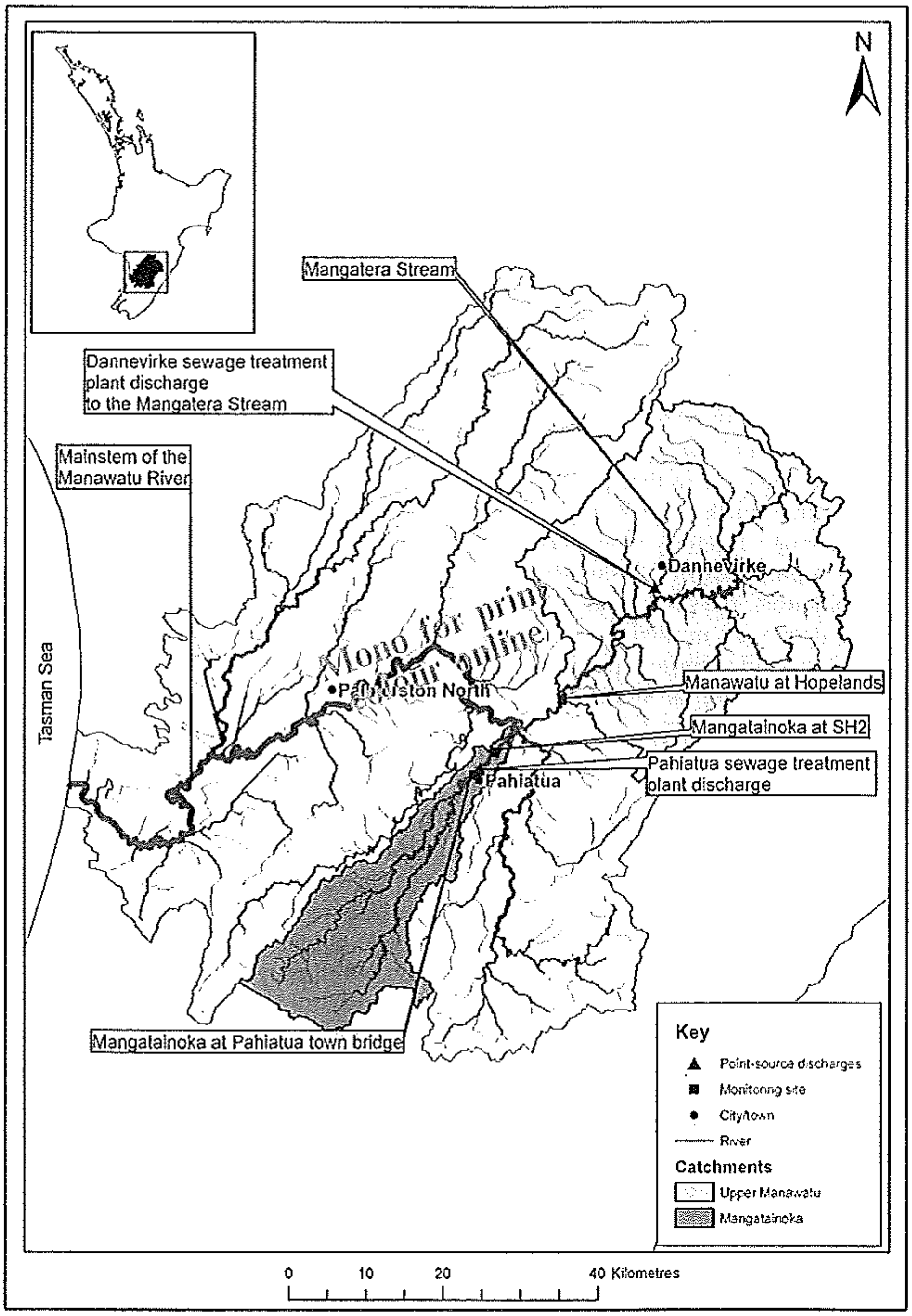


Figure 1 The Manawatu River catchment showing the water quality and flow recording sites of two study catchments: the upper Manawatu and the Mangatainoka.

(1) Regression/rating curve approaches: the regression relationship (or visualised rating curve) between flow and measured nutrient concentration is used to estimate a representative concentration for time between samples, from which a load for the period is calculated.
(2) Averaging approaches: various forms of average concentration and average flow over the same time period are multiplied to calculate loads.
(3) Period-weighted approaches: measured nutrient concentrations are representative of a period of time around which the sample was collected and are multiplied by a measure of flow during that period (e.g. a single monthly nutrient result is multiplied by the average monthly flow). This approach is highly sensitive to sample size.
(4) Ratio estimators: the average load is calculated for days with nutrient concentration observations and adjusted proportionally by a variable that is more frequently measured (i.e. flow).

United States Environmental Protection Agency guidance on calculating pollutant loads identified that regression approaches can be subject to retransformation bias because raw data does not fit a linear regression model (Richards 1998). This can lead to large errors in load calculation (Richards 1998).

Accuracy and precision in load calculation is highly influenced by sampling frequency (Richards 1998; Aulenbach & Hooper 2006). In New Zealand, monthly water quality sampling is the most common sampling frequency with ~~both~~ the National Rivers Water Quality Network (Ballantine et al. 2010c) and most regional councils ~~(including the data for this study)~~. Monthly sampling programmes for simple load estimation yielded estimates, which were biased low by 35% or more, 50% of the time in load simulation studies for some tributaries of the Great Lakes in the United States (Richards & Holloway 1987). These underestimates may in part be related to inaccurate calculation of some of the key components of the annual load. For example, it is not uncommon for more than 80–90% of an annual load to be delivered over 10% of the time during the highest flows (Richards 1998). Richards (1998) noted that the accuracy and precision of loading estimates from averaging approaches increased when stratification was employed and an additional approach, such as a ratio estimator, was used within strata. Aluenbach & Hooper (2006) also advocated a composite method to increase accuracy in loading estimates.

Following the recommendations of Richards (1998) and Aluenbach & Hooper (2006) our study employed a composite load calculation method which incorporated flow stratification (period-weighted) in addition to an averaging approach to nutrient concentration within each of the strata (defined below). Stratification was achieved by defining 10 flow categories based on the percentage of time flow was within a certain range. Ten equal time-based categories (flow decile bins) were defined using flow distribution statistics. By design, these were period weighted, as each flow decile bin represented a range of flows for 10% of the time over the length of the flow record.

The flow-stratified averaging approach potentially reduces bias resulting from monthly sampling, which does not representatively sample the full range of flows (e.g. either very high or very low flows). This stratification also provided a framework to answer the questions of this study as it enabled the relative contributions of nutrient load from point and diffuse sources to be calculated for each flow stratification category to determine how these sources varied at certain flows.

Conversion of concentration-based targets to annual loads

Conversion of concentration-based targets to annual target loads was completed using each 15-min flow observation multiplied by the concentration based targets. These loads were then assigned to the appropriate flow decile bins for each year. Data in each flow decile bin for all years were then summed and divided by the number of years of record to determine the average-annual target load for the period of record.

Exclusion of flood flows

Loads at flows below the 20th exceedance percentile flow were calculated by removing the loads assigned to the two flow decile bins that represented data for the highest two flow decile bins (0–10th and 10th–20th exceedance deciles) from the annual load calculations.

Measured loads

River flow at the time of sampling and concentration of the nutrient sample were multiplied to characterise an instantaneous load (flux). This load was then applied as a representative sample for the flow decile bin within which the flow at the time of sampling fell. These representative samples were used to calculate the averages for the flow decile bins, which were then multiplied by the frequency of occurrence of the flows within the bins (10% of the record, i.e. 36.5 days of the year on average). These totals were then summed to calculate a long-term loading estimate over an annual period.

Relative contributions from point and diffuse sources

Calculations of relative contributions from point and diffuse sources were completed under the conservative assumptions that the point source inputs do not change between the point of discharge and the downstream recording sites, i.e. there is no reduction of soluble nutrients by plant uptake or other processes and no increase in soluble nutrients through transformation of the organic nutrient discharged by the point source. The calculations for diffuse contributions include any changes in soluble nutrient loads through assimilative or transformative mechanisms.

A flow-stratified method was used to calculate load based on river flow data and measurements of nutrient concentrations upstream and downstream of the Dannevirke township sewage treatment plant effluent discharge. Because of an absence of sampling data in the highest two flow decile bins (0–10th and 10th–20th exceedance deciles), concentrations for these bins were estimated using the value for the 20th–30th flow decile bin.

In the absence of ~~reliable~~ data for the ~~effluent discharge rate~~, an alternative ~~to the flow-stratified method~~ was used to determine the point source load in the Mangatainoka catchment. Loads for each flow decile bin were calculated from the average discharge volume and average effluent concentration ($n = 60$). The underlying assumption that flow and concentration (and therefore load) were not correlated requires re-examination when improved data becomes available. Annual diffuse source inputs were determined by subtracting point source loads from the measured load for each flow decile and summing these.

Change in relative contributions with flow

The flow-stratified approach was used to determine relative contributions of point and diffuse sources in each flow decile bin. This was only possible for the upper Manawatu case study where the upstream and downstream monitoring information for the Dannevirke STP discharge was available to determine variation in the point source inputs with flow, providing for the application of the flow-stratified methodology.

Results

Nutrient concentrations compared with water quality targets

Concentrations of soluble nutrient at the Hopelands site regularly exceeded the regulatory targets in all flow categories (Fig. 2). Over all

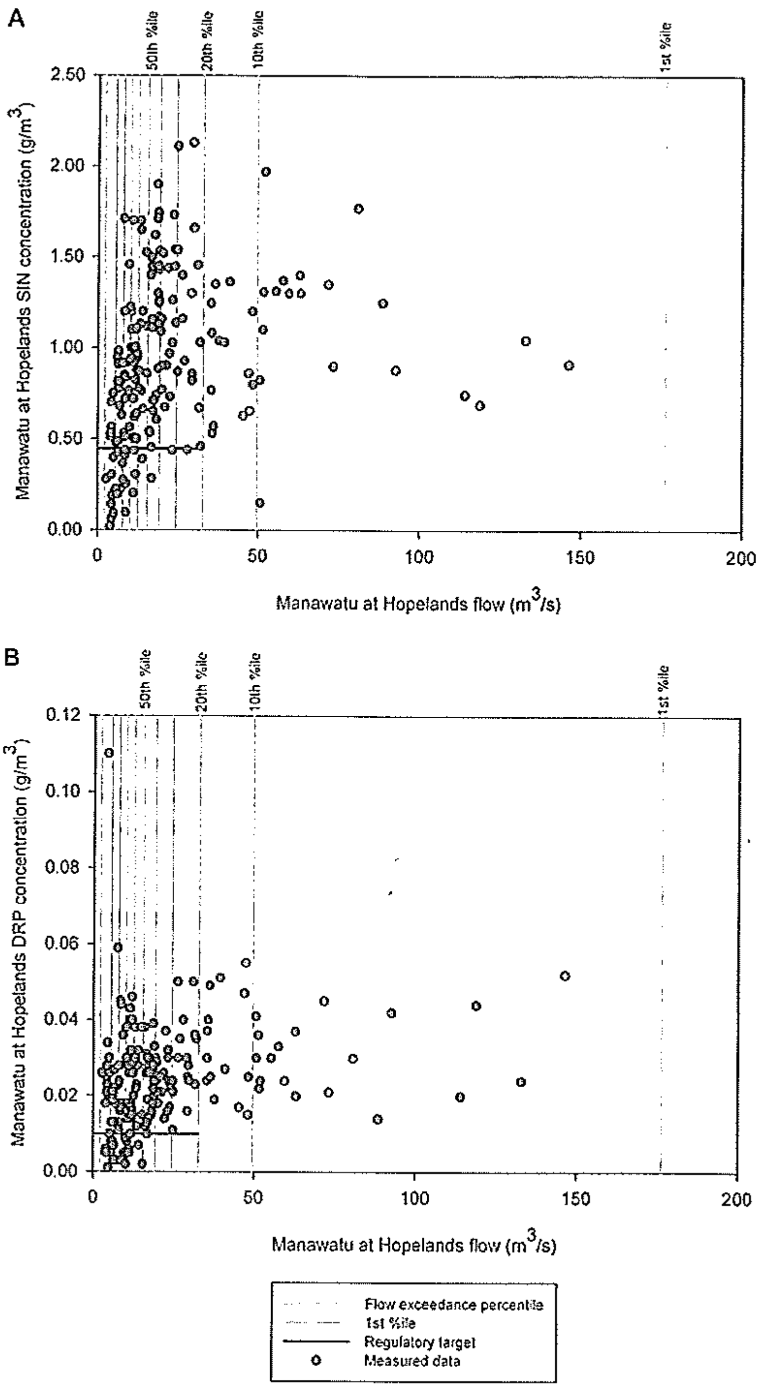


Figure 2 Concentrations of soluble nutrients at the Manawatu at Hopelands site in decile flow bins as defined by exceedance percentiles (%ile) for **A**, soluble inorganic nitrogen (SIN); and **B**, dissolved reactive phosphorus (DRP). Note: the 1st flow exceedance percentile (1st%ile) is shown as a reference to indicate the range of flows, the maximum recorded flow at Hopelands is approximately 1700 m^3/s.

flows, 16% of SIN samples and 13% of DRP complied with (were less than) the regulatory targets. Above median flow, few nutrient samples at Hopelands were within the regulatory target concentrations ~~above median flow~~ (4% for SIN and none for DRP). Below median flow, about a quarter of the samples at Hopelands were within the regulatory limits (28% for SIN, 26% of DRP). In the Mangatera tributary, 47% of SIN samples complied upstream of the discharge and this reduced to 7% downstream (Fig. 3A). However, no samples of DRP complied with the regulatory targets upstream or downstream of the Dannevirke STP discharge (Fig. 3B).

Nutrient targets expressed as loads

The concentration based water quality targets of 0.444 g SIN/m^3 and 0.010 g DRP/m^3 were determined to be equivalent to average-annual target loads of 358 t SIN/year and 8.1 t DRP/year at the Manawatu at Hopelands (Hopelands) site, and 268 t SIN/year and 6.0 t DRP/year the Mangatainoka at SH2 (Mangatainoka) site (Table 1).

When calculated for each individual year, the target loads ranged from 54% lower to 45% higher at the Hopelands site and 40% lower to 31% higher at the Mangatainoka site (Table 1). The variation was entirely explained by variation in flow volumes in each year, as constant concentrations were used in the calculations (i.e. the target concentrations).

Excluding flood flows from target loads

Excluding the flood flows (highest 20% of flows) provided loads for the periods when the nutrient concentration targets in the One Plan apply. Removing flood flows reduced the average-annual target loads by 57% at the Hopelands site and 64% at the Mangatainoka site (Table 2). Again, these calculations used constant concentrations so the reductions are related to variations in annual flow volumes. The inference is that at Hopelands 57% of the total volume flows through the site during 20% of the time, at the highest flows. Similarly, for the Mangatainoka 64% of the flow volume occurs 20% of the time.

Variability in target loads

The variability of the annual loads for each individual year around the average-annual target load reduced when flood flows were excluded. At Hopelands, the standard deviations reduced from 89 (Table 1) to 9.5 t SIN/year (Table 2) and from 2 to 0.2 t DRP/year. Similar reductions occurred at the Mangatainoka site, where standard deviations reduced from 54 (Table 1) to 7 t SIN/year (Table 2) and 1.2 to 0.2 t DRP/year. The reductions show flood flows were primarily responsible for the inter-annual variation around the average target loads.

Measured nutrient loads and comparison with target loads

Measured loads were between 55% and 154% greater than target loads for SIN and DRP at the two sites (Table 3). Measured loads at Hopelands were 745 and 20.6 t SIN and DRP/year being 108% and 154% greater than the target loads (Fig. 4). Mangatainoka measured loads were 603 and 9.3 t SIN and DRP/year being 125% and 55% greater than the target loads (Fig. 4; Table 3).

Excluding flood flows from measured loads

In all cases, measured loads still exceeded target loads after the removal of flood flows (Fig. 4; Table 3). The gap between measured loads and targets increased when flood flows were removed from SIN load calculations (Table 3). The gap increased at Hopelands from 108% to 129% and at Mangatainoka from 125% to 190%. The increased gap is attributable to measured SIN loads having higher concentrations below flood flows than above flood flows. This can be concluded as

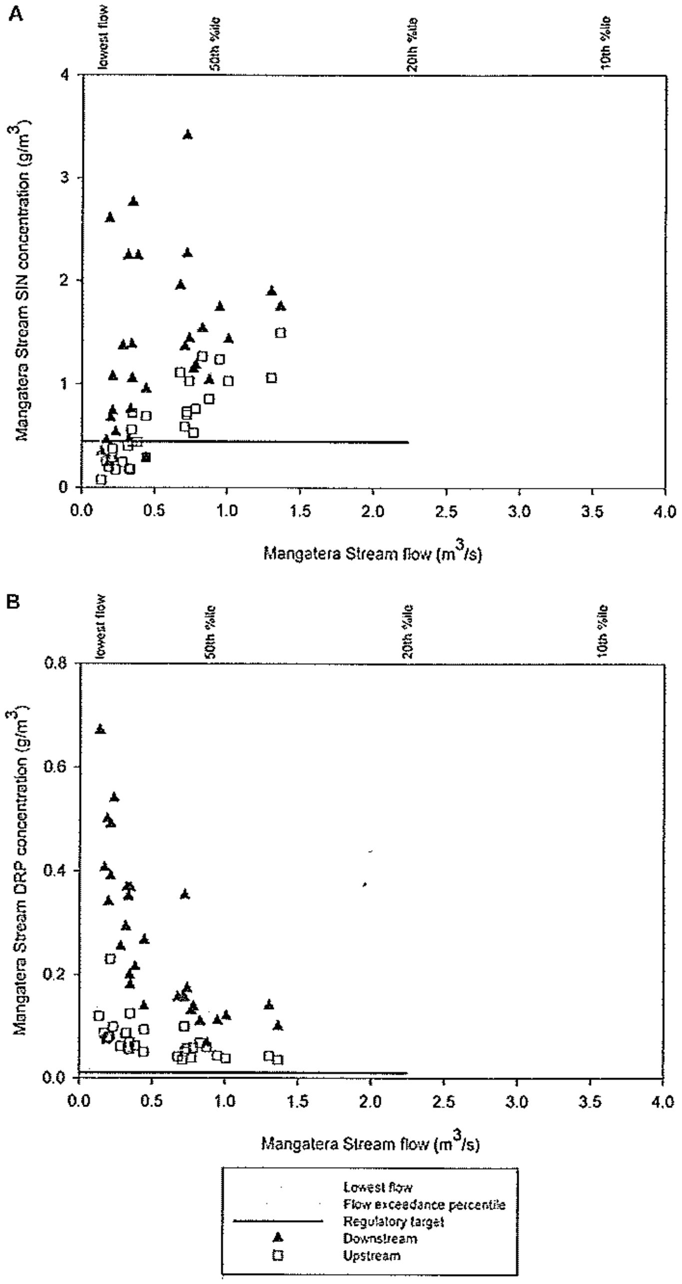


Figure 3 Comparison of soluble nutrient concentrations in the Mangatera Stream upstream (open squares) and downstream (closed triangles) of the Dannevirke Sewage Treatment Plant (STP) discharge for A, soluble inorganic nitrogen (SIN); and B, dissolved reactive phosphorus (DRP). Flow exceedance percentiles (%ile) indicate the range of flows in the Mangatera Stream. The regulatory targets and flows at which these apply are shown for each nutrient by the black solid line.

Table 1 Comparison of annual target loads from individual years with mean target load limits calculated from all years of record for the Manawatu at Hopelands ($n = 15$) and Mangatainoka at SH2 ($n = 12$) monitoring sites between 1989 and 2005.

	Manawatu at Hopelands			Mangatainoka at SH2		
	Annual target load (all flows)			Annual target load (all flows)		
Water year	SIN	DRP	Deviation from mean target load	SIN	DRP	Deviation from mean target load
1989	325	7.3	+9%	–	–	–
1990	390	8.8	−9%	–	–	–
1991	388	8.8	−8%	–	–	–
1992	–	–	–	–	–	–
1993	198	4.5	+45%	185	4.2	+31%
1994	406	9.1	−13%	296	6.7	−10%
1995	425	9.6	−19%	295	6.7	−10%
1996	389	8.8	−9%	311	7.0	−16%
1997	276	6.2	+23%	224	5.1	+16%
1998	283	6.4	+21%	294	6.6	−10%
1999	264	5.9	+26%	209	4.7	+22%
2000	307	6.9	+14%	265	6.0	+1%
2001	396	8.9	−10%	225	5.1	+16%
2002	317	7.1	+11%	233	5.2	+13%
2003	553	12.5	−54%	374	8.4	−40%
2004	453	10.2	−27%	301	6.8	−12%
Mean	358	8.1		268	6.0	
Median	388	8.8		280	6.3	
Max	553	12.5	+45%	374	8.4	+31%
Min	198	4.5	−54%	185	4.2	−40%
SD	89	2.0		54	1.2	

Target load limits were determined from concentration-based nutrient targets in the Proposed One Plan (0.444 g soluble inorganic nitrogen (SIN)/m^3 and 0.010 g dissolved reactive phosphorus (DRP)/m^3) and are expressed in tonnes per year (t/year). Water years were 1 July to 30 June.

Table 2 Comparison of mean annual target loads from all years of record separated by flow decile bin for the Manawatu at Hopelands ($n = 15$) and Mangatainoka at SH2 ($n = 12$) monitoring sites.

	Manawatu at Hopelands				Mangatainoka at SH2			
Flow decile bin	Mean target load (all years SIN)	Mean target load (all years DRP)	Total target load in this flow decile bin (%)	Mean target load in this flow decile bin or less (%)	Mean target load (all years SIN)	Mean target load (all years DRP)	Total target load in this flow decile bin (%)	Mean target load in this flow decile bin or less (%)
0–10th	147	3.3	41	100	123	2.8	46	100
10th–20th	56	1.3	16	59	48	1.1	18	54
20th–30th	39	0.9	11	43	31	0.7	12	36
30th–40th	30	0.7	8	32	22	0.5	8	24
40th–50th	24	0.5	7	24	14	0.3	5	16
50th–60th	19	0.4	5	17	11	0.2	4	11
60th–70th	16	0.4	4	12	8	0.2	3	7
70th–80th	12	0.3	3	8	5	0.1	2	4
80th–90th	9	0.2	3	4	3	0.1	1	2
90th–100th	6	0.1	2	2	2	<0.1	1	1
All flows	358.0	8.1	100		267.6	6.0	100	
Flows less than 20th percentile	155.6	3.51	43.5		96.7	2.2	36	
SD	9.5	0.21			7.4	0.17		

Target loads were determined from concentration-based nutrient targets in the Proposed One Plan (0.444 g soluble inorganic nitrogen (SIN) /m^3 and 0.010 g dissolved reactive phosphorus (DRP) /m^3) and are expressed in tonnes per year (t/year). These standards apply at all flows less than flood flows (<20th flow exceedance percentile for the site).

Table 3 Comparison of the percentage change in measured and target soluble inorganic nitrogen (SIN) and dissolved reactive phosphorus (DRP) loads in tonnes per year (t/year) at all flows and with flood flows excluded for the Manawatu at Hopelands and Mangatainoka at SH2 state of the environment monitoring sites in the upper Manawatu River catchment.

	SIN			DRP		
	Measured load (t/year)	Target load (t/year)	Measured load greater than target load (%)	Measured load (t/year)	Target load (t/year)	Measured load greater than target load (%)
Manawatu at Hopelands						
All flows load	745	358	108%	20.6	8.1	154%
Load excluding flood flows	358	156	129%	8.6	3.5	146%
All flows load greater than load excluding flood flows (%)	108%	129%		140%	131%	
Mangatainoka at SH2						
All flows load	603	268	125%	9.3	6.0	55%
Load excluding flood flows	281	97	190%	2.9	2.2	32%
All flows load greater than load excluding flood flows (%)	115%	176%		221%	173%	

Flood flows = all flows less than the 20th flow exceedance percentile.

target loads were calculated using a constant concentration and both measured loads and target loads have the same changes because of the flow component of the load calculation when flood flows are removed. In contrast to the SIN results, when flood flows were removed from the DRP load calculations the gap between measured loads and targets decreased (Table 3). The gap decreased at Hopelands from 154% to 146% and at Mangatainoka from 55% to 32%. The decreased gap is attributable to measured loads having higher DRP concentrations at flood flows, than below these flows. The difference between SIN and DRP concentrations in relation to flood flows likely reflects differing transport pathways for these two nutrients.

Relative contributions from point and diffuse sources

Diffuse sources contributed 98% or more of SIN and 84–88% of the DRP measured loads in the two study catchments (Fig. 5).

At Hopelands, the flow-stratified load calculation method was applied to nutrient concentration data collected upstream and downstream of the Dannevirke sewage treatment plant discharge. The mean annual point source load from Dannevirke was estimated to be 17.1 t SIN/year (Table 4) and 2.56 t DRP/year (Table 5) at all flows. This equated to 2% of

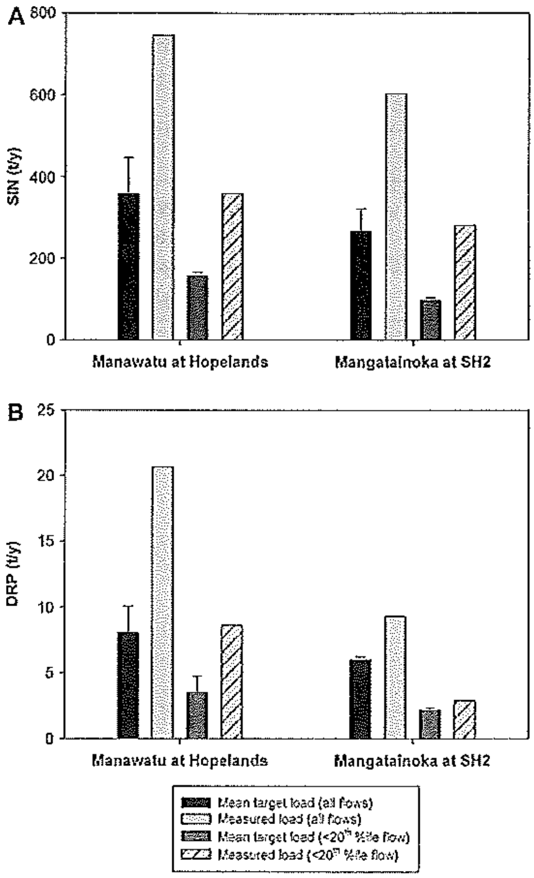


Figure 4 Comparison of regulatory target loads with measured loads in tonnes per year (t/year) at all flows and flows less than the 20th flow exceedance percentile for two study sites in the Manawatu River catchment for **A**, soluble inorganic nitrogen (SIN); and **B**, dissolved reactive phosphorus (DRP). Error bars = + 1SD.

the measured SIN load (Fig. 5A) and 12% of the measured DRP load (Fig. 5B). Subtraction of the point source load from the measured load provided a diffuse source load estimate of 728 t SIN/year and 18.06 t DRP/year at all flows, a proportional contribution of 98% of the measured SIN load (Fig. 5A, Table 4) and 88% of the measured DRP load (Table 5, Fig. 5B).

For the Mangatainoka, the average annual loads for the Pahiatua sewage discharge were estimated to be 3.4 and 1.5 t SIN and DRP per year, respectively, comprising 0.6% of the total measured SIN load (Fig. 5A) and 16% of DRP load (Fig. 5B). Removal of the point source contribution from the measured load provided a diffuse source estimate of 600 t SIN/year and 7.8 t DRP/year, a proportional diffuse source contribution of 99.4% of the measured SIN load (Fig. 5A) and 84% of the measured DRP load (Fig. 5B).

Change in relative contributions with flow

Relative contributions of nutrients calculated for the flow deciles at Hopelands showed point sources contributed between 1% and 10% of measured SIN load (Table 4; column 6) and were between 1% to 14% of the target load

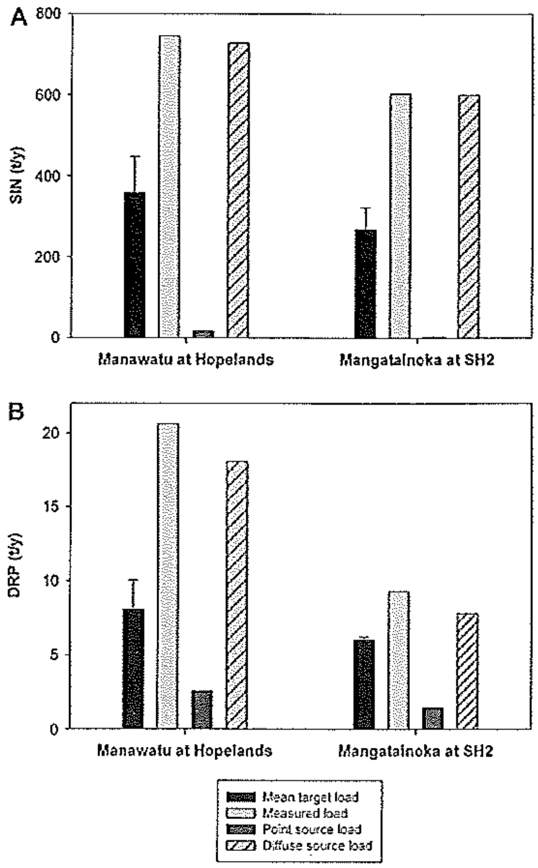


Figure 5 Summary of relative contributions of soluble nutrients from point and diffuse sources for the Manawatu at Hopelands and Mangatainoka at SH2 study sites, in comparison with target and measured loads for **A**, soluble inorganic nitrogen (SIN); and **B**, dissolved reactive phosphorus (DRP). All loads are expressed in tonnes per year (t/year). Error bars = + 1SD.

(Table 4; column 8). The proportion of DRP from point sources ranged from 4% to 64% of the measured load (Table 5; column 6) and from 9% to 170% of target load (Table 5; column 8). Point source contributions were less than the target load for both SIN and DRP in all flow deciles except the lowest flow decile for DRP. This shows management of point source DRP inputs will be important to meet targets at low flows. Diffuse source contributions were greater than the target load for SIN in all flow deciles except the lowest. For DRP, diffuse inputs exceeded the target loads in all flow deciles except the two lowest. This shows management of diffuse sources of SIN and DRP inputs will be important to meet targets during most flow conditions.

Discussion

There are few studies in New Zealand that define the contributions of nutrients to rivers from various sources (PCE 2010). This study has developed and applied a calculation framework to determine the relative contributions of point and diffuse sources to measured nutrient

Table 4 Comparison of relative loads of soluble inorganic nitrogen from point and diffuse sources at different flows calculated in tonnes per year (t/year) for the Manawatu at Hopelands state of environment monitoring site in the upper Manawatu River catchment.

Flow decile bin	Mean target load (t/year)	Mean measured load (t/year)	Mean point source load (t/year)	Mean non-point source load (t/year)	Point source contribution to measured load (%)	Non-point source contribution to measured load (%)	Point source contribution to target (%)	Non-point source contribution to target (%)
0–10th	146.7	267.4	2	265.4	1	99	1	181
10th–20th	55.7	119.2	2	117.2	2	98	4	211
20th–30th	39.3	104.3	2	102.3	2	98	5	260
30th–40th	30.1	76.5	3.5	73	5	95	12	243
40th–50th	24	65.8	1.3	64.5	2	98	5	269
50th–60th	19.4	45.9	1.9	44	4	96	10	226
60th–70th	15.5	30	2.2	27.7	7	93	14	179
70th–80th	12.3	18.9	0.4	18.5	2	98	3	150
80th–90th	9.2	12.4	1.3	11.1	10	90	14	121
90th–100th	5.7	4.7	0.5	4.2	10	90	9	74
All flows	**358**	**745.1**	**17.1**	**728**	**2**	**98**	**5**	**203**
Flows >20th percentile	202.4	386.6	4	382.6	1	99	2	189
Flows <20th percentile	155.6	358.5	13.1	345.3	4	96	8	222
Flows <50th percentile	62.2	111.9	6.3	105.6	6	94	10	170
Flows <80th percentile	14.9	17.1	1.8	15.3	10	90	12	103
		Percentage of total load						
All flows	100%	100%	100%	100%				
Flows >20th percentile	57%	52%	23%	53%				

Table 4 (*Continued*)

Flow decile bin	Mean target load (t/year)	Mean measured load (t/year)	Mean point source load (t/year)	Mean non-point source load (t/year)	Point source contribution to measured load (%)	Non-point source contribution to measured load (%)	Point source contribution to target (%)	Non-point source contribution to target (%)
Flows <20th percentile	44%	48%	77%	47%				
Flows <50th percentile	17%	15%	37%	15%				
Flows <80th percentile	4%	2%	10%	2%				

loads in comparison with the regulatory targets at the flows where these apply. The methodology has provided a way to show how relative contributions from point sources and diffuse sources change at various flows in the two study catchments providing guidance for the setting of targets as required by the NPS (2011). The framework also enables development of regulatory and non-regulatory methods to achieve these targets through management of point and diffuse source nutrients and could easily be applied to other catchments.

Application of the framework has provided specific information on the size of the nutrient issue in the Manawatu Catchment relative to the concentration based regulatory targets of the One Plan. The information provided goes beyond identification of the issue, confirming the level of current over-allocation of the resource relative to nutrient targets. Diffuse contributions were the predominant reason for over-allocation of the resource, providing the majority of nutrient to the study catchments and exceeding the regulatory targets in nearly all flow categories. These findings identify the management of diffuse sources will be key to managing cumulative inputs of nutrients to achieve water quality targets in these sub-catchments. This is consistent with the recommendations of other commentators on this topic (PCE 2004; Hill Young Cooper 2006; Monaghan et al. 2007b; Quinn et al. 2009). For the Manawatu catchment, this finding is significant as the previous catchment plan (MCWQRP 1998) did not address cumulative nutrient effects and only regulated point sources. Management of point sources will continue to be important particularly at low flows where point source contributions were identified as being most significant in these study catchments.

Catchment specific analysis is recommended to determine the overall importance of diffuse and point sources as wastewater discharges remain a key influence on water quality in some areas (McArthur & Clark 2007; Ministry for the Environment 2007). This study has lead

Table 5 Comparison of relative loads of dissolved reactive phosphorus from point and diffuse sources at different flows calculated in tonnes per year (t/year) for the Manawatu at Hopelands state of environment monitoring site in the upper Manawatu River catchment.

Flow decile bin	Mean target load (t/year)	Mean measured load (t/year)	Mean point source load (t/year)	Mean non-point source load (t/year)	Point source contribution to measured load (%)	Non-point source contribution to measured load (%)	Point source contribution to target (%)	Non-point source contribution to target (%)
0–10th	3.30	7.80	0.28	7.52	4	96	9	228
10th–20th	1.25	4.20	0.28	3.92	7	93	22	313
20th–30th	0.89	2.70	0.28	2.42	10	90	32	273
30th–40th	0.68	1.66	0.42	1.24	26	74	62	182
40th–50th	0.54	1.34	0.22	1.12	16	84	40	207
50th–60th	0.44	0.96	0.24	0.72	25	75	54	165
60th–70th	0.35	0.80	0.27	0.53	33	67	76	152
70th–80th	0.28	0.47	0.18	0.29	38	62	65	105
80th–90th	0.21	0.34	0.18	0.17	52	48	86	80
90th–100th	0.13	0.34	0.22	0.12	64	36	170	96
All flows	**8.06**	**20.62**	**2.56**	**18.06**	**12**	**88**	**32**	**224**
Flows >20th percentile	4.56	12.01	0.56	11.44	5	95	12	251
Flows <20th percentile	3.50	8.61	2.00	6.61	23	77	57	189
Flows <50th percentile	1.40	2.92	1.08	1.84	37	63	77	131
Flows <80th percentile	0.34	0.69	0.40	0.29	58	42	118	86
	Percentage of total load							
All flows	100.0%	100.0%	100.0%	100.0%				
Flows >20th percentile	56.5%	58.2%	21.9%	63.4%				

Table 5 (*Continued*)

Flow decile bin	Mean target load (t/year)	Mean measured load (t/year)	Mean point source load (t/year)	Mean non-point source load (t/year)	Point source contribution to measured load (%)	Non-point source contribution to measured load (%)	Point source contribution to target (%)	Non-point source contribution to target (%)
Flows <20th percentile	43.4%	41.8%	78.1%	36.6%				
Flows <50th percentile	17.4%	14.1%	42.1%	10.2%				
Flows <80th percentile	4.2%	3.3%	15.5%	1.6%				

to the Manawatu–Wanganui Regional Council upgrading its monitoring programme to enable catchment specific analyses. The monitoring programme now measures upstream and downstream of the major point sources on the same day as sampling river water quality at state of environment monitoring sites (Roygard 2009). The revised monitoring programme provides information for reporting on the effectiveness of managing point sources and diffuse sources over time. This effectiveness will be able to be reported separately (e.g. has management of diffuse sources been effective?) and as an overall effectiveness (e.g. has the combined management of point and diffuse sources been effective?). This type of analysis will be informative for future policy development.

To achieve water quality targets, regional councils will need to consider the combined inputs from point and diffuse sources. This type of approach is similar to the Total Maximum Daily Load Approach used by the United States Environmental Protection Agency (USEPA 1999), which caps the amount of contaminant in order to meet a regulatory target. The framework provided by the flow-stratified averaging approach can be used on daily and annual timescales to meet the targets within the various flow categories. For example, point sources could be managed to remove the discharge at times where their influence is most significant i.e. at low flows. This could be achieved by using land based treatment or storage of the effluent at these times. However, this study shows that overall it is management of diffuse sources that is more important to achieve water quality targets in these study catchments.

Reducing nutrient inputs from diffuse sources is not as simple as for point sources and requires consideration of the mechanisms by which nutrients reach waterways, such as run-off during rainfall events, leaching from the root zone of saturated soils and direct inputs (Monaghan et al. 2007a). These mechanisms occur over all flow categories and may differ in their relative contribution as flows increase or decrease. If the outcome sought is reduced diffuse source inputs at low flows, consideration should be given to methods that reduce direct diffuse source inputs such as stock access to water (Quinn et al. 2009) and poorly managed farm dairy effluent (Houlbrooke et al. 2004, 2008), including leakage from effluent ponds (Wilcock et al. 1999; Roygard 2009). Direct diffuse source inputs are obvious mechanisms for nutrient transport; another major pathway is via groundwater. Groundwater can be the primary source of water to rivers during low flows and may provide a considerable proportion of the diffuse nutrient input to the catchment at these flows. These inputs cannot be controlled at particular flows, as there are time lags between diffuse source nutrient losses and this nutrient reaching waterways, which may be in the order of decades in some cases (Hamilton 2005). Reductions in diffuse contributions for particular or all flow categories will therefore require management of year round nutrient losses from the landscape.

Conclusion

Application of the flow-stratified calculation framework determined that diffuse inputs were the predominant sources of nutrient load in the study catchments, but at low flows, discharges were important contributors of phosphorus. The framework enables determination of the reductions required from point and diffuse sources at various flows, in order to meet regulatory targets. When considering reductions in diffuse source contributions in any flow category, entire farm losses need to be managed to account for mechanisms of nutrient transport from the farm to the river. The framework linked management of concentration-based standards to annual target loads, providing targets relevant to management of diffuse sources on an annual basis. High annual variability in the annual target loads for these river systems was found and this was determined to be predominately driven by the frequency of flood flows in any given year. This variability should be considered when setting annual load targets and assessing the effectiveness of actions to achieve these.

Acknowledgements

We would like to acknowledge the staff of the Manawatu–Wanganui Regional Council who assisted with this study. The comments of Raelene Mercer, Alec Mackay, Helen Marr and Rob Davies-Colley significantly improved earlier versions of this manuscript.

References

Anzecc & Armcanz 2000. National water quality management strategy: Australian and New Zealand guidelines for fresh and marine water quality. Canberra, Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand.

Aulenbach BT, Hooper RP 2006. The composite method: an improved method for stream-water solute load estimation. Hydrological Processes 20: 3029–3047.

Ballantine DJ, Davies-Colley RJ 2009a. Water quality state and trends in the Horizons Region. Prepared for the Horizons Regional Council. NIWA Client Report No. HAM2009-090. Horizons Regional Council Report No. 2009/EXT/1025, ISBN 978-1-877516-57-3.

Ballantine DJ, Davies-Colley RJ 2009b. Water quality at National water quality network sites for 1989–2007. Prepared for the Ministry for the Environment. NIWA Client Report HAM2009-026. http://www.mfe.govt.nz/publications/water/water-quality-trends-1989-2007/final-report-water-quality-trends-NRWQN.pdf [accessed 29 July 2011].

Ballantine DJ, Davies-Colley RJ, Thompson M, Gray T 2010a. The expanding footprint of pastoral agriculture: trends in national river water quality. In: Currie LD ed, Christensen CL. Occasional report No. 23. Palmerston North, Massey University, Fertiliser and Lime Research Centre. Pp. 15–24.

Ballantine DJ, Davies-Colley RJ, McArthur K 2010b. The footprint of pastoral agriculture: river water quality in the Horizons Region (2001–2008). In: Currie LD, Christensen CL eds. Farming's future: minimising footprints and maximizing margins. Occasional Report No. 23. Palmerston

North, Massey University, Fertiliser and Lime Research Centre. Pp. 110–118.

Ballantine DJ, Booker, D, Unwin M, Snelder T 2010c. Analysis of national river water quality data for the period 1998–2007. Report prepared by the National Institute of Water and Atmospheric Research for the Ministry for the Environment, Wellington. http://www.mfe.govt.nz/publications/water/analysis-of-national-river-water-quality-data-1998-2007/analysis-of-river-water-quality-final.pdf [accessed 19 April 2011]

Biggs BJF 1990. Periphyton communities and their environments in New Zealand Rivers. New Zealand Journal of Marine and Freshwater Research 24: 367–386.

Biggs BJF 1995. The contribution of disturbance, catchment geology and landuse to the habitat template of periphyton in stream ecosystems. Freshwater Biology 33: 419–438.

Biggs BJF 2000a. New Zealand periphyton guidelines: detecting, monitoring and managing enrichment of streams. Prepared for the Ministry for the Environment by the National Institute for Water and Atmospheric Research (NIWA). Wellington, Ministry for the Environment.

Biggs BJF 2000b. Eutrophication of streams and rivers: dissolved nutrient-chlorophyll relationships for benthic algae. Journal of the North American Benthological Society 19: 17–31.

Biggs BJF, Ibbitt RP, Jowett IG 2008. Determination of flow regimes for protection of in-river values in New Zealand: an overview. Journal of Ecohydrology and Hydrobiology 8: 17–29.

Boothroyd IJ, Quinn JM, Costley KJ, Langer ER, Steward G 2004. Riparian buffers mitigate effects of pine plantation logging on New Zealand streams: 1. Riparian vegetation structure, stream geomorphology and periphyton. Forest Ecology and Management 194: 199–213.

Clark M, Roygard J 2008. Land use and land use capability in the Manawatu–Wanganui Region: internal technical report to support policy development. Horizons Regional Council Internal Report No. 2008/INT/616, Palmerston North.

Clark M 2010. A new methodology for determining the impact of point-source discharges on freshwater. A thesis prepared in partial fulfilment of Master in Applied Science. Palmerston North, Massey University.

Davies-Colley RJ, Quinn JM 1998. Stream lighting in five regions of North Island, New Zealand: control by channel size and riparian vegetation. New Zealand Journal of Marine and Freshwater Research 32: 591–605.

Dean TL, Richardson J 1999. Response of seven species of native freshwater fish and a shrimp to low levels of dissolved oxygen. New Zealand Journal of Marine and Freshwater Research 33: 99–106.

Elliott AH, Alexander RB, Schwarz GE, Shankar U, Sukias JPS, McBride GB 2005. Estimation of nutrient sources and transport for New Zealand using the hybrid mechanistic-statistical model SPARROW. Journal of Hydrology (NZ) 44: 127.

Ferguson RI 1986. River loads underestimated by rating curves. Water Resources Research 22: 74–76.

Ferguson RI 1987. Accuracy and precision of methods for estimating river loads. Earth Surface Processes and Landforms 12: 95–104.

Guo Y, Markus M, Dmeissie M 2002. Uncertainty of nitrate-N load computations for agricultural watershed. Water Resources Research 38: 1185–1197.

Hamilton D 2005. Land use impacts on nutrient export in the Central Volcanic Plateau, North Island. New Zealand Journal of Forestry 49: 27–31.

Hickey CW, Martin ML 2009. A review of nitrate toxicity to freshwater aquatic species. Prepared for Environment Canterbury By NIWA. Environment Canterbury Report No. R09/57. ISBN 978-1-86937-997-1.

Hickey CW, Vickers ML 1994. Toxicity of ammonia to nine native New Zealand freshwater invertebrate species. Archives of Environmental Contamination and Toxicology 26: 87–93.

Hill Young Cooper Ltd 2006. Improving the management of freshwater resources: issues and opportunities. Prepared for the Ministry for the Environment: Wellington, New Zealand. http://www.mfe.govt.nz/publications/water/improving-management-freshwater-resources/improving-management-freshwater-resources.pdf [accessed 14 April 2011]

Houlbrooke DJ, Horne DJ, Hedley MJ, Hanly JA, Scotter DR 2004. Minimising surface water pollution resulting from farm-dairy effluent application to mole-pipe drained soils 1. An evaluation of the deferred irrigation system for sustainable land treatment in the Manawatu. New Zealand Journal of Agricultural Research 47: 405–415.

Houlbrooke DJ, Horne DJ, Hedley MJ, Snow VO, Hanly JA 2008. Land application of farm dairy effluent to a mole and pipe drained soil: implications for nutrient enrichment of winter-spring drainage. Australian Journal of Soil Research 46: 45–52.

Kilroy C, Nicholson C, McArthur KJ, Chakraborty M, Roygard J 2010. Review of Horizons Regional Council periphyton monitoring programme 2009. NIWA Client Report CHC2010-0 prepared in conjunction with Horizons Regional Council. Horizons Regional Council Report No. 2010/EXT/1124, ISBN 978-1-877556-49-4.

Ledgard SF, Thorrold BS, Petch RA, Young J 2001. Use of OVERSEER™ as a tool to identify management strategies for reducing nitrate leaching from farms around Lake Taupo. In: Currie LD, Loganathan P. Precision tools for improving land management. Occasional Report No. 14. Palmerston North, Massey University, Fertiliser and Lime Research Centre. Pp. 187–194

McArthur K, Clark M 2007. Nitrogen and phosphorus loads to rivers in the Manawatu–Wanganui Region: an analysis of low flow state. Horizons Regional Council Report No: 2007/EXT/793. ISBN 1-877413-81-X.

McArthur KJ 2010. Supplementary evidence to the section 42A report of Mrs Kathryn Jane McArthur on behalf of Horizons Regional Council. http://www.horizons.govt.nz/assets/horizons/Images/One%20Plan%20officers%20reports/Mrs%20Kathryn%20Jane%20McArthur.pdf [accessed 19 May 2011]

McArthur KJ, Roygard J, Clark M 2010. Understanding variations in the limiting nitrogen and phosphorus status of rivers in the Manawatu–Wanganui Region, New Zealand. New Zealand Journal of Hydrology 49: 15–33.

McDowell RW, Larned ST 2008. Surface water quality and nutrients: what should the focus be? In: Carbon and nutrient management in agriculture. In: Currie LD, Yates LJ eds. Occasional Report No. 21. Palmerston North, Massey University, Fertiliser and Lime Research Centre. Pp. 448–453.

MCWQRP 1998. Manawatu Catchment Water Quality Regional Plan. http://www.horizons.govt.nz/assets/publications/managing-our-environment/plans-and-strategies/Manawatu-catchment-Water-quality-regional-plan.pdf [accessed May 2011].

Ministry for the Environment (MfE) 2007. Environment New Zealand. Published by the Ministry for the Environment, Wellington. MfE Report No. ME847.

Ministry for the Environment (MfE) 2009. Nutrient river water quality league table: nitrate, total nitrogen, dissolved reactive phosphorus, total phosphorus. http://www.mfe.govt.nz/environmental-reporting/freshwater/river/league-table/nutrient-league.html [accessed 1 April 2011].

Monaghan RM, Hedley MJ, Di HJ, McDowell RW, Cameron KC, Ledgard SF 2007a. Nutrient management in New Zealand pastures–recent developments and future issues. New Zealand Journal of Agricultural Research 50: 181–201.

Monaghan RM, Wilcock RJ, Smith LC, Tikkisetty B, Thorrold BS, Costall D 2007b. Linkages between land management activities and water quality in an intensively farmed catchment in southern New Zealand. Agriculture Ecosystems and Environment 118: 211–222.

National Policy Statement for Freshwater Management (NPS) 2011. http://NewZealand.govt.nz [accessed 12 May 2011].

Parliamentary Commissioner for the Environment (PCE) 2004. Growing for good: intensive farming sustainability and New Zealand's environment. Wellington: Parliamentary Commissioner for the Environment. ISBN 1-877274-51-8.

Parliamentary Commissioner for the Environment (PCE) 2010. How clean is New Zealand? Measuring and reporting on the health of our environment. Wellington. ISBN 978-1-977274-10-7.

Quinn JM, Wilcock RJ, Monaghan RM, McDowell RW, Journeaux PR 2009. Grassland farming and water quality in New Zealand. Irish Journal of Agri-environmental Research 7: 69–88.

Resource Management Act (RMA) 1991. New Zealand Government, Wellington.

Richards RP 1998. Estimation of pollutant loads in rivers and streams: a guidance document for NPS programs. Project report prepared under Grant X998397-01-0, US Environmental Protection Agency, Region VIII, Denver, Colorado.

Richards RP, Holloway J 1987. Monte Carlo studies of sampling strategies for estimating tributary loads. Water Resources Research 23: 1939–1948.

Richardson J 1997. Acute ammonia toxicity for eight New Zealand indigenous freshwater species. New Zealand Journal of Marine and Freshwater Research 31: 185–190.

Richardson J, Williams EK, Hickey CW 2001. Avoidance behaviour of freshwater fish and shrimp exposed to ammonia and low dissolved oxygen separately and in combination. New Zealand Journal of Freshwater and Marine Research 25: 625–633.

Richmond C, Froude V, Fenemor A, Zuur B 2004. Management and conservation of natural waters. In: Harding J, Mosley P, Pearson C, Sorrell B eds. Freshwaters of New Zealand.

Christchurch, New Zealand Hydrological Society and New Zealand Limnological Society.

Rhode M, Suhr U 2007. Uncertainties in selected river water quality data. Hydrology and Earth System Sciences 11: 863–874.

Roygard J, McArthur K 2008. A framework for managing non-point source and point source nutrient contributions to water quality. Technical report to support policy development. Horizons Regional Council Report No. 2008/EXT/792. ISBN 978-1-877468-39-1.

Roygard J 2009. Section 42A Report of Dr Jonathan Kelvin Fletcher Roygard on behalf of Horizons Regional Council. http://www.horizons.govt.nz/assets/horizons/Images/One%20Plan%20Officers%20reports%20water%20hearing/Dr%20Jonathon%20Kelvin%20Fletcher%20Roygard.pdf [accessed 1 May 2011].

Scarsbrook M 2006. State and trends in the national river water quality network. Report published by Ministry for the Environment. ISBN 0-478-30109-X. MfE report number 778. http://www.mfe.govt.nz [accessed 1 June 2007].

USEPA 1999. Protocols for developing nutrient TMDLs. First Edition. United States Environmental Protection Agency, Office of Water, Washington DC. EPA 841-B-99-007.

Wheeler DM, Ledgard SF, De Klein CAM, Monaghan RM, Carey PL, McDowell RW, Johns KL 2003. OVERSEER® nutrient budgets—moving towards on-farm resource accounting. Proceedings of the New Zealand Grassland Association 65: 191–194.

Wheeler DM, Ledgard SF, Monaghan RM, McDowell RW de Klein CAM 2006. OVERSEER® nutrient budget model: what it is, what it does. In: Currie LD, Hanly JA eds. Implementing sustainable nutrient management strategies in agriculture. Occasional Report No. 19. Palmerston North, Massey University, Fertiliser and Lime Research Centre. Pp. 231–236.

Wheeler DM, Ledgard SF, Monaghan RM 2007. Role of the OVERSEER® nutrient budget model in nutrient management plans. In: Currie LD, Yates L eds. Designing sustainable farms, critical aspects of soil and water management. Occasional Report No. 20. Palmerston North, Massey University, Fertiliser and Lime Research Centre. Pp. 53–58.

Wilcock RJ, Nagels JW, Rodda HJE, O'Connor MB, Thorrold BS, Barnett JW 1999. Water quality of a lowland stream in a New Zealand dairy farming catchment. New Zealand Journal of Marine and Freshwater Research 33: 683–696.

Wilcock B, Biggs B, Death R, Hickey C, Larned S, Quinn J 2007. Limiting nutrients for controlling undesirable periphyton growth. Prepared for Horizons Regional Council. NIWA Client Report No. 00HAM2007-006. Horizons Regional Council Report No. 2007/EXT/788. ISBN 978-1-877556-82-1.

Appendix 5: Nutrient budget summary

1. Loss rates from dairy and cropping activities has been able to be estimated from nutrient budgets for dairy farms provided to Horizons as a part of regulatory processes or on a voluntary basis. All of the budgets used in this analysis have been provided to Horizons Consents or Compliance teams. Out of a total of 950 dairy farms, 325 farms (34%) have provided nutrient budgets.

2. Of these, 48 farms have cropping blocks and some nutrient budgets include multiple cropping blocks. The cropping block information provided by these budgets shows an average direct leaching rate of 50.5 kg N/ha/year which translates to 25.25 kg SIN/ha/year in-river.

3. The table and graphs below provide a summary of the information for whole nutrient losses for the target catchment areas analysed in this study and for the whole region.

Site	Catchment Area (ha)	Area in Dairy (ha)	Proportion of catchment in Dairy	Number of farms	Number of budgets with N loss identified	% of farms in zone with budgets	Ave N loss kg/ha/year
Manawatu Catchment	589,876.0	102,067.8	17.3%	663	246	37.10%	23.42
Manawatu at Weber Rd	68,841.8	5,470.4	7.9%	39	14	35.90%	26.85
Manawatu at Hopelands	124,345.4	20,138.8	16.2%	147	47	31.97%	26.09
Tiraumea at Ngaturi	74,217.4	1,260.3	1.7%	7	5	71.43%	28.60
Mangatainoka at Putara	1,866.9	0.0	0.0				
Mangatainoka at Larsons	6,807.8	267.8	3.9%				
Makakahi at Hamua	16,537.0	5,010.3	30.3%	34	9	26.47%	24.11
Mangatainoka at SH2	42,808.5	12,883.2	30.1%	90	25	27.78%	24.71
Mangahao at Ballance	27,736.1	2,579.1	9.3%	13	4	30.77%	34.75
Manawatu at upper Gorge	319,329.6	48,376.7	15.1%	333	120	36.04%	25.29
Waikawa Catchment	7,988.3	1,883.1	23.6%	7	1	14.29%	16.00
Waikawa at Nth Manakau	2,980.8	170.4	5.7%				
Manakau at SH1	1,480.4	15.24	1.0%				
Rangitikei catchment	394,811.3	16,549.6	4.2%	112	46	41.07%	21.82
Rangitikei at Mangaweka	268,367.4	1,014.9	0.4%	1	0	0%	
Rangitikei at Onepuhi	327,504.0	3,335.5	1.0%	17	8	47.06%	26.38
Rangitikei at McKelvies	388,815.9	14,940.0	3.8%	107	45	42.06%	21.95

Appendix 4: McArthur et al. (2010)

UNDERSTANDING THE VARIATION IN LIMITING NUTRIENT STATUS OF RIVERS IN THE HORIZONS REGION

Kate McArthur[1], Jon Roygard[1] and Maree Clark[1]

[1] *Horizons Regional Council, Private Bag 11025, Palmerston North 4442*

Abstract

Nitrogen (N) and phosphorus (P) enrichment of waterways can have adverse effects on ecological, aesthetic and recreational values due to growths of nuisance algae and other organisms, collectively known as periphyton. In the past, P was commonly thought to be 'the limiting nutrient' for periphyton growth in many of the Region's Rivers. Management of the Manawatu River in particular relied on reducing P inputs at low flows to avoid nuisance periphyton growth.

Long-term State of the Environment (SOE) N & P data were analysed against river flow for a number of sites in the Region's river catchments. This paper presents the results from this analysis for the Manawatu and Rangitikei catchments.

Variation in the limiting nutrient status was found between a number of sites in the Manawatu catchment and this variation was highly influenced by flow. Specific low flow investigations of water quality in two catchments found large spatial variation in limiting nutrient status at a number of sites on the same day, within the same sub-catchment.

More analysis of the variation in limiting nutrient status with flow, geology, land use and periphyton community composition is planned so the complex relationship between these variables is better understood.

The One Plan proposes management of both N and P at all flows less than floods. As we learn more about the interactions between nutrient concentration, flow and periphyton in impacted river catchments, it becomes clear that the best approach is a catchment-specific framework, based on the combined management of N and P.

Introduction

Like all plants, periphyton (the community of algal, fungal, bacterial and cyanobacterial organisms that grow within rivers and streams) needs space, light and nutrients in order to grow on the bed of a river or stream. N and P in waterways need to be in a soluble and inorganic form in order to be bioavailable for uptake by periphyton.

High concentrations of soluble N and P are found in many waterways throughout New Zealand (Scarsbrook, 2006) as a result of either direct (point source) discharges of waste, or from diffuse (non-point source) run off and leaching from the catchment land use. The Manawatu River catchment in the Manawatu-Wanganui Region is subject to considerable point and non-point source nutrient enrichment. The Rangitikei River catchment is also affected by enrichment, but to a lesser extent.

High periphyton growth negatively affects the ecological and recreational values of waterways (Biggs, 2000). The Manawatu and Rangitikei River catchments have both been subject to either considerable growths of potentially toxic cyanobacterial growths (Manawatu) or large unsightly growths of green filamentous algae (Rangitikei) in recent years. Since 2006, anecdotal observations of increasing periphyton growth in these catchments have highlighted a growing awareness of the effects on aesthetic and recreational values.

The theory of nutrient limitation of plant growth comes from the application of the Redfield Ratio of 1:16 P to N (or 1:7 by weight) for optimal aquatic algal growth (Redfield et al., 1963). The assumption being that if there is more than 16 moles of N present for every mole of P then growth is likely to be P limited and conversely if there are less than 16 moles of N for every mole of P then growth is likely to be N limited. This theory was applied to the management of the Manawatu River catchment in the late 1990's where the management focus was on reducing P below concentrations required for periphyton proliferation and inducing a P limited system.

The nutrient limitation of a river system is often expressed as the ratio of P to N, as discussed above. Examination of nutrient ratios to determine limiting status was used by McDowell and Larned (2008) in their study of national patterns in nutrient limitation. However, the actual concentration of nutrients is also of particular interest as this is the actual state of nutrient condition experienced and influenced by aquatic communities such as periphyton. In this study the actual concentration of nutrients has been used for all analysis to determine potential nutrient limitation status.

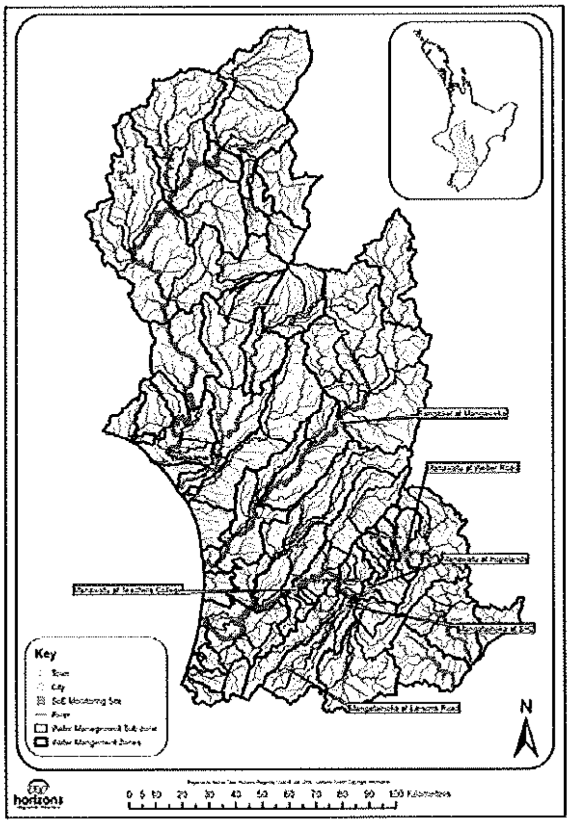
A nutrient diffusing substrate study was undertaken in the Rangitikei River catchment in recent years (Death et al., 2007) to determine whether assumptions about the Rangitikei River being 'N limited' held true. Nutrient diffusing substrates are *in situ* experimental plots containing different levels of N and P which diffuse through a medium placed on the river bed and left to grow periphyton over a controlled period of time. This method is considered to be the most conclusive way of determining the limiting nutrient status of a river (Biggs, 2000). However, the results are only a snapshot of the limiting nutrient condition at the time of the experiment and may be confounded by the stable flows at which the experiment is possible and by the species of periphyton that are able to colonise the artificial substrates. Some of the sites surveyed by Death et al. (2007) using this method showed results indicative of N limitation at the time of the experiment. Roygard and Carlyon (2004) also found results indicative of nitrogen limitation in their basic water quality assessment of the Rangitikei catchment.

The Proposed One Plan, Manawatu-Wanganui Regional Council's second generation combined Regional Plan and Policy Statements will eventually supersede the Manawatu Catchment Water Quality plan. Technical and expert advice received during the development of nutrient standards for the One Plan highlighted the need to manage both N and P because nutrient limitation could not be relied upon to reduce periphyton growth under the wide range of environmental conditions in the rivers of the Region (Wilcock et al., 2007).

Consequently, through the objectives and policies of the One Plan, water quality standards have been proposed for both N and P in all waterways of the Region for the purposes of maintaining Ecosystem, Recreational and Cultural values of water.

Methods

Water quality data for the box and whisker plots below was collated from monthly state of the environment water quality monitoring between March 2007 and March 2008 at five sites in the Manawatu River catchment. Data for the scatter plots was also collated from monthly monitoring between 1989 and 2008 at three key sites in the upper Manawatu River catchment and one site in the middle Rangitikei River catchment (Map 1).



Map 1: Map of sites in the Manawatu-Wanganui Region used in the nutrient limitation investigation.

Concentrations of ammonia, nitrite, or nitrate nitrogen or ammonia and total oxidised nitrogen were summed to determine the soluble inorganic nitrogen concentration for each sample. Raw dissolved reactive phosphorus was plotted against the summed soluble inorganic nitrogen concentrations. Any values below the level of analytical detection had the 'less than' sign removed and the datum halved, as per the recommendations of Scarsbrook and McBride (2007).

Flow at the time of sampling was determined from continuous hydrometric monitoring stations. At all sites except the Mangatainoka at State Highway 2 the water quality samples were collected from the same location as the flow recorder. For the Mangatainoka at State Highway 2 site flow from the Mangatainoka at Pahiatua Town Bridge site approximately 5 km upstream was used. Statistics for flow exceedence percentiles at each site were determined from Henderson and Diettrich (2007).

Results and Discussion

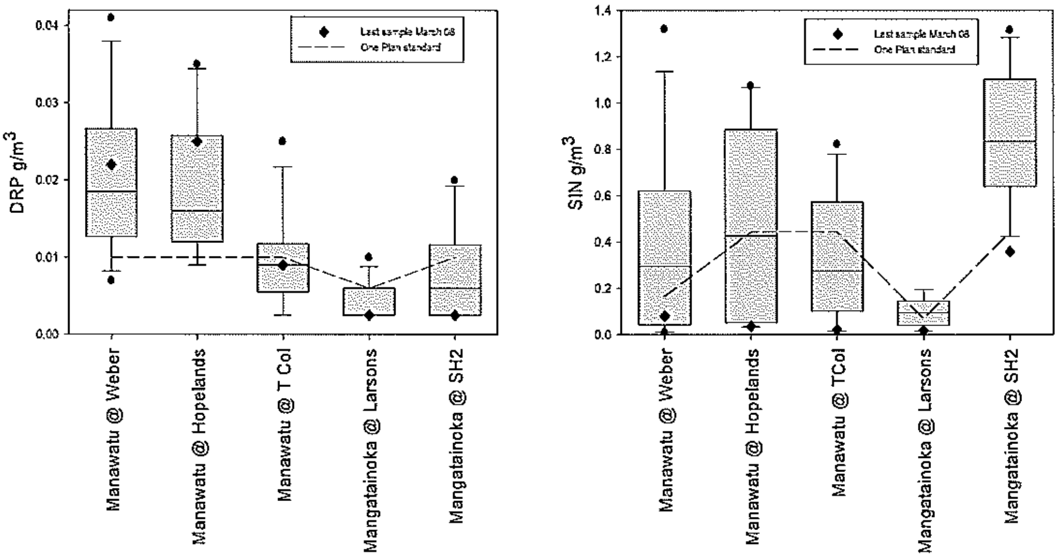
The 2007/2008 summer was unusually dry for most of the central North Island. The upper Manawatu catchment, particularly the Mangatainoka River was at record low flows from January to April and flow restrictions were in place for most of the Region's irrigation takes.

In the Manawatu catchment upstream of the Hopelands monitoring site, where P 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 1a). These results were relatively unexpected, given the assumption that there are few mechanisms for P to reach waterways during dry conditions.

SIN results for the same sample period were extremely low (below the level of detection) at all three Manawatu mainstem sites (Figure 1b). These findings suggest there were two key processes that may have been at work during this low flow event in the upper Manawatu: 1) DRP was potentially being released from bed sediments and becoming bioavailabile during low flow conditions (B. Wilcock *pers. comm.*; Parfitt *et al.*, 2007), and 2) periphyton growth was potentially *N* limited, unlike previous assumptions of general P limitation.

In the Mangatainoka catchment, the results were somewhat the opposite of the three Manawatu mainstem sites. N in the Mangatainoka River commonly reaches high concentrations at flows less than half median (McArthur & Clark, 2007). During March 2008, concentrations of both DRP (Figure 1a) and SINN (Figure 1b) at the Mangatainoka at Larsons site (upper Mangatainoka catchment) were below the level of detection. Although the N concentration at the downstream Mangatainoka at SH2 site (lower catchment) was not 'extremely low' when compared to the Manawatu mainstem sites, it was still below the 10th percentile of the SIN results for the preceding twelve months.

These results suggest that any DRP entering the water from the Pahiatua Sewage Treatment Plant upstream of the SH2 site was being utilised by periphyton. These results also suggest that at the same time the upper Manawatu River was N limited, the Mangatainoka River was P limited in the middle to lower reaches (near the SH2 site).



a) b)

Figure 1: **a)** Box and whisker plot of DRP and **b)** SIN concentrations at five monitoring sites in the upper Manawatu and Mangatainoka River catchments between March 2007 and March 2008 (n = 12). Central bar denotes median, box denotes inter-quartile range and whiskers are 10th and 90th percentiles.

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 analysis of the March 2008 data. The potential for nutrient limitation was examined by applying the nutrient standards for controlling periphyton growth recommended in Ausseil & Clark (2007) and the Proposed One Plan to all SIN and DRP data collected since 1989 at the Weber Road and Hopelands monitoring sites, and since 1993 at the Mangatainoka at SH2 site.

When the data for all flows was examined for the Manawatu at Weber Rd (Figure 2) and Hopelands sites (Figure 3) it became clear that there was no 'average' limiting nutrient status at either site. Observations were collected that were either P or N limited. This relationship may have been influenced by the flow at the time of sampling so to better understand the influence of flow on P and N limitation, the results for the Manawatu at Hopelands site were plotted according to four flow categories (Figure 4).

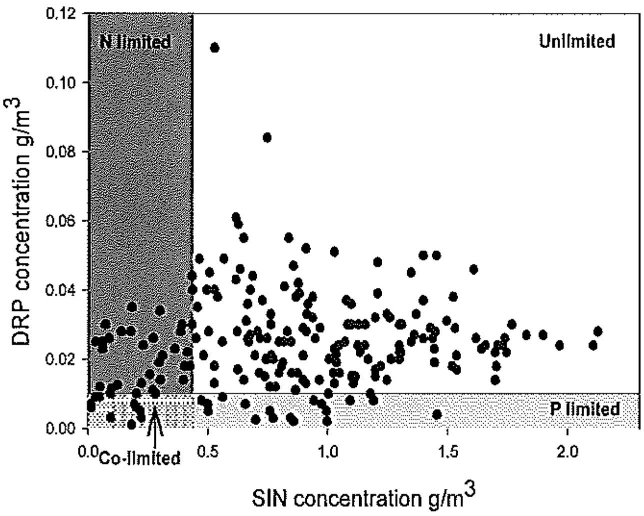


Figure 2: SIN and DRP concentration from samples collected monthly at Manawatu at Weber Road SOE monitoring site between 1989 and 2006, displayed with potential nutrient limitation status determined using Proposed One Plan nutrient standards. *Data courtesy of NIWA collected for the National River Water Quality Network programme.*

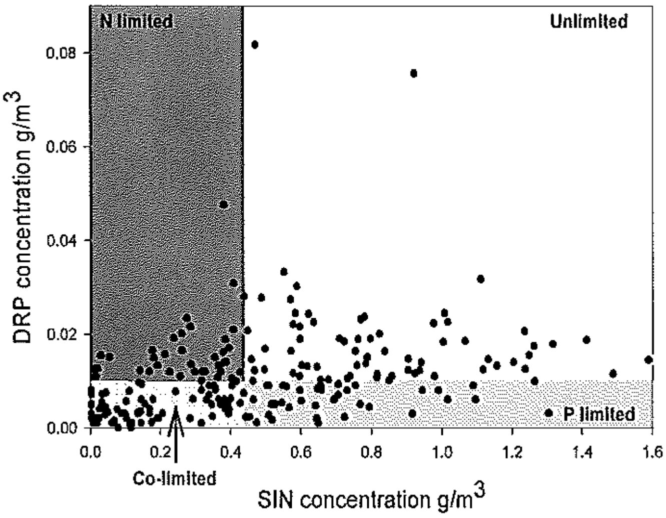


Figure 3: SIN and DRP concentration from samples collected monthly at Manawatu at Hopelands SOE monitoring site between 1989 and 2008, displayed with potential nutrient limitation status determined using Proposed One Plan nutrient standards.

Figure 4 shows the influence of flow on nutrient limitation status in the upper Manawatu at Hopelands. At low flows (Figure 4a), some samples were of co-limited status (meaning there was unlikely to be enough input of both P and N to stimulate periphyton growth), some were N-limited, some P-limited and some unlimited by either nutrient. At flows less than median (Figure 4b), there were less co-limited and more unlimited observations. P and N limitation was still found in roughly equal numbers of samples. For higher flows (above median Figure 4c) 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 Figure 4d) all observations except two were unlimited by either N or P concentrations.

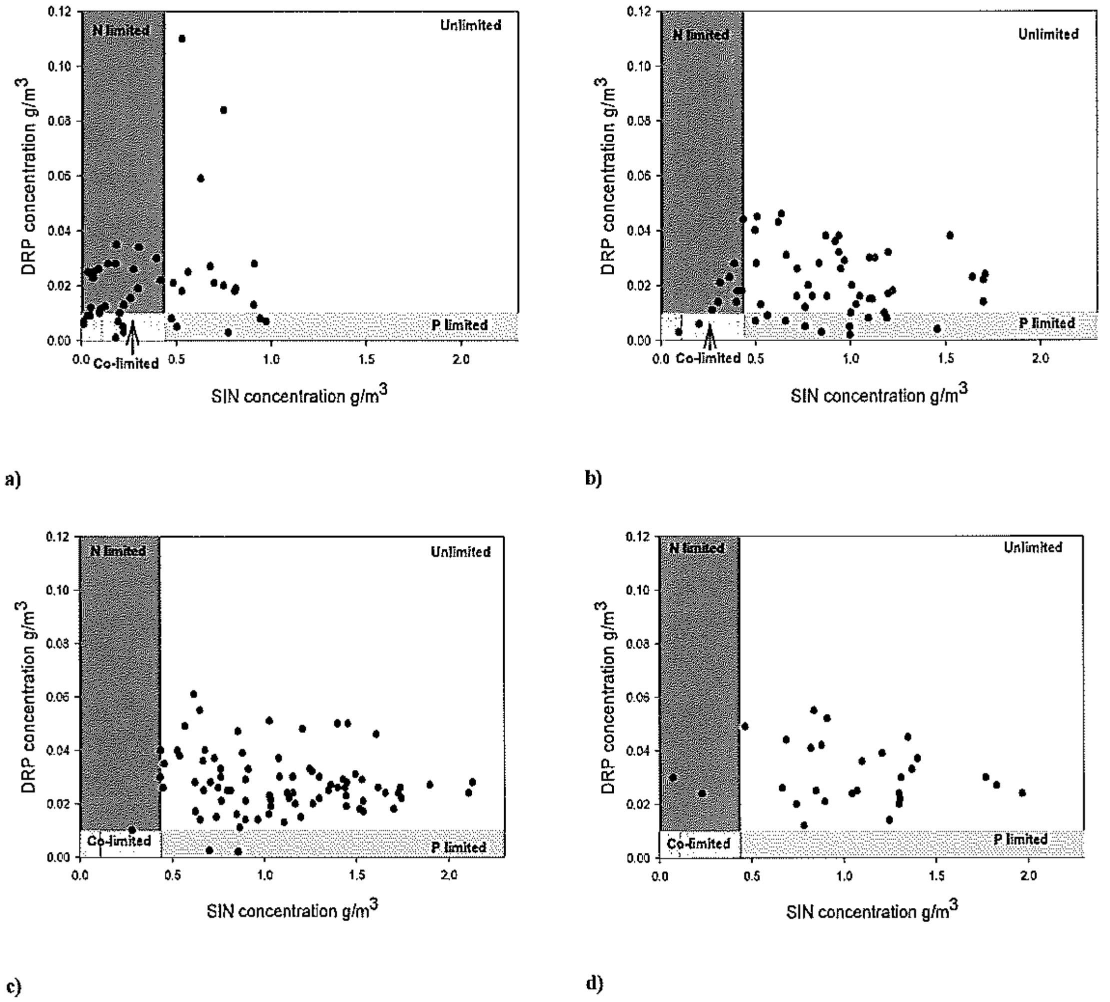
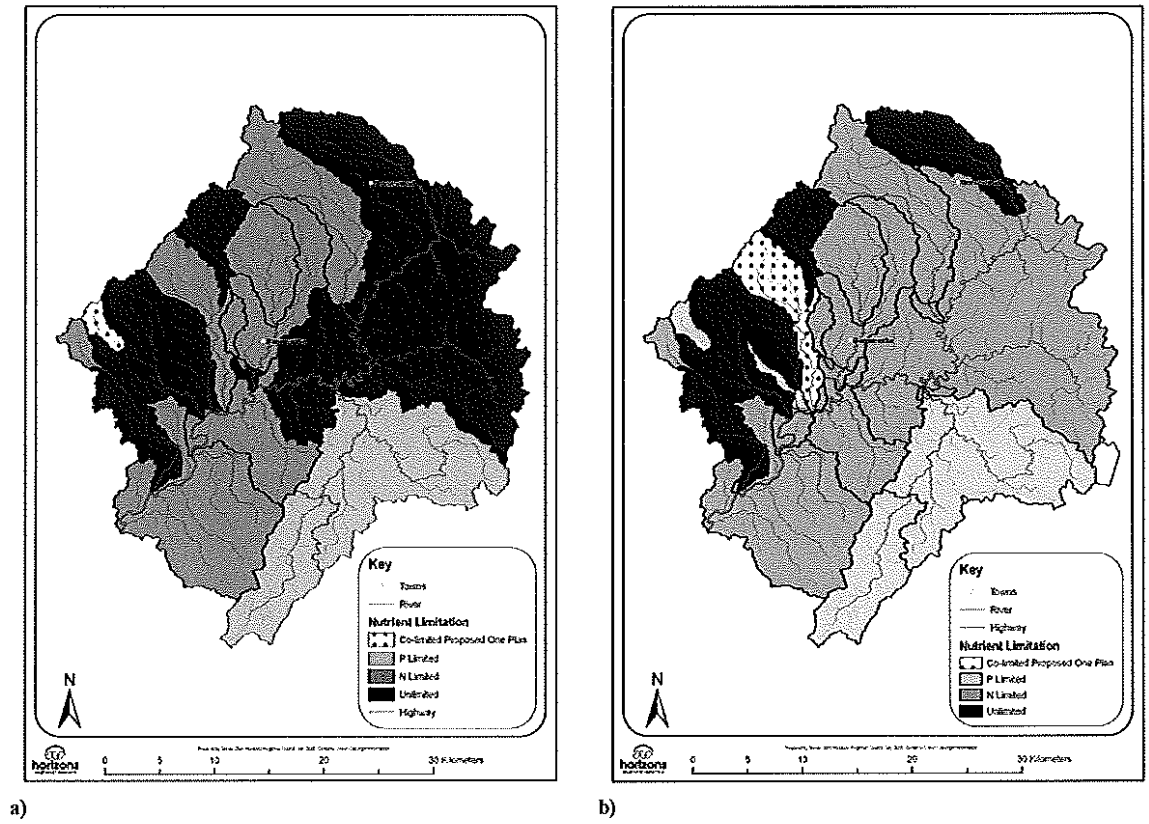


Figure 4: SIN and DRP concentration from samples collected at Manawatu at Hopelands monitoring site between 1989 and 2008 under varying flows: a) low flows (< 80th %ile), b) flows below median (50th – 80th %ile), c) flows above median (50th – 10th %ile), and d) high flows (> 10th %ile), displayed with potential nutrient limitation status determined using Proposed One Plan nutrient standards.

Data collected during a low flow investigation of flow, water quality and aquatic ecosystem health at 20 sites in the upper Manawatu catchment once monthly in January and February 2007 (Clark et al., 2009), was analysed for potential limiting nutrient status (Map 2). Although these maps are based on only two data points at each sub-catchment site, the results indicate that nutrient limitation status can change quickly over both spatial and temporal scales.



Map 2: Maps of sub-catchment nutrient limitation status in the upper Manawatu catchment on two monitoring occasions in early 2007. Map 'a' represents sampling in January 2007 at the 89th percentile of flow in the Manawatu River at Hopelands and map 'b' represents sampling in February 2007 at the 96th percentile of flow measured in the Manawatu River at Hopelands.

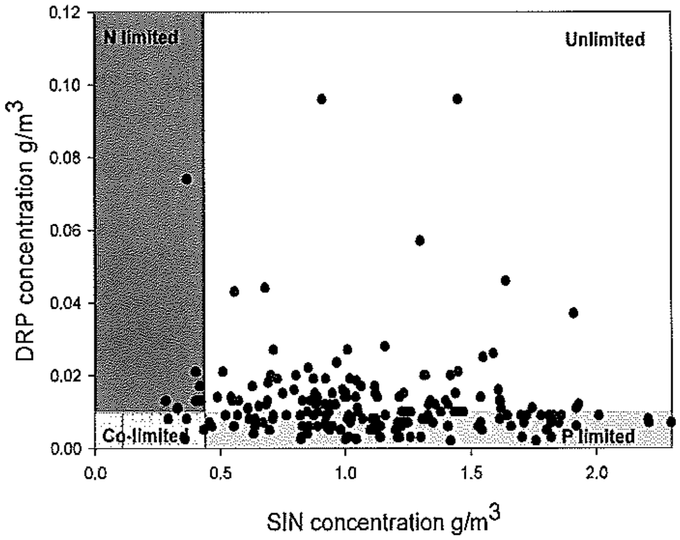
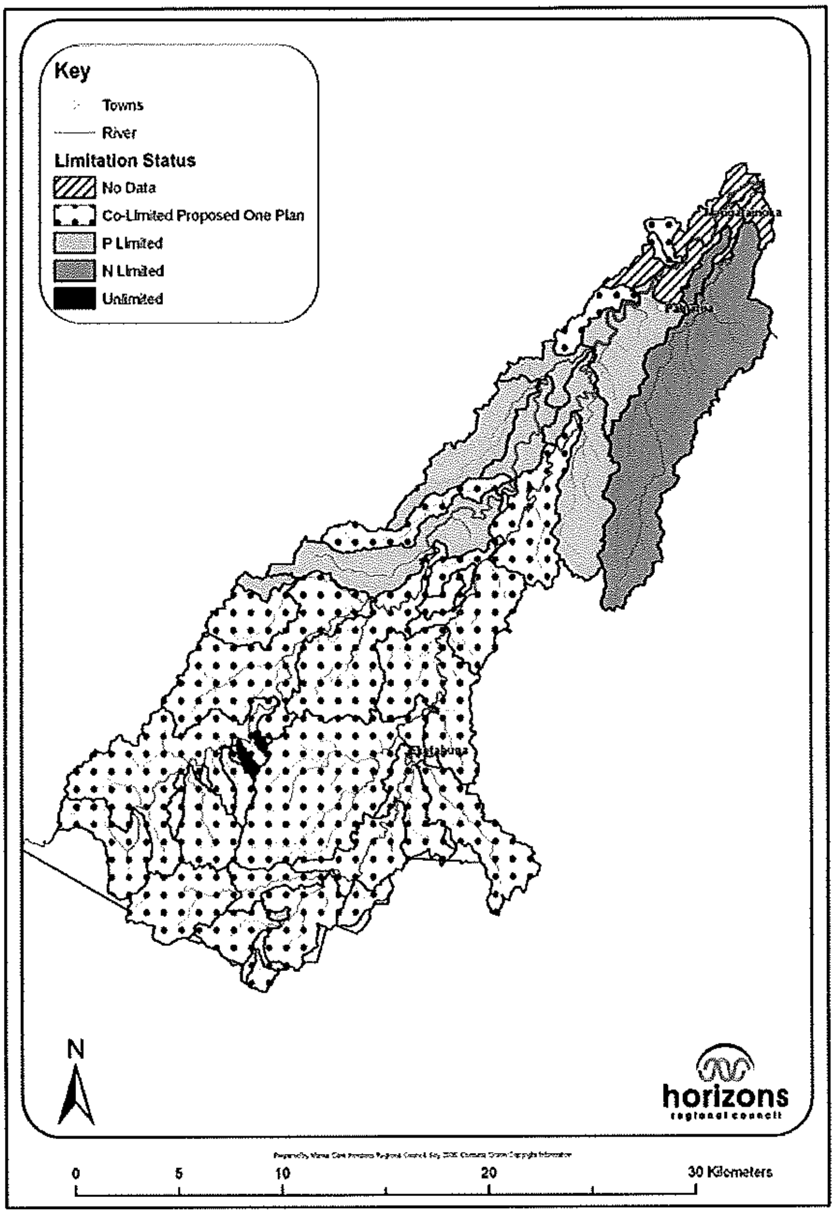


Figure 5: SIN and DRP concentration from samples collected at Mangatainoka at SH2 SOE monitoring site between 1993 and 2008, displayed with potential nutrient limitation status determined using Proposed One Plan nutrient standards.



Map 3: Potential limiting nutrient status in the Mangatainoka River catchment during low flows (< 99th flow percentile for the Pahiatua at Town Bridge flow site) February 2008, based on Proposed One Plan standards.

When SIN and DRP data for all flows was examined for the Mangatainoka at SH2 site, the situation was quite different from the upper Manawatu results (Figure 5). The Mangatainoka samples showed a clear pattern of P limitation or unlimited nutrient status for most samples.

However, a one day investigation of water quality at 43 sites during low flows in the Mangatainoka catchment in February 2008 (Clark et al., 2008) suggests that like the upper Manawatu catchment (Map 2), limiting nutrient status varies spatially across the Mangatainoka catchment under low flow conditions (Map 3).

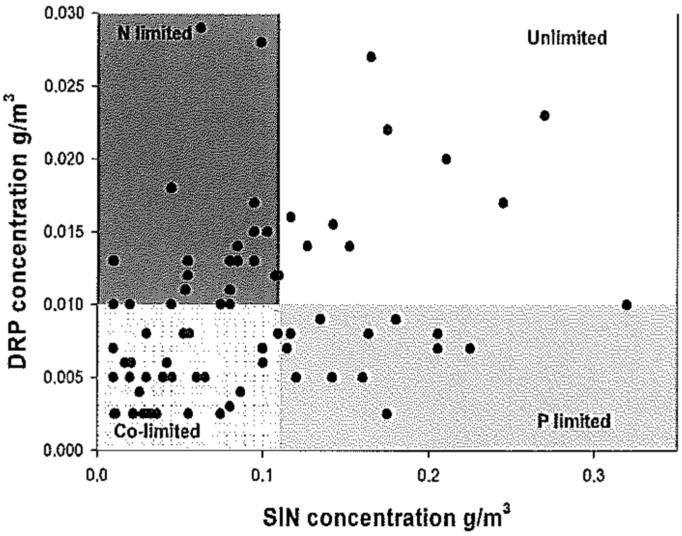


Figure 6: SIN and DRP concentration from samples collected from the Rangitikei at Mangaweka monitoring site between 1989 and 2008, displayed with potential nutrient limitation status determined using Proposed One Plan nutrient standards. *Note: the Rangitikei N standard differs from the upper Manawatu and Mangatainoka standard presented above.*

By contrast with the Manawatu catchment, the Rangitikei River has been considered to be predominantly N limited in the past (Death et al., 2007). However, data collected from monthly state of the environment monitoring of the Rangitikei at Mangaweka between 1989 and 2008 suggests that variation in potential limiting nutrient status occurs here too (Figure 6). Nutrient concentrations in the Rangitikei River are generally lower than in the Manawatu catchment, as shown by the large number of co-limited observations in Figure 6. This reflects the lesser resource pressures in this catchment. More stringent N standards have been proposed in the One Plan for the Rangitikei River than for many sites in the Manawatu catchment, to ensure that the current effects of nutrient inputs do not become significant adverse effects over time as a result of land use intensification.

Conclusions

The take-home messages from the nutrient limitation investigation were:

1. nutrient limitation varies with time, flow, season and by sub-catchment location;
2. managing such a dynamic system via control of one 'limiting nutrient' is likely to fail as a result of the complexities in these relationships; and
3. management of the adverse effects of enrichment requires an approach which limits the inputs of both N and P to waterways, across all nutrient sources and under most flow conditions.

Further work is underway in other major river catchments to examine the factors affecting nutrient concentration and limitation. Results of this research will be used to technically inform policy decision making around nutrient standards and controls for the Manawatu-Wanganui Region.

Acknowledgements

Carol Nicholson, Jeff Cooke, Brent Watson and Jeff Watson of the Horizons Research, Compliance and Hydrology Teams.

References

Biggs B. 2000: New Zealand Periphyton Guidelines: Detecting, Monitoring and Managing Enrichment of Streams. *Prepared for the Ministry for the Environment by the National Institute for Water and Atmospheric Research (NIWA).*

Clark M., McArthur K.J. and Roygard J. 2009: Upper Manawatu: an analysis at low flow. Technical Report to Support Policy Development. *Horizons Regional Council Regional Council Draft Report.*

Clark M., Nicholson C., Roygard J., Hurndell R. and McArthur K.J. 2008: Mangatainoka Catchment Analysis for Tier 2 Clean Streams Accord Baseline Monitoring. *Horizons Regional Council Draft Report Prepared for Ministry for the Environment.*

Death R.G., Death F. and Ausseil, O.M.N. 2007: Nutrient limitation and periphyton growth in tributaries and the mainstem of a central North Island river, New Zealand. *New Zealand Journal of Marine and Freshwater Research 41*: 273-281.

Henderson R. and Diettrich J. 2007: Statistical analysis of river flow data in the Horizons Region. *Prepared for Horizons Regional Council. NIWA Client report CHC2006-154.*

McArthur, K.J. and Clark, M. 2007: Nitrogen and Phosphorus Loads to Rivers in the Manawatu-Wanganui Region: a regional analysis of low flow state. *Horizons Regional Council Report No.* 2007/EXT/793. ISBN 1-877413-81-X

McDowell R.W. and Larned S.T. 2008: *Surface Water Quality and Nutrients: What should the focus be? In:* Carbon and nutrient management in agriculture. *(*Eds *Currie L.D. & Yates L.J.). Occasional Report No. 21. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand.*

Parfitt R., Dymond J., Ausseil A., Clothier B., Deurer M., Gillingham A., Gray R., Houlbrooke D., Mackay A. & McDowell R. *2007: Best Practice Phosphorus Losses from Agricultural Land.* Prepared for Horizons Regional Council. Landcare Research Contract Report No. LC0708/012.

Redfield A.C., Ketchum B.H. and Richards F.A. 1963: The influence of organisms on the composition of seawater. In: M.N. Hill (*ed*), *The Sea,* Vol. 2, Wiley Interscience, New York, pp. 26-79.

Roygard J. and Carlyon G. 2004: Water Allocation Project Rangitikei River Water Resource Assessment – Allocation Limits and Minimum Flows: technical report to support policy development. *Horizons Regional Council Report No 2004/EXT/606.*

Scarsbrook M. 2006: State and trends in the national river water quality network. *Report published by Ministry for the Environment. ISBN 0-478-30109-X. ME number 778.* www.mfe.govt.nz.

Scarsbrook M and McBride G.B. 2007: Best practice guidelines for the statistical analysis of freshwater quality data (Version 1). *Report prepared for the Ministry for the Environment. NIWA Client Report HAM2007-088.*

Wilcock B., Biggs B., Death R., Hickey C., Larned S. and Quinn J. 2007: Limiting nutrients for controlling undesirable periphyton growth. *Prepared for Horizons Regional Council. NIWA Client Report HAM2007-006.*