Draft Memo

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To	Hurunui Science Stakeholder Group
CC	
From	Kimberley Dynes and Ned Norton

What are the predicted environmental effects of a percent increase in nitrogen and phosphorus for the Waiau River catchment?

Introduction and purpose

Development to dryland and irrigated farming is anticipated in the Waiau River catchment. Such developments may include increases in relative stock units (RSU's), total winter foraging crop area, and the total irrigable area. These developments have the potential to increase nutrient losses to the Waiau River and its tributaries (Brown, 2017 (draft), Ellwood, 2017). Current state nutrient concentrations in the Waiau River and tributaries are reflective of the current nutrient losses from the root zone under consented and implemented land use practices in this catchment, not accounting for any time lag for nutrients entering the river. In the Waiau River catchment there are two sources of future nutrient increases:

1. Permitted dryland development
2. Future irrigated development

Norton (2018) summarised nominal predicted increases for the Waiau River based on the worst-case scenario of permitted dryland increases.

Dark (2017) and Ellwood (2017) estimate what the predicted increases of nitrate-N would be to the Waiau River and tributaries from two sources of development.

1. Development of land that is already consented but unimplemented in the Waiau River catchment.
2. The predicted increase in nutrient losses from a proposed further 3500 ha irrigated area in the Emu Plains Irrigation Scheme command area. Emu Plains Irrigation (EPI) already has consent for 4000 ha of existing irrigation.

The combined effect of these developments on nutrient concentrations is referred to in this memo as the "predicted nutrient increase".

EPI has lodged application for resource consents with Environment Canterbury (ECan) in 2017 including an assessment of effects (AEE) based on the above referenced prediction of nutrient increases. ECan has formally requested (by letter dated 11 January 2018) further information on the application including around the predictions of nutrient increases.

The purpose of this document is to inform of the risks of predicted increases in nitrogen and phosphorus on nuisance periphyton growth in the Waiau River catchment. This assessment is based on the information available at this point in time in order to inform discussions of the Hurunui Waiau Zone Committee (and the associated Hurunui Science Stakeholders Group). Nuisance periphyton growth may have subsequent effects on ecological, aesthetic, recreation, and other values.

Summary of findings

1. Key findings

1. Current State
   1.1. The Waiau River increases in Dissolved Inorganic Nitrogen with distance downstream. The upper Waiau River usually meets the plan chlorophyll A objective of 120mg/m3 except during occasional periods of stable low flow. DIN concentrations for the lower Waiau River indicate a risk of chlorophyll A not meeting the plan objectives.
   1.2. The Mason River has elevated concentrations of both Dissolved Inorganic Nitrogen (DIN) and Dissolved Reactive Phosphorus (DRP). Both N & P concentrations indicate the risk of chlorophyll A objectives being exceeded. Observed chlorophyll A concentrations indicate this river may be susceptible to nuisance periphyton blooms, with greater than 200mg/m^2 concentrations observed in 2011-12.
   1.3. Smaller tributaries such as Home Stream and Pass Stream have the highest concentrations of DIN and DRP
2. Predicted nutrient increases
   2.1. Predicted nutrient increases from land consented for irrigated development but unimplemented, and the proposed EPI irrigation development have been applied to existing nutrient concentrations for water quality monitoring sites in the Waiau River and tributaries.
   2.2. A nominal estimate of nitrogen increases under worst case permitted dryland development has also been included in the analysis for sites in the Waiau River.
   2.3. The combined increases in nitrate-N losses predicted for the upper Waiau are about 7% and 10% in the lower Waiau. The greatest increases in nitrate-N losses are anticipated for the Mason River (49%).
3. Factors influencing periphyton risk
   3.1. Flow
      3.1.1. Frequent effective flushing flows and short accrual periods of less than 30 days appear to be good regulators of periphyton growth in the Waiau River. The risk of periphyton growth was greater during longer accrual periods.
      3.1.2. The Mason River had less frequent effective flushing flows and long accrual periods compared to the Waiau River. When periphyton growth is well established, a flushing flow of 2 times the median may not be effective and may require a larger fresh to remove.
   3.2. Nutrient concentrations
      3.2.1. Nutrient concentrations in the upper Waiau River do not exceed nutrient thresholds for nuisance periphyton growth. In the lower Waiau River, DIN concentrations indicate a greater risk of exceeding chlorophyll A plan

objectives. Further predicted nitrate-N increases are likely to exacerbate the risk of nuisance periphyton growth in an already susceptible environment

3.2.2. Median DIN concentrations in the Mason River do not meet the site specific nutrient threshold (developed from Biggs, 2000)

4. Chlorophyll A biomass and predicted increases
   4.1. Nutrient concentrations for the upper Waiau River generally do not indicate a risk of exceeding the HWRRP plan objectives for chlorophyll A. In contrast, the lower Waiau River is predicted likely to exceed the HWRRP plan objectives based on DIN concentrations, and this has been observed in reality during infrequent periods of stable low flows. A 5% increase in chlorophyll A biomass is estimated for the lower river when the predicted nitrate-N increase from both irrigated and worst-case dryland development is applied to DIN concentrations.
   4.2. The Mason River has the potential to exceed the national bottom line for chlorophyll A based on both DIN and DRP concentrations. An 18% increase in chlorophyll A biomass is estimated when the predicted nitrate-N increase from irrigated development is applied to DIN concentrations.
5. Cyanobacteria
   5.1. Flow can be one of the factors regulating cyanobacteria growth. The Waiau River at Leslie Hills requires an effective flushing flow of 1.5 times median flow to remove cyanobacteria, while the Mason River requires 3 times median flow. This is greater than the effective flushing flow to regulate chlorophyll A biomass in the Mason River.
   5.2. Cyanobacteria generally occurs in rivers with elevated DIN and low DRP concentrations. Evidence suggests that cyanobacteria mats can obtain their phosphorus requirements by release of phosphorus from sediments via internal geochemical processes. In the Waiau River catchment, potential risk factors of cyanobacteria blooms include long individual accrual periods between effective flushing flows, coupled with elevated DIN and a source of particulate phosphorus.

2. Synopsis

The mainstem of the Waiau River generally shows a low susceptibility to nuisance periphyton growth due to the frequency of effective flushing flows. However, an increase of DIN concentrations at SH1 and below indicates a higher risk of periphyton growth during periods of stable low flow, especially if phosphorus is available from sediment for cyanobacteria growth.

The Mason River currently shows a high susceptibility to nuisance periphyton growth based on longer accrual periods, and elevated DIN and DRP concentrations. Predicted nitrate-N increases are greatest for the Mason River catchment (49%) and likely to exacerbate the current periphyton issue. Chlorophyll A biomass is predicted to increase by 18% based on estimated DIN increases and 5% based on DRP increases. The chlorophyll A biomass prediction based on DRP may be conservative if cyanobacteria (*Phormidium*) is the dominant algae. This is because there is potential for cyanobacteria to acquire phosphorus that is released from sediment when instream DRP concentrations are low.

The smaller tributary streams of Home Stream and Pass Stream have a limited dataset of 1 year. This monitoring indicates elevated nitrate concentrations that are currently close to toxicity limits in Home Stream. Further monitoring will provide a more robust assessment of water quality during different climatic conditions.

The predicted nutrient increases indicate modest increases for the Waiau River mainstem. However, the current state of the SH1 site indicates this lower stretch of the river may already be susceptible to the influences of nutrients for periphyton growth under stable low flows. Any increases would further exacerbate this risk. Current state and short-term monitoring of tributary streams indicate these sub-catchments are already susceptible environments that the predicted increases have the potential to intensify.

What makes the Waiau River and tributaries susceptible to periphyton growth from nutrient increases?

1. Flow

Flushing flow events two and three times the size of the median flow have been identified as important factors related to nuisance periphyton growth (Snelder, Biggs, Kilroy and Booker, 2013). The frequency of these flushing flow events influences the magnitude, frequency and duration of nuisance benthic periphyton blooms. In the Waiau River catchment, more specific flushing flow thresholds have been developed based on periphyton and continuous flow monitoring for the Waiau River at Leslie Hills Rd, and the Mason River at SH70 (Kilroy, Wech, Kelly, & Clarke, 2017 unpubl.). The Waiau River is an alpine river with regular freshes and classified as an 'unstable' site with an effective flushing flow threshold of 1.5x median flow ($FRE_{1.5}$). The Mason River is a hill-fed river, classified as 'unstable' with an effective flushing flow threshold of 2x median flow (FRE_2), although 3x median flow (FRE_3) is required for *Phormidium* mats. (See Table 5-1 from Kilroy *et al*., (2017 unpubl.) below). For the purpose of this memo, these effective flushing flow thresholds will be used for the analysis of periphyton risk at these two rivers. The Waiau and Mason Rivers will be used to indicate periphyton risk and flow relationship in the wider Waiau River catchment.

Table 5-1: Optimum sizes of flows for removal of periphyton cover in various categories. Flow is shown in the light-grey shaded columns as multiples of median flow (*n*). The relationship between days since *n* x median flow and cover with the highest R^2 defines optimum size. Results for chlorophyll *a* (from Table 2-1) are shown for comparison (darker shaded columns on the left). Sites arranged from north to south. Non-significant relationships are shown in grey type. Blank cells under didymo and *Phormidium* indicate sites where there were insufficient data to define a relationship (i.e., very low or no cover on most survey dates).

Site	Type	Mean flow	Chlorophyll *a*		All filaments			All mats			WCC			Didymo			*Phormidium*		
		(m^3/s)	R^2	flow	R^2	P	flow	R^2	P	flow	R^2	P	flow	R^2	P	flow	R^2	P	flow
Conway	hill	9.2	0.30	10	0.37	0.00	1.5	0.16	0.02	10	0.29	0.00	1.5						
Mason	hill	4.5	0.23	2	0.27	0.01	2	0.21	0.01	2	0.27	0.01	2				0.20	0.02	3
Waiau	alpine	91.6	0.52	1.5	0.18	0.05		0.25	0.00	1.5	0.18	0.06					0.28	0.03	1.5
Pahau	hill	4.6	0.30	2	0.30	0.00	2	0.14	0.02	2	0.25	0.00	2						
Hurunui	alpine	66.1	0.79	2	0.51	0.00	2	0.65	0.00	2	0.49	0.00	2	0.19	0.02	5	0.51	0.00	2
Waipara	hill	3.9	0.60	5	0.51	0.00	5	0.36	0.00	5	0.51	0.00	7				0.13	0.03	5
Ashley	hill	11.2	0.43	3	0.61	0.00	3	0.24	0.00	5	0.42	0.00	5						
Waimak	alpine	111.3	0.60	1.5	0.31	0.00	1.5	0.44	0.00	1.5	0.28	0.00	1.5	0.24	0.01	1.5	0.49	0.00	1.5
Cust	hill	1.8	0.50	2	0.17	0.01	5	0.45	0.00	5	0.42	0.00	5				0.15	0.02	2
Selwyn	hill	3	0.64	10	0.61	0.00	10	0.62	0.00	10	0.69	0.00	10				0.41	0.00	2
Rakaia	alpine	197.7	0.64	3	0.06	0.10		0.45	0.00	1.5	0.45	0.00	2	0.64	0.00	2	0.24	0.00	2
Ashb_SH72	hill	7.9	0.44	1.5	0.21	0.01	1.5	0.10	0.04	10	0.24	0.00	3				0.37	0.00	5
Ashb_SH1	hill	20.3	0.47	1.5	0.16	0.01	1.5	0.30	0.00	1.5	0.34	0.00	1.5				0.38	0.00	1.5
Rangitata	alpine	91.1	0.29	1.5	0.00	0.35		0.28	0.00	2	0.21	0.02	1.5	0.29	0.00	1.5	0.03	0.21	
Forks	alpine	3.1	0.47	3	0.47	0.00	1.5	0.39	0.00	3	0.41	0.00	3						
Te_moana	hill	1.1	0.48	7	0.26	0.00	1.5	0.31	0.00	2	0.31	0.00	2	0.10	0.04	5			
Opihi_rock	hill	5	0.63	5	0.35	0.00	2	0.42	0.00	2	0.49	0.00	2				0.07	0.07	
Orari	hill	5.4	0.54	7	-0.02	0.58		0.52	0.00	5	0.42	0.00	5				0.76	0.00	3
Temuka	hill	6.2	0.53	10	-0.01	0.41		0.36	0.00	10	0.28	0.00	10				0.36	0.00	10
Opihi_SH1	hill	15.1	0.27	5	-0.02	0.49		0.26	0.00	5	0.24	0.00	5				0.47	0.00	10
Twizel	alpine	2.8	0.62	7	0.32	0.00	3	0.47	0.00	3	0.48	0.00	3	0.44	0.00	10	0.01	0.28	
Tengawai	hill	4.1	0.49	10	0.22	0.00	10	0.39	0.00	10	0.32	0.00	10				0.19	0.01	3
Pareora	hill	4	0.31	5	0.13	0.03	10	0.28	0.00	3	0.20	0.01	3				0.08	0.07	
Waihao	hill	4	0.18		0.03	0.19		0.48	0.00	10	0.10	0.05					-0.01	0.38	

Effective flushing flows occur more frequently for the Waiau River compared to the Mason River. The frequency of effective flushing flows ($FRE_{1.5}$) had an annual average frequency of 14.67 for the Waiau River at Marble Point between 2011-17, and 12.17 for the Waiau Mouth. In comparison, the annual average frequency of effective flushing flows (FRE_2) for the Mason River during this period was 7.83. Periphyton accrual periods for the Waiau River are relatively short at Marble Point (18.22 days) and the Waiau Mouth (22.38 days). Accrual periods for an effective flushing flow for the Mason River are longer than for the Waiau River (62.57 days) (Table 1).

A three-year investigation monitoring benthic chlorophyll A concentrations was carried out between July 2011-14 for the Waiau River at Leslie Hills Rd and the Mason River at SH70. The maximum chlorophyll A concentration for the Waiau River was observed in April 2012 (Figure 1). An accrual period of 47 days since an effective flushing flow preceded this measurement. The 47-day accrual period is greater than what is observed for a 1 in 10-year "dry year' annual average accrual period. This indicates a lengthy accrual period comparable to what is observed on average in a dry year. However, the 2011-12 water year would not be considered a dry year with an annual average accrual period of 21.3 days, compared to a 1 in 10-year dry year annual average accrual period of 29.3 days (Jeanine Topelen, pers. Comms.). When fresh frequency is heavily skewed to the winter months, average fresh frequency (Fre3 etc) may not give a good indication of summer periphyton risk. The maximum chlorophyll A concentration for the Waiau River at Leslie Hills Rd was 115 mg/m^2. This is close to the HWRRP plan limit for the Waiau River of 120mg/m^2, and was measured 11 days prior to the next effective flushing flow event. This indicates the potential for further periphyton growth in that time, and chlorophyll A may have exceeded the 120 mg/m^2 threshold by the end of that period. While the 95th percentile plan limit for chlorophyll A was not exceeded, it does indicate that the Waiau River is at risk of exceeding this limit during a prolonged accrual period, especially if nutrient availability is further increased. The length of the individual accrual period in this instance appeared to have more influence than if the year was considered a "dry year".

There is no HWRRP limit in place for the Mason River, however 200 mg/m^2 can be used in this instance as a guide. This is the HWRRP limit for similar tributary streams in the Hurunui River catchment, and the National Bottom Line in the *National Policy Statement for Freshwater Management* (MfE, 2017). In 2011-12, two chlorophyll A measurement consecutively exceeded the 200 mg/m^2 threshold (**Error! Reference source not found.**). This indicates that a 95th percentile limit would be breached for this river. The maximum chlorophyll A measurement occurred 26 days after an effective flushing flow (5m^3/s) of 6.17m^3/s, and 40 days after 6.48 m^3/s. A chlorophyll A sample taken 2 days after the 6.48 m^3/s flushing flow indicated no periphyton (0 mg/m^2 chlorophyll A) was present and that the site was effectively reset. The second greatest chlorophyll A sample was taken a month later within the same accrual period that had extended out to 58 days since the 6.17m^3/s fresh. The average annual accrual period for 2011-17 in the Mason River was 62.57 days. This indicates that the accrual period prior to the maximum chlorophyll A measurement for the Mason River was relatively short and that periphyton growth was rapid. It is likely that factors other than accrual period facilitated such rapid periphyton growth. The role of nutrients is discussed in Section 2. Following these maximum chlorophyll A concentrations, a series of flushing flows failed to remove the standing crop of periphyton in the Mason

River. Chlorophyll A concentrations were reduced to below the 200 mg/m^2 threshold, although two of the three monthly measurements remained above the 120 mg/m^2 threshold. Comparison of flow-chlorophyll A relationships cannot be carried out with a 1 in 10-year "dry year" statistics. The flow record for the Mason River is too short to calculate these statistic with reasonable certainty.

In summary, annual average accrual periods of less than 30 days in the Waiau River appear to be a good regulator for periphyton growth. Chlorophyll A concentrations generally do not exceed the 120mg/m^2 plan limit. The impact of a 1 in 10-year "dry year" is apparent for the Waiau River, where chlorophyll A concentrations close to the plan limit were observed following an extended accrual period of 47 days. In contrast, maximum chlorophyll A concentrations were observed for the Mason River during relatively short accrual periods, and in some instances following effective flushing flows. Kilroy *et al*. 2017 found a weak relationship between accrual period and chlorophyll A for the Mason River and suggested that a larger flood may be required for effective flushing at this site. This is likely the case in this instance where the large periphyton blooms prior to these freshes were well established and required larger freshes to reset the site to zero periphyton. It is possible other influences such as a flux of nutrients from these flushing flows play an important role in this instance.

Table 1: Frequency of flushing flows and accrual periods for the Waiau and Mason Rivers

Waiau River at Marble Point

Water year	$FRE_{1.5}$ (observed)	average accrual period $FRE_{1.5}$	FRE_2 (observed)	average accrual period FRE_2	FRE_3 (observed)	average accrual period FRE_3
2011-12	15	21.3	10	36.2	5	76.2
2012-13	13	19.7	14	20.9	7	45.6
2013-14	12	17.3	11	24.3	9	39.0
2014-15	15	19.1	11	30.8	7	48.0
2015-16	17	17.4	11	29.9	6	55.5
2016-17	16	14.6	11	23.0	8	37.9
Average 2011-17	**14.67**	**18.22**	**11.33**	**27.50**	**7.00**	**50.36**
Average (entire record)	**12.59**	**21.19**	**11.69**	**27.81**	**7.59**	**52.14**

Mason River at Waiau Lyndon Road Bridge

Water year	$FRE_{1.5}$ (observed)	average accrual period $FRE_{1.5}$	FRE_2 (observed)	average accrual period FRE_2	FRE_3 (observed)	average accrual period FRE_3
2011-12	13	14.8	14	18.7	13	21.4
2012-13	12	17.2	13	18.4	10	31.6
2013-14	8	20.9	10	21.1	10	25.0
2014-15	5	28.8	3	33.3	0	365.0*
2015-16	3	92.3	2	172.5	2	231.5
2016-17	12	47.6	5	111.4	3	187.7
Average 2011-17	**8.83**	**36.92**	**7.83**	**62.57**	**6.33**	**143.70**
Average (entire record)	**9.50**	**32.37**	**8.50**	**52.76**	**6.88**	**80.93**

* the accrual period is more than a year, this is reflected in the high average of 2015

Waiau River at the Mouth

Water year	$FRE_{1.5}$ (observed)	average accrual period $FRE_{1.5}$	FRE_2 (observed)	average accrual period FRE_2	FRE_3 (observed)	average accrual period FRE_3
2011-12	12	25.3	10	34.3	6	63.2
2012-13	12	21.3	11	26.7	10	32.5
2013-14	10	18.5	11	20.8	12	26.6
2014-15	13	21.8	8	44.6	6	56.0
2015-16	11	28.8	8	38.9	6	55.5
2016-17	15	18.6	10	26.7	8	38.0
Average 2011-17	**12.17**	**22.38**	**9.67**	**32.00**	**8.00**	**45.29**
Average (entire record)	**12.14**	**22.22**	**9.57**	**31.97**	**8.43**	**42.72**

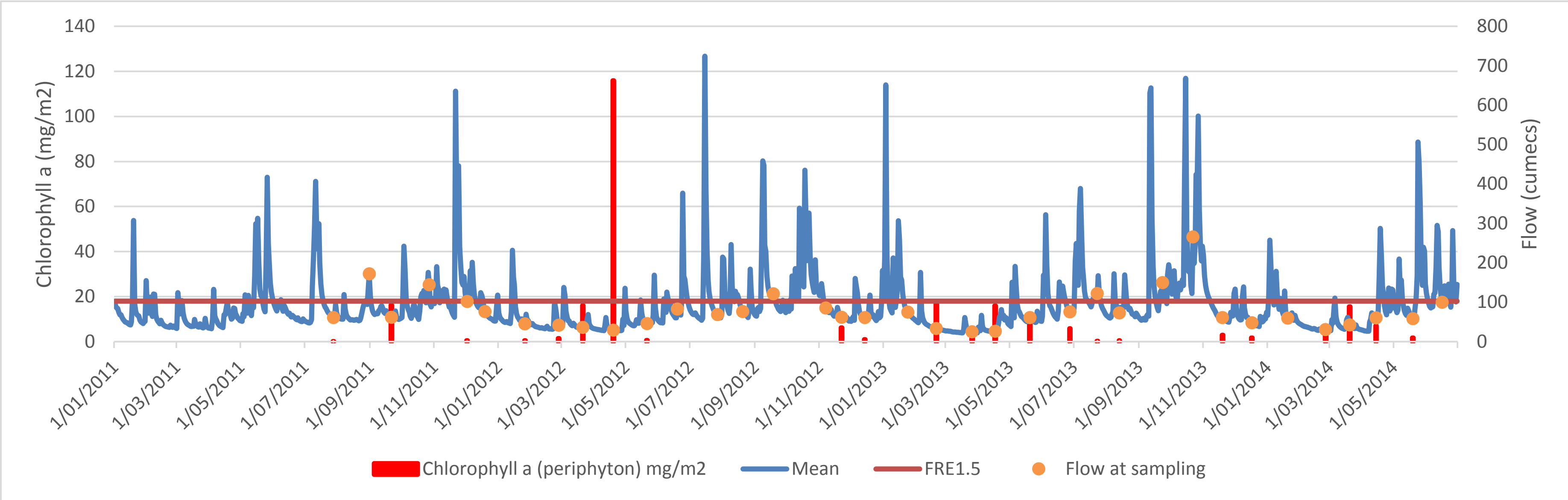

Figure 1: Chlorophyll a concentration and preceding flow relationship for the duration of the 3-year monitoring period for the Waiau River at Leslie Hills

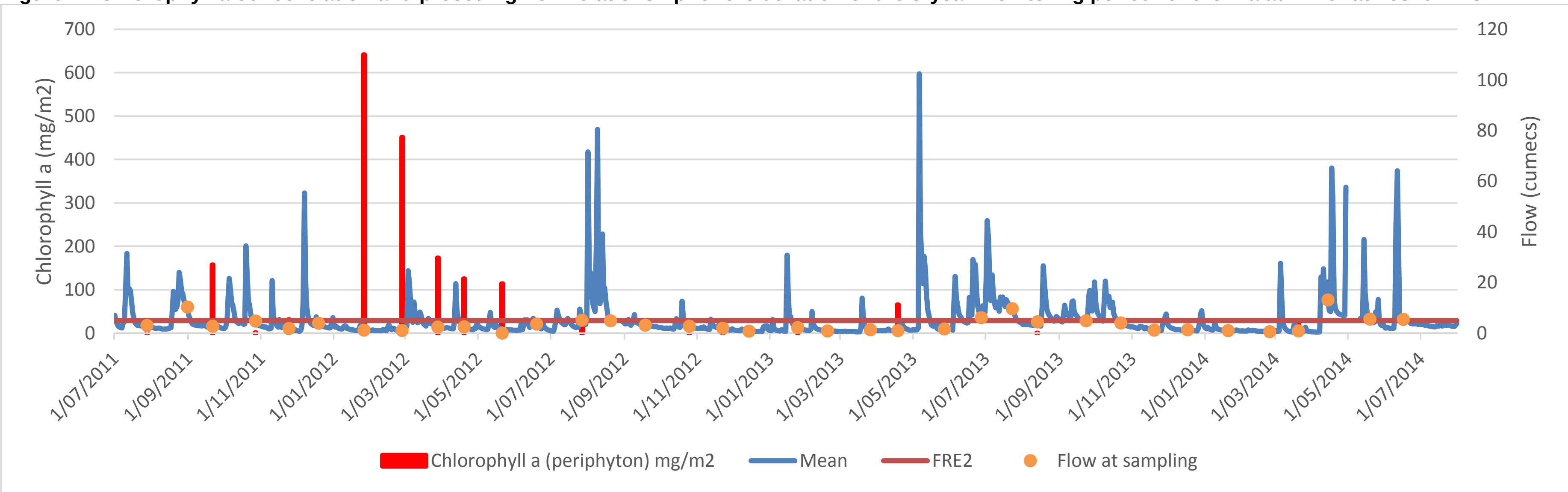

Figure 2: Chlorophyll a concentration and preceding flow relationship for the duration of the 3-year monitoring period for the Mason River at SH70

2. Nutrients - Current nutrient status, Predicted nutrient increases and the risk of nuisance periphyton growth

2.1. Nutrient thresholds to assess the risk of nuisance periphyton growth

The risk of nuisance periphyton growth can be estimated by considering the nutrient status of a given waterway. There are several New Zealand specific nutrient thresholds developed to predict the risk of nuisance periphyton growths from nutrient data. Biggs (2000) uses nutrient-flow-periphyton (chlorophyll A) relationships to predict maximum chlorophyll A biomass. These equations can be used for developing nutrient or chlorophyll A thresholds in conjunction with the accrual period for a given river. However, these equations are not Canterbury specific. Kilroy *et al*. (2017) found they tend to overestimate periphyton biomass when applied to alpine and hill-fed rivers in Canterbury. The Biggs equations use accrual periods based on FRE_3 flushing flows. Kilroy *et al*. (2017) found that by using site-specific effective flushing flows to determine the accrual period, these equations were more robust.

Nutrient thresholds for the Waiau and Mason rivers were developed for comparison with the nutrient availability at sites monitored on these rivers. The thresholds are presented in Table 2. The accrual periods for these equations were based on the effective flushing flows determined for the Waiau and Mason rivers by Kilroy *et al*. (2017). This is consistent with the data presented in Section 1. This differs from the original Biggs (2000) equations where an effective flushing flow was considered to be 3 times median flow. In the case of the Waiau and the Mason rivers, the use of these site specific effective flushing flow accrual periods means the nutrient thresholds are a lot less conservative (i.e. – higher) than if the FRE_3 flushing flow was used. Chlorophyll A objectives are set for the Waiau River in the HWRRP. No Chlorophyll A objectives were set for the Mason River in this plan, therefore the national bottom line from the *National Policy Statement for Freshwater Management* (2017) was used. This value is consistent with the Chlorophyll A objectives set in the HWRRP for similar tributary streams in the Hurunui River catchment.

Table 2: Nutrient thresholds developed from Biggs (2000) chlorophyll equations, based on site-specific accrual periods from Kilroy *et al*. (2017)

Nutrient Thresholds based on Chlorophyll A Plan objectives			
	CHL A objective	DIN (mg/L)	DRP (mg/L)
Waiau River at Leslie Hills	120	0.152	0.0153
Waiau River at SH1	120	0.071	0.0069
Mason River at SH70	200	0.012	0.0012

The Matheson *et al*. (2012) periphyton guidelines were developed as a risk assessment tool of instream periphyton growth. Matheson *et al*. (2012) found that periphyton growth showed a strong relationship with nutrient concentrations, with nutrients being one of the most important variables controlling periphyton growth in rivers. The four risk categories of nuisance periphyton growth can be used as an indication of trophic levels when considering if a site has maintained, improved or declined. Median DIN and DRP concentrations for all sites monitored in the Waiau River catchment during 2016-17 are presented in Appendix 1. The periphyton risk categories are applied to these sites. This dataset does not represent the current state, rather compares a wider range of sites monitored over the last year to indicate sub-catchments of greatest nutrient enrichment.

Both the current state of nutrient concentrations, and current nutrient concentrations plus predicted nutrient increases are compared to these nutrient thresholds (Biggs, 2000, Matheson *et al* 2012) in Section 2.3.

2.2. Predicted nutrient increases

Predicted nutrient increases in the Waiau River catchment have been estimated from two sources of future development:

1. Permitted dryland development
2. Future irrigated development

Norton (2018) considered several different lines of evidence (e.g. those reported by Brown 2018, Brown 2015 and Mojsilovic 2018) to suggest that future increases in nitrogen loss from permitted dryland farming properties, as a whole catchment group, are likely to be small; i.e. in the order of 0-3%, relative to the total nitrogen load lost in the Waiau catchment (as summed at the mouth). This conclusion was presented at the public workshop on 29 January. This provides a basis to estimate that increases for in-river dissolved nitrogen (arising from permitted dryland development) could be in the order of 3% in the lower Waiau catchment under a nominal 'worst-case' scenario, although it is acknowledged that any increases would likely be variable in different parts of the catchment. A simple 3% worst case dryland increase has been assumed in the analysis in this memo. A 7% worst-case dryland increase has been assumed for the Waiau River at Leslie Hills site, based on Mojsilovic 2018.

Dark (2017) and Ellwood (2017) estimate what the predicted increases of nitrate-N would be to the Waiau River and tributaries from two sources of irrigation development.

1. Development of land that is already consented but unimplemented in the Waiau River catchment.
2. The predicted increase in nutrient losses from a proposed further 3500 ha irrigated area in the Emu Plains Irrigation Scheme command area. Emu Plains Irrigation (EPI) already has consent for 4000 ha of existing irrigation.

Nitrate-N losses within the Emu Plains Irrigation Scheme command area were estimated by Dark (2017) and Ellwood (2017) for the Waiau River and tributary streams with existing water quality data. These tributary streams included the Mason River, as well as short term monitoring for Pass Stream and Home Stream. A nominal 10% increase in phosphorus is predicted across all sites. Both Pass Stream and Home Stream are located exclusively within the EPI scheme command area. The predicted nitrate-nitrogen increases are estimated solely on this basis, assuming there is no permitted dryland development. Predicted nutrient increases for the Mason River only takes into consideration the estimated increases from EPI development. There is no Mason River catchment specific estimate for permitted dryland farming, however it is assumed that these increases would be minimal in comparison to the predicted increases from EPI development.

There are no known predicted nutrient increase estimates available for tributary stream catchments within other irrigation scheme command areas. Nitrate-nitrogen predicted increases to the Waiau River mainstem are estimated by Ellwood (2017) for irrigation development that is already consented but unimplemented. However, this does not take into consideration predicted increases to tributary streams within development areas of irrigation schemes such as the Amuri Irrigation Company (AIC). Additionally, there is potential for nutrient increases in tributary streams from the piping of the AIC scheme, because the piping of this scheme has the potential to reduce dilution of nitrate-nitrogen in these streams. It is unclear what impact these combined nutrient increases will have on tributary streams in these areas.

Predicted nitrate-N losses for the Waiau River, and tributary streams within the EPI scheme command area are presented in Table 3. The nitrate-N loss increase is applied to dissolved inorganic nitrogen (DIN) concentrations for these streams, under the assumption that there is no predicted increase of total ammoniacal nitrogen (NH4-N) and nitrite-N, and that these nitrogen species make up a very small proportion of the DIN load.

Table 3: Predicted change in root zone Nitrate-N concentration from baseline to the fully developed scenario (including currently consented by unimplemented potential increases and worst-case scenario dryland increases)

	Predicted change in root zone Nitrate-N concentration
Upper Waiau River	7%
Lower Waiau River	10%
Mason River	49%
Pass Stream	17%
Home Stream	6.7%

2.3. Current state of the Waiau and Mason Rivers, and predicted nutrient increases

Long term monitoring of nutrient concentrations is carried out for three sites in the Waiau River and one on the Mason River. The long-term monitoring data for the Leader River is not included in this analysis for two reasons.

1. An appropriate Biggs (2000) nutrient threshold could not be developed as an effective flushing flow (to determine the accrual period) has not been determined for this site.
2. There is no known consented but not yet implemented development in the Leader River catchment that would cause changes to nutrient losses nor do we have any information about proposed irrigation development. It is assumed the only increases in this catchment would come from permitted farming.

Table 4 indicates the current state of dissolved reactive phosphorus (DRP) and dissolved inorganic nitrogen (DIN) and the predicted increases to instream nutrient concentrations. These are compared to the adapted Biggs (2000) nutrient thresholds. Monitoring data indicates the current median DRP concentrations in the Waiau River are below the appropriate Biggs (2000) nutrient thresholds for Leslie Hills Rd and SH1 (Table 4).

Continuous flow data to establish accrual periods were not available to estimate Biggs (2000) nutrient thresholds for the Waiau River at Waiau. However, concentrations at this site are below both the other Waiau River DRP nutrient thresholds. The Mason River site shows the median DRP concentrations do not meet the adapted Biggs (2000) DRP threshold. This indicates this site is at risk of nuisance periphyton growth based on phosphorus concentrations and accrual periods.

DIN concentrations in the Waiau River are variable, with an increase in both median and 95th percentile results with distance downstream (Table 4). Median DIN concentrations for the Waiau River at Leslie Hills Rd are below the appropriate Biggs (2000) nutrient threshold. In contrast, median DIN concentrations for the Waiau River at SH1 are above the appropriate Biggs (2000) threshold for this site. This indicates the potential for this site to not meet HWRRP chlorophyll A objectives if conditions are suitable (e.g., flow). The Mason River site shows median DIN concentrations do not meet the adapted Biggs (2000) DIN threshold. This indicates this site is at risk of nuisance periphyton growth based on nitrogen concentrations and accrual periods. This is consistent with DRP concentrations not meeting the Biggs guidelines.

Table 4: Current state of dissolved nutrients and predicted increases from development sources for the Waiau and Mason River long term monitoring sites (July 2012-17) compared to nutrient thresholds adapted from Biggs (2000)

	DRP					DIN				
	Biggs Nutrient Threshold	Median (Current State)	Median predicted increase	95th %ile	95th %ile predicted increase	Biggs Nutrient Threshold	Median (Current State)	Median predicted increase	95th %ile	95th %ile predicted increase
Waiau River u/s Leslie Hills Rd	0.0153	0.0044	0.0048	0.0065	0.0072	0.1522	0.0440	0.0471	0.1326	0.1419
Waiau River at Waiau	-	0.0042	0.0046	0.0071	0.0078	-	0.0775	0.0853	0.2445	0.2690
Waiau River u/s SH1	0.0069	0.0037	0.0041	0.0078	0.0086	0.0712	0.2800	0.3080	0.8930	0.9823
Mason River d/s SH70	0.0012	0.0039	0.0043	0.0118	0.0130	0.0122	0.0240	0.0358	0.3250	0.4843

Error! Reference source not found. and **Error! Reference source not found.** indicate the current state of dissolved reactive phosphorus (DRP) and dissolved inorganic nitrogen (DIN) (blue bars), and the predicted increases to instream nutrient concentrations (green bars). These are compared to the Matheson (2012) nuisance periphyton risk thresholds.

Median DRP concentrations for all sites fall within the "adequate" category from the Matheson (2012) guidelines. This indicates that phosphorus concentrations generally pose a 50% risk of nuisance periphyton growth. When the predicted phosphorus increase is applied to the current state, median DRP concentrations stay within the same risk category.

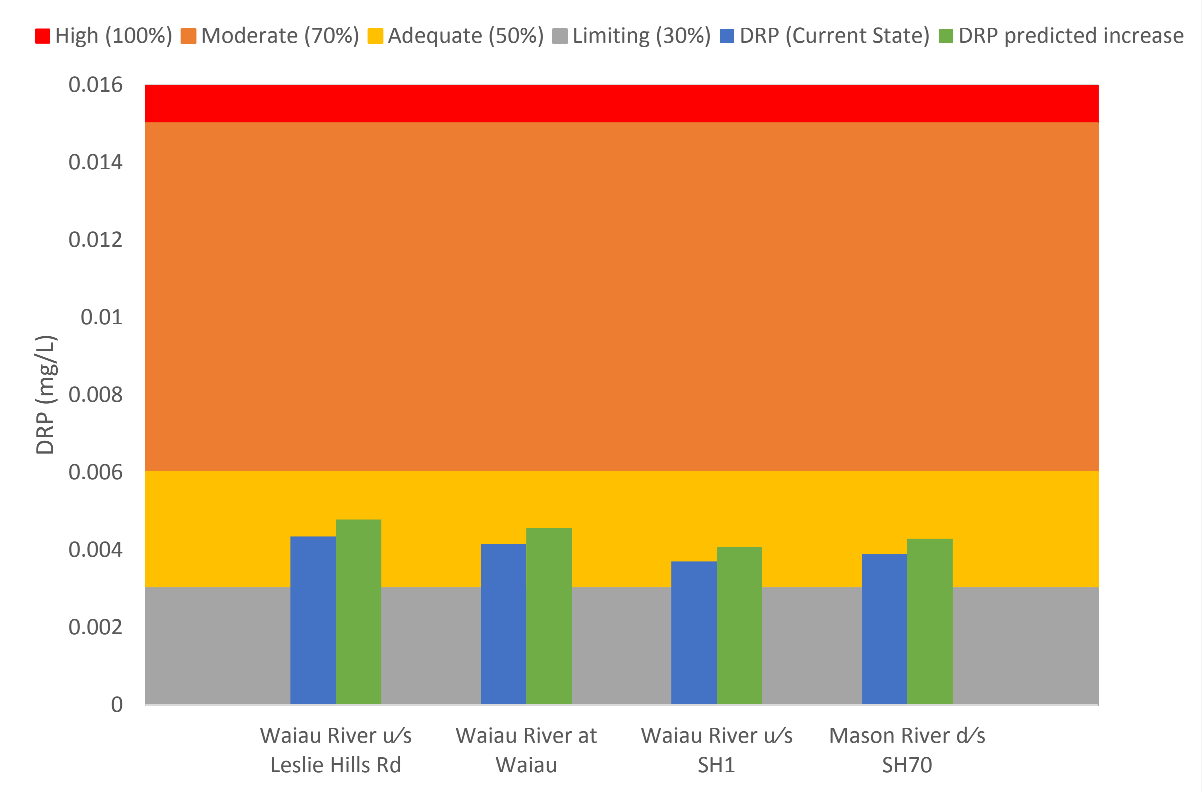

Figure 3: Median dissolved reactive phosphorus current state of and predicted increase from development sources for the Waiau and Mason River long term monitoring sites (July 2012-17) compared to the predicted risk categories for nuisance periphyton (Matheson *et al*. 2012)

The probability of nuisance periphyton growth based on median DIN concentrations increases in risk category with distance downstream in the Waiau River (**Error! Reference source not found.**) (Matheson *et al*. 2012). Median DIN concentrations for the Leslie Hills Rd site fall within the limiting category (30% risk factor), the Waiau township site falls within the adequate category (50% risk factor), and the SH1 site falls within the moderate category (70% risk factor). Median DIN concentrations for the Mason River at SH70 fall within the limiting (30% risk factor) category. However, 95th percentile DIN concentrations for this site indicate elevated DIN concentrations that may increase the risk of nuisance periphyton growth on occasion (Table 4). The longer accrual periods and elevated DIN concentrations may make this site more susceptible to nuisance periphyton growth than what is predicted by the Matheson *et al*. (2012) risk categories. This is reflected by the more conservative Biggs (2000) DIN threshold.

When the predicted nitrogen increase is applied to the current state, median DIN concentrations stay within the same risk category, with the exception of the Waiau River at SH1. The predicted increase for SH1 indicates that this site could become highly susceptible to nuisance periphyton growth in the absence of effective flushing flows. The predicted increase in DIN for the Mason River did not appear to have a great influence on median DIN. However, raw nutrient data for the Mason River was highly variable. The 95th percentile for DIN in the Mason River indicates concentrations can be elevated (Table 4). It is likely that when the predicted increases are applied, these concentrations would become highly variable and more extreme. Coupled with the longer accrual periods for this site, periphyton growth could at times be problematic. Figure 2 shows chlorophyll A concentrations exceeded the national bottom line threshold of 200 mg/m^2 on two occasions in 2012 for the Mason River. This indicates nuisance periphyton growths on occasion, that an increase in nitrogen concentrations at this site may exacerbate.

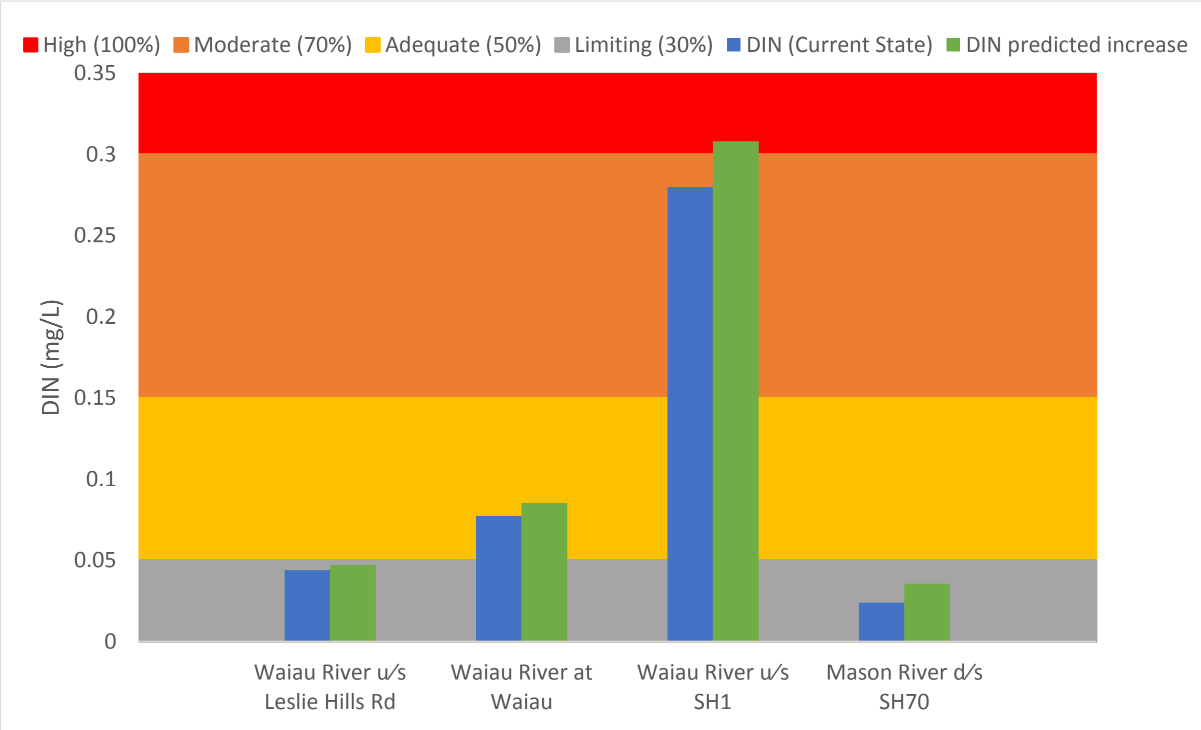

Figure 4: Median dissolved inorganic nitrogen current state of and predicted increase from development sources for the Waiau and Mason River long term monitoring sites (July 2012-17) compared to the predicted risk categories for nuisance periphyton (Matheson *et al*. 2012)

2.4. The impact of predicted nutrient increases on tributary streams within the Emu Plain Irrigation scheme command area

Table 5 summarises current and predicted nutrient concentrations from 1 year of monitoring the Waiau River and tributary streams within the Emu Plains Irrigation (EPI) scheme command area. The predicted nutrient increases from EPI are applied to these streams to show the potential risk of nuisance periphyton growth and toxicity impacts on aquatic life from nutrient increases. It is important to note that this is a limited data set of only 1 year where monitoring has been extended out to include additional sites. It does not represent the current state of these streams as it does not account for longer term climatic variation. This analysis is intended to show what influence each predicted increase would have had on these nutrient concentrations over a wider range of sites.

Current and predicted nutrient concentrations are greatest for Pass Stream and Home Stream, in comparison to the Mason River in the Emu Plains area (Table 5). These streams are likely to exhibit larger changes in nutrient concentrations, depending on the location of land use intensification. Given they are possibly impacted already, their communities may be less sensitive to enrichment. Policy 5.3A (c) states "the annual median and 95th percentile nitrate-nitrogen concentrations in the mainstem of the Waiau River, and in its tributaries at their confluence with the mainstem, below the Marble Point flow recorder site shall not exceed 2.3 and 3.6 mg NO3-N/L respectively, these being the chronic nitrate-nitrogen toxicity thresholds for maintaining a 95% level of species protection". A predicted increase for DIN in Home Stream indicates this site would not meet the 95th percentile objective in Policy 5.3A (c), and that the median concentration indicates the site is at risk of not meeting this objective. This is based on a single year of monitoring data, in which climatic conditions were dry. Nitrate-nitrogen losses may have been below average for this year, and it likely the full extent of potential nitrate-nitrogen losses was not observed during this period.

Table 5: Current and predicted dissolved nutrient concentrations for streams monitored within the Emu Plains Irrigation scheme command area

	DRP				DIN			
	Median	Median Predicted increase	95 %ile	95 %ile predicted increase	Median	Median Predicted increase	95 %ile	95 %ile predicted increase
Pass Stream at Pass Stream Rd	0.004	0.004	-	-	0.755	0.883	-	-
Home Stream u/s River Rd	0.007	0.007	0.028	0.031	1.995	2.129	3.525	3.761
Mason River d/s SH70	0.002	0.002	0.009	0.010	0.034	0.051	0.386	0.575
Mason River u/s Waiau confl	0.002	0.002	0.009	0.010	0.030	0.044	0.422	0.629

Predicted modelled periphyton biomass

The predicted nutrient concentration increases from various predicted development losses in the Waiau River catchment were applied to the Biggs (2000) equations (adapted using site-specific accrual periods based on the effective flushing flows from Kilroy *et al*. (2017). This aims to assess the potential risk of increases in chlorophyll A biomass with increases to instream nutrient concentrations.

The current state of nutrient concentrations for the Waiau River at Leslie Hills Rd indicate this site generally does not exceed chlorophyll A objectives (Table 7 and Table 7). In contrast, the current state of DIN concentrations for the Waiau River at SH1 indicate potential for the HWRRP plan objective to be exceeded, with an overall predicted 5% increase in chlorophyll A biomass based on the predicted nitrate-N increase from irrigation and dryland development. The 2015-16 year could be considered comparable to a dry year based on annual average accrual periods. The Waiau River at the Mouth had an annual average accrual period of 28.8 days, while a 1 in 10-year dry year is estimated to have an accrual period of 29.3 days (Table 1, Jeanine Topelen pers. comms.). Chlorophyll A predictions based on both DIN and DRP exceeded the HWRRP plan objectives for this year. Overall, the Mason River shows potential to exceed chlorophyll A national bottom line (MfE, 2017) based on predictions from both DIN and DRP concentrations. Chlorophyll A biomass is estimated to increase by 18% in based on the predicted nitrate-N increase from EPI.

Table 6: Chlorophyll A predictions based on 5-year median DIN and DRP concentrations for current state and predicted nutrient increases. Note, red indicates plan objectives are exceeded

Chlorophyll a Predictions based on nutrient data		
	Chl A (modelled based on DIN) (mg/m2)	Chl A (modelled based on DRP) (mg/m2)
Waiau River at Leslie Hills		
Current state	64	64
Predicted nutrient increases	66	68
% increase in Chl A	3%	5%
Waiau River at SH1		
Current state	239	88
Predicted nutrient increases	251	92
% increase in Chl A	5%	5%
Mason River at SH70		
Current state	281	355
Predicted nutrient increases	344	372
% increase in Chl A	18%	5%

Table 7: Chlorophyll A predictions based on 1-year median DIN and DRP concentrations for current state and predicted nutrient increases. Note, red indicates plan objectives are exceeded

Chlorophyll A Predictions based on nutrient data			
	Year	Chl A (modelled based on DIN) (mg/m2)	Chl A (modelled based on DRP) (mg/m2)
Waiau River at Leslie Hills			
Current state	2011-12	85	93
Predicted nutrient increases		88	98
Current state	2012-13	104	81
Predicted nutrient increases		107	84
Current state	2013-14	71	59
Predicted nutrient increases		74	62
Current state	2014-15	61	68
Predicted nutrient increases		63	71
Current state	2015-16	57	58
Predicted nutrient increases		59	61
Current state	2016-17	44	42
Predicted nutrient increases		45	44
Waiau River at SH1			
Current state	2011-12	N/A	
Predicted nutrient increases			
Current state	2012-13		
Predicted nutrient increases			
Current state	2013-14	200	68
Predicted nutrient increases		210	71
Current state	2014-15	232	82
Predicted nutrient increases		244	86
Current state	2015-16	362	122
Predicted nutrient increases		379	128
Current state	2016-17	130	59
Predicted nutrient increases		136	62
Mason River at SH70			
Current state	2011-12	61	65
Predicted nutrient increases		75	68
Current state	2012-13	127	89
Predicted nutrient increases		155	93
Current state	2013-14	136	117
Predicted nutrient increases		166	123
Current state	2014-15	83	119
Predicted nutrient increases		101	125
Current state	2015-16	363	510
Predicted nutrient increases		444	535
Current state	2016-17	506	366
Predicted nutrient increases		619	383

Potential risk of cyanobacteria blooms based on current research

As with any benthic periphyton, river flow is generally the greatest regulator of biomass (Heath & Greenfield, 2016). During flood or fresh conditions, *Phormidium* mats can be scoured from rocks via sheer stress and abrasion of suspended particles. Rivers that are susceptible to frequent freshes are less likely to have prolific *Phormidium* blooms. Freshes must be of a magnitude great enough to allow for scouring from sediment mobility and abrasion. The magnitude of a fresh required varies among rivers due to differences in river geomorphology and substrate stability (Hoyle, Kilroy, Hicks, & Brown, 2017). The Waiau River at Leslie Hills indicated a fresh of 1.5 times the median flow was required to scour periphyton, while the Mason River required a flushing flow of 3 times the median flow specifically for *Phormidium* (Kilroy, Wech, Kelly, & Clarke, 2017).

Flushing flows do not account for the regulation of all cyanobacteria blooms in rivers. Cyanobacterial growth promoting factors such as nutrients, temperature and light may be important drivers of *Phormidium* accrual especially during periods of low and/or stable flow. Cyanobacteria blooms generally coincide with the summer months, although the role of temperature and light is poorly understood (Heath, Wood and Ryan, 2011; McAllister, 2014; Wood, Wagenhoff and Kelly, 2015).

Heath *et al*. 2013 found that *Phormidium* abundance had a positive correlation with elevated nitrogen concentrations during periods of low, stable flow. A total nitrogen: total phosphorus ratio of greater than 20:1 has been observed for the majority of waterways with cyanobacteria blooms (a bloom is defined as greater than 20% cover) ((Wood and Young, 2012). Lab-based studies of varying nitrogen and phosphorus concentrations indicate greatest *Phormidium* biomass under a high nitrogen-high phosphorus treatment (Heath *et al.* 2016). *Phormidium* blooms are likely to require elevated concentrations of both nitrogen and phosphorus. However, *Phormidium* blooms generally show a correlation with low river water concentrations of phosphorus (<0.01 mg/L) (Wood, Wagenhoff, and Young, 2014; McAllister, 2014). *Phormidium* mats may use alternative sources of phosphorus (e.g. those attached to particles such as sediment) when water column phosphorus is low. Wood *et al.* 2015 found that phosphorus may be released from sediment that has become trapped beneath the *Phormidium* mats via internal geochemical conditions. When the mats experience elevated pH or low DO conditions, phosphorus may be released from trapped sediment. When water column phosphorus is low and nitrogen is elevated, *Phormidium* sp. may have a competitive advantage over other periphyton by obtaining phosphorus from sediment.

In the Waiau River catchment, potential risk factors for cyanobacteria could include low, stable periods of flow accompanied by elevated nitrogen concentrations and sediment bound phosphorus. At present, the Waiau River does not appear to be susceptible to cyanobacteria blooms. In dry years when the frequency of effective flushing flows is reduced, there may be potential for cyanobacteria blooms due to longer accrual periods. With Nitrogen predicted to increase in the Waiau River catchment, the role of sediment bound phosphorus is likely to become an important factor with regards to *Phormidium* blooms.

Summary

The Mason River is most likely to exhibit large nutrient increases under the modelled scenario. Nitrate-N is predicted to increase 49% in this catchment. With longer accrual periods, this catchment is susceptible to the influence of elevated nutrient concentrations on periphyton biomass. This is reflected by the more conservative nutrient thresholds adapted from the Biggs (2000) equations when compared to nutrient thresholds for the Waiau River and the Matheson guidelines. Chlorophyll A concentrations for the Mason River at SH70 indicate this site exceeds national bottom line objectives from the National Policy Statement on occasion. Further nutrient increases are likely to exacerbate this, with a predicted increase of 18% in chlorophyll A biomass based on nitrate-N increases from EPI. The predicted increase of 5% in chlorophyll A biomass based on DRP concentrations is likely to be conservative for the Mason River. The Biggs (2000) equation does not take into consideration the release of phosphorus from sediment that can be utilised by cyanobacteria. When this source of phosphorus is coupled with elevated DIN, the chlorophyll A biomass may be greater than predicted if cyanobacteria is the dominant algae at this site.

DRP concentrations were below the nutrient thresholds adapted from the Biggs (2000) equations for all three Waiau River sites. In contrast, DIN concentrations increased with distance downstream. The SH1 site exceeded the nutrient threshold, and was considered moderate to high risk for nuisance periphyton growth for DIN. The influence of instream phosphorus may be less important in this instance if the elevated DIN concentrations are coupled with low flow and a sediment bound phosphorus source. The latest research indicates that cyanobacteria may obtain their phosphorus requirements from a sediment source via internal geochemical conditions. Therefore, the role of DIN and effective flushing flows are more likely to limit periphyton biomass than instream DRP for the Waiau River.

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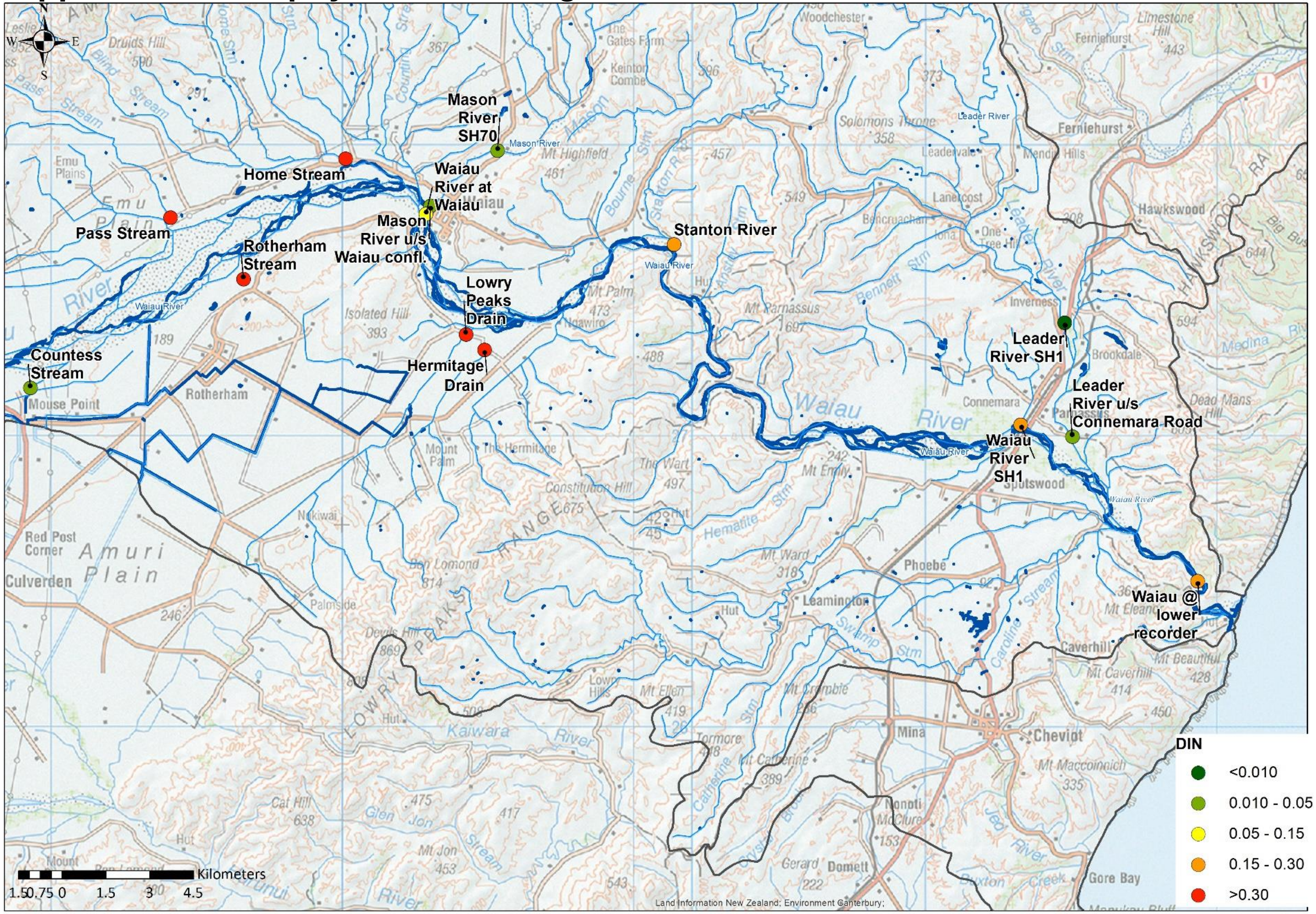
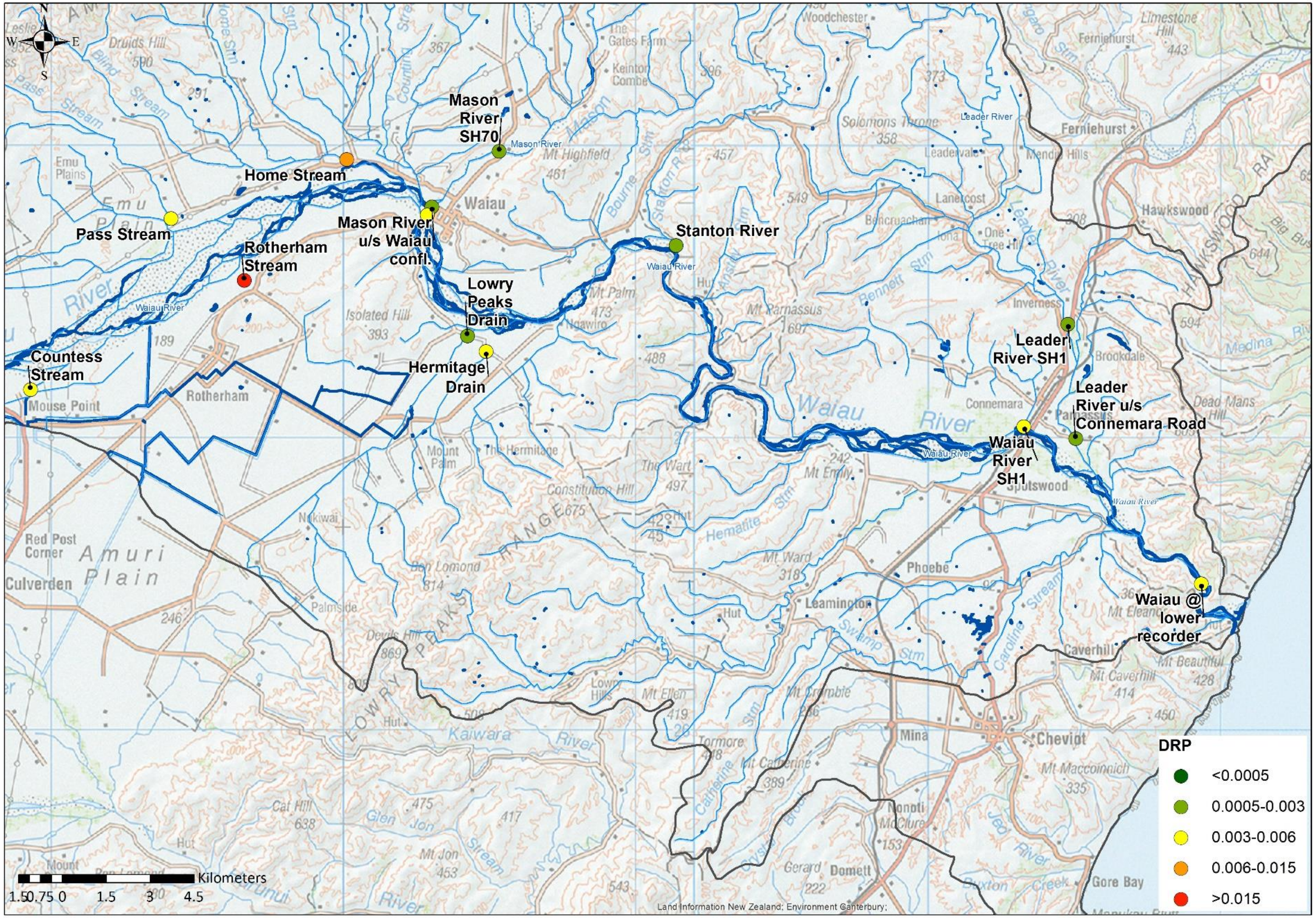
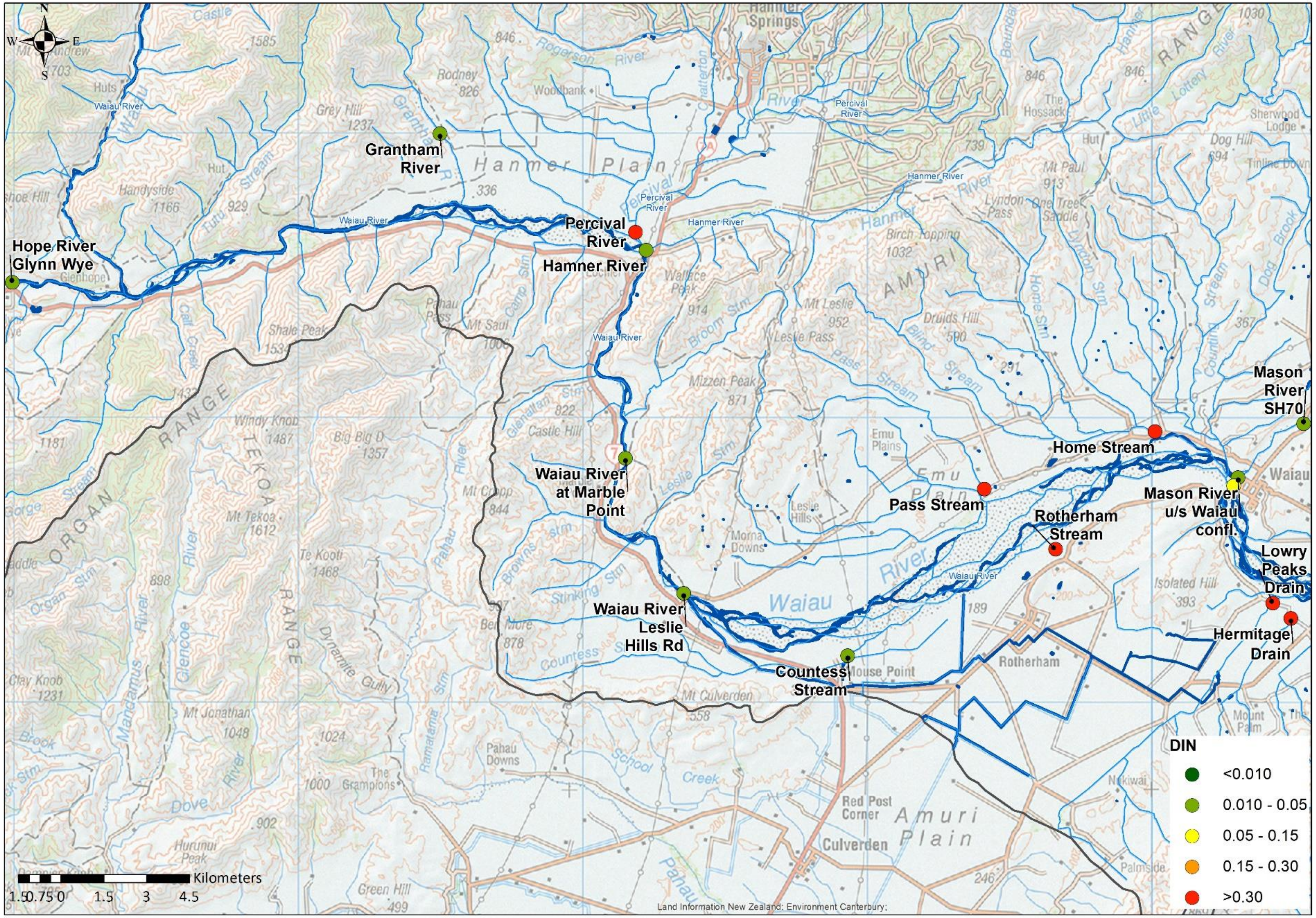
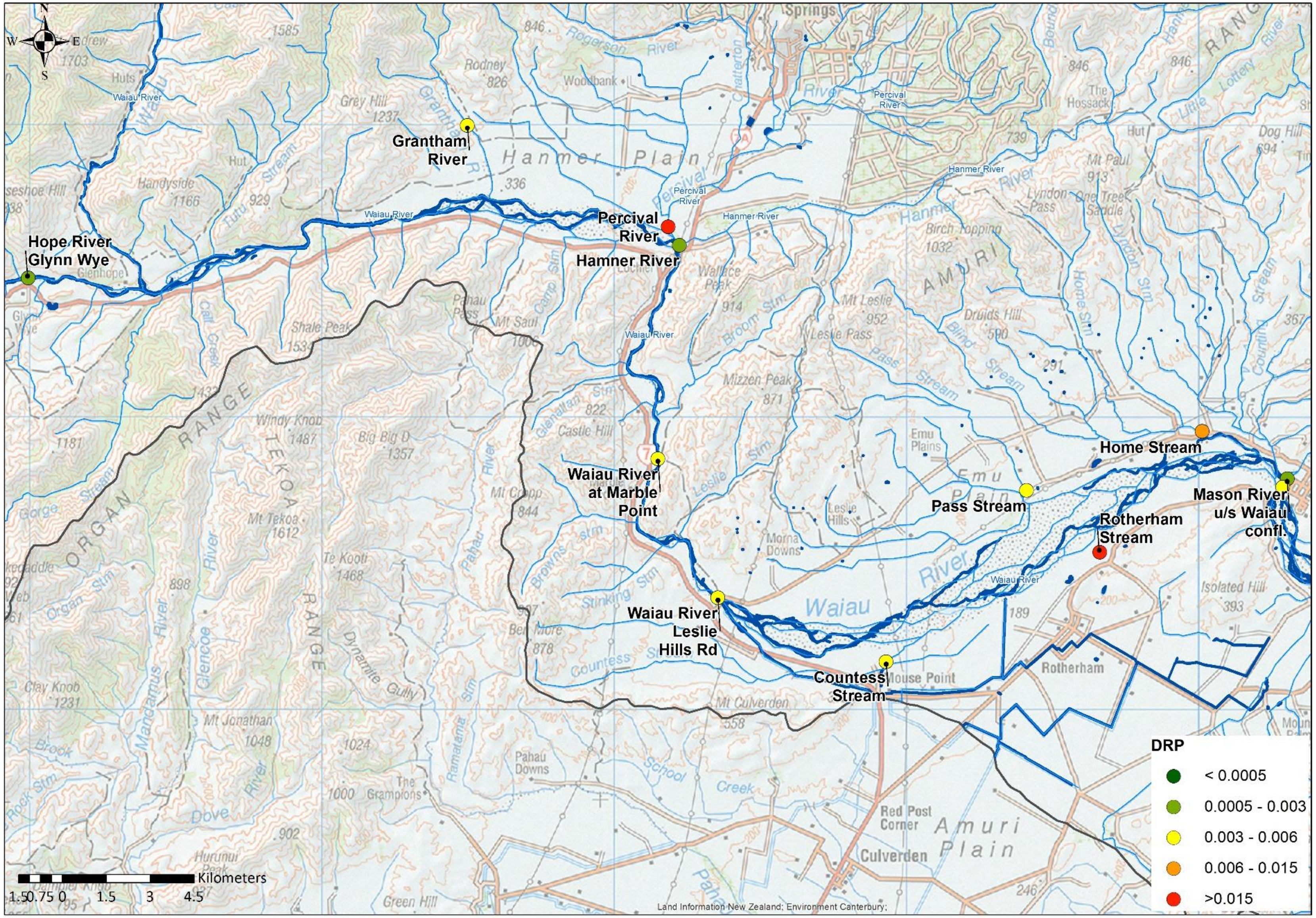
Appendix 1. Periphyton Risk categories based on median nutrient concentrations 2016-17




Mason River SH70
Home Stream
Pass Stream
Rotherham Stream
Mason River u/s Waiau confl.
Stanton River
Lowry Peaks Drain
Hermitage Drain
Countess Stream
Leader River SH1
Leader River u/s Connemara Road
Waiau River SH1
Waiau @ lower recorder
DRP
<0.0005
0.0005-0.003
0.003-0.006
0.006-0.015
>0.015
Kilometers
1.5 0.75 0 1.5 3 4.5
Land Information New Zealand; Environment Canterbury;


Hope River Glynn Wye
Grantham River
Percival River
Hamner River
Waiau River at Marble Point
Waiau River Leslie Hills Rd
Countess Stream
Pass Stream
Home Stream
Rotherham Stream
Mason River SH70
Mason River u/s Waiau confl.
Lowry Peaks Drain
Hermitage Drain
DIN
<0.010
0.010 - 0.05
0.05 - 0.15
0.15 - 0.30
>0.30
Kilometers
1.5 0.75 0 1.5 3 4.5
Land Information New Zealand; Environment Canterbury;



Grantham River
Percival River
Hamner River
Hope River Glynn Wye
Waiau River at Marble Point
Waiau River Leslie Hills Rd
Countess Stream
Pass Stream
Home Stream
Rotherham Stream
Mason River u/s Waiau confl.
Hanmer Plain
Amuri Plain
Waiau River
Culverden
Rotherham
Red Post Corner
DRP
< 0.0005
0.0005 - 0.003
0.003 - 0.006
0.006 - 0.015
>0.015
Kilometers
1.5 0.75 0 1.5 3 4.5
Land Information New Zealand; Environment Canterbury;