Average annual and seasonal accrual periods for Northland streams

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Prepared by:
Craig Depree
Kathy Walter

For any information regarding this report please contact:

Craig Depree
Water Quality Scientist - Group Manager
Environmental Chemistry and Ecotoxicology
+64-7-856 1750
craig.depree@niwa.co.nz

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

Phone +64 7 856 7026

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	Reviewed by:	Cathy Kilroy
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Executive summary

Accrual periods, along with in-stream nutrient concentrations, are key drivers of periphyton biomass in streams. In nutrient limited systems, while lower nutrient concentrations afford slower growth rates, long accrual periods can still allow for the accumulation of 'nuisance levels' of periphyton biomass. The interplay between nutrient concentrations and accrual period requires an understanding of the latter (in addition to other potentially limiting factors such as substrate and shading) in order to ultimately set guidelines for the former (i.e., instream nutrient concentrations).

A metric used to estimate the frequency of relevant freshes is FRE3, which is defined as the average number of flow events, per year, that exceed 3 times median river flow. The average annual accrual period is then the average number of days between qualifying flow events. During the initial scoping of this work, the general view was that issues relating to excessive periphyton biomass in Northland's streams are largely confined to summer months, on account of typically long, dry Northland summers that have extended periods of stable flow, and consequently long summer accrual periods. To better understand the potential importance of summer accrual periods in driving nuisance periphyton biomass in Northland hard-bottomed streams, Northland Regional Council engaged NIWA to undertake a study:

- to investigate seasonal variation in the two key drivers, namely (1) accrual period and (2) nutrient concentrations
- to use accrual period and nutrient concentration data to predict sites with potential nuisance growths of periphyton, and
- to compare the predictions with available periphyton monitoring data.

Seasonal variation of FRE3 and accrual periods

Flow records from 19 sites were analysed. Average accrual periods (median values of 19 sites) were: 27, 45-55, and 19 days for annual, summer and winter time periods, respectively. On average, accrual periods for summer periods were around 1.8-times longer than average annual values. Winter values were typically 30% shorter than average annual accrual periods. There were no significant differences in the average accrual periods calculated for different summer periods (3 and 6 month durations).

Over the 19 sites, average annual accrual periods ranged between 26 and 43 days, and average summer periods (for the 6 month period Nov-Apr inclusive) accruals ranged from 34 to 95 days. Sites with longer accrual periods corresponded to spring-fed streams (e.g., Waipao). The significance of the increased average summer accrual periods (i.e., 1.8-times longer than average annual) requires additional analyses to be undertaken in other regions.

Summer seasonal accrual periods were moderately to weakly correlated with average annual accrual. If periphyton nuisance growths are largely confined to summer months, then a seasonal (i.e., summer) accrual period metric may be a better predictor of 'nuisance' periphyton pressure in Northland streams.

Seasonal variation in nutrient concentrations

Nutrient concentration data were available from 20 sites. Dissolved inorganic nitrogen (DIN) concentrations showed a strong seasonal pattern, being highest in winter months and lowest in summer months. The median DIN concentration for annual, 6-month summer (Nov-Apr) and 3-month (Dec-Feb) time periods were 0.17, 0.10 and 0.07 g/m^3, respectively. Exceptions to this were spring-fed streams such as Waipao and Otaika, both of which had higher median DIN concentrations (2.6 and 1.3 g/m^3, respectively). Assuming lower DIN does not reflect plant uptake, the approximately 50% lower summer DIN concentrations may ‘offset’ some of added biomass ‘pressure’ associated with longer accrual periods.

Dissolved reactive phosphorus (DRP) concentrations showed no significant seasonal variation. Median DRP concentrations for summer (6-months, Nov-Apr) and annual time periods were similar (i.e., 0.015 and 0.010 g/m^3, respectively). Highest median DRP concentrations (annual) were at Ruakaka, Hakaru, and Awanui (@Waihue) with values of 0.10, 0.05, and 0.06 g/m^3, respectively.

The use of DIN:DRP ratios indicated that nutrition limitation status is dependent on season, with nitrogen and phosphorus limitation dominating over summer and winter periods, respectively (Table ES-1). Phosphorus limitation generally corresponded to sites with median DIN concentrations of >0.3 g/m^3.

Table ES-1: Summary of nutrient limitation status of 20 selected Northland stream sites inferred from DIN:DRP ratios calculated from median concentrations (SoE monitoring data) .

Time period	P-limited (N:P >15)	N-limited (N:P <7)	N:P (7 to 15)
Annual	7	10	3
Summer (NDJFMA)	5	13	2
Winter (MJJASO)	9	5	6

Summary of current periphyton biomass monitoring data:

Eighteen of the 20 water quality sites had periphyton biomass monitoring data comprising between 10 and 20 monthly measurements. Although a minimum of 3 years of monthly monitoring data (i.e., 36 measurements) are required for assessment against the NPS-FM attribute bands, a preliminary assessment of the available data was undertaken. Any sites that exceeded 200 mg/m^2 chlorophyll a (chla) on more than three occasions could already be classified as ‘D’ band (or below the national bottom line). Sites that exceed 200 mg/m^2 of chla on one or two occasions may exceed the D-band threshold (>1 exceedance per year, on average over at least 3 year period) depending on the outcome of monitoring over the next 18-24 months. Based on 8% exceedance frequency of 200 mg/m^2 chla, three sites were potentially classified as ‘D’ band – Hakaru, Punakitere and Waiharakeke. High periphyton biomass in Northland streams was not limited to summer months, with the highest number of sites exceeding 200 and 120 mg/m^2 occurring in April, May and June (although this may reflect dryer than average conditions in 2015). Periphyton impacted sites consisted of both N- and P-limited streams.

Comparison of measured nutrient concentrations with periphyton biomass guideline concentrations: Using average annual accrual periods and modified NZ periphyton guideline values (incorporating a 5-day filter correction), indicative guideline values (to limit periphyton to <200 mg/m^2) for DIN ranged from 0.09 g/m^3 (Waiharakeke) to 0.40 g/m^3 (Mangakahia). DRP guideline concentrations ranged from 0.007 g/m^3 (Waiharakeke) to 0.028 g/m^3 (Mangakahia). Deriving equivalent guideline values using average summer accrual periods resulted, as expected, in overly conservative values. Using summer accrual periods, DIN guideline concentrations (to limit periphyton to <200 mg/m^2) ranged from 0.02 g/m^3 (Waiharakeke) to 0.11 g/m^3 (Waiarohia); and DRP guideline concentrations ranged from 0.002 g/m^3 (Waiharakeke) to 0.009 g/m^3 (Waiarohia). Estimated DIN (from total nitrogen, TN) and DRP periphyton threshold concentrations (to limit periphyton to <200 mg/m^2) derived by Larned et al. (2015) were 0.25 and 0.011 g/m^3, respectively.

Of the three sets of guideline values, those based on average annual accrual periods appeared to provide the most accurate predictions of sites with the potential for nuisance periphyton biomass. As anticipated, the guidance values derived using average summer accrual periods were too conservative, while the single threshold values for DIN and DRP of Larned et al. (2015) were not conservative enough. Results are summarised in Table ES-2.

Table ES-2: Comparison of 'guideline predictions' of nuisance periphyton sites (x) with monitored data (orange and red shaded sites) for selected Northland sites.

Water quality site	Annual period (12 months)			Summer period (Nov-Apr)		
	Limiting nutrient	'modified MfE' guideline	Larned et al. guideline	Limiting nutrient	'modified MfE' guideline	Larned et al. guideline
Awanui at FNDC	N			N		
Hakaru at Topuni	N	x		N	x	
Hatea at Mair Park	P			P	x	
Kaihu at Gorge	P			N/P	x	
Mangahahuru at Main Rd	N/P	x		N	x	
Mangakahia at Twin Br	N			N		
Ngunguru at Coalhill Lane	N/P			N	x	
Opouteke at Suspension Br	N			N		
Otaika at Otaika Valley Rd	P	x	x	P	x	x
Punakitere at Taheke	P	x	x	N/P	x	x
Victoria at Victoria Valley Rd	N			N		
Waiarohia at Second Ave	P			P	x	
Waiharakeke at Stringers	N/P	x		N	x	
Waipapa at Forest Ranger	N			N		
Waipoua at SH12	N			N		
Waitangi at Waimate Rd	P			P	x	

Caveats include: the analysis was limited to median nutrient concentrations (other metrics may be more informative); the comparison with 'guideline values' was based on limited periphyton data that may not be representative of long-term trends if higher than average algal biomass experienced in 2015; and accrual periods are based on a non-standardised flow record time-period (ranging from c. 5 to 45 years) and it is uncertain how historic flows relate to current flow regimes.

However, these caveats aside, given the variation in accrual periods across the 19 flow records examined in this study and the relative importance of this as a driver of periphyton biomass, it is recommended that any future nutrient guidelines would need to incorporate a suitable accrual metric. It is unlikely that a single nutrient limit (for DIN and DRP) would be an effective means of managing nuisance periphyton biomass in Northland streams.

1 Introduction

1.1 Background

As part of their process to give effect to the National Policy Statement for Freshwater Management (NPS-FM) Northland Regional Council is looking at the relative merits of developing instream nutrient limits for managing nuisance levels of periphyton biomass. As part of this process, NIWA was commissioned to increase the understanding of flow regimes, and in particular, average accrual periods, and the implications these periods have on nutrient threshold/guideline development for the region.

Accrual periods, along with in-stream nutrient (dissolved inorganic nitrogen, DIN and dissolved reactive phosphorus, DRP) concentrations, are key drivers of periphyton biomass in streams. In nutrient limited systems, while lower concentrations of the limiting nutrient lead to slower growth rates, long accrual periods can still allow for the accumulation of 'nuisance levels' of periphyton biomass. The interplay between nutrient concentrations and accrual period requires an understanding of the latter in order to ultimately set guidelines for the former (i.e., instream nutrient concentrations). Periphyton biomass in streams is controlled by a number of other factors (e.g., substrate suitability, level of shading and grazing pressure). This report considers only nutrients and accrual[1] period as drivers.

The NPS-FM provides attribute states (i.e., bands) for periphyton biomass [using chlorophyll a (chla) concentration as a proxy measure], including a national bottom line value (boundary between the C and D band) of 200 mg/m^2 chla. The NPS-FM specifies an average exceedance criterion of 1 in every 12 months (8%) for most River Environment Classifications (REC) classes. Exceptions to this include 'warm dry' (WD) and 'cold dry' (CD) climate classes (with certain catchment geology[2]) where exceedance of 200 mg/m^2 of chla is permitted, on average, 2 months in every year (16%).

An accrual period is defined as the period of time between flood events of sufficient magnitude to physically remove (slough) periphyton biomass from the stream substrate. In other words it is the period available for periphyton to accumulate without interference from flood removal processes. The length of the accrual period has implications for instream nutrient limit setting – the longer the accrual period, the greater the mass of periphyton that can establish. If accrual periods are typically short, nuisance levels of periphyton can accrue only if nutrient concentrations are high enough to lead to rapid growth rates. This is reflected in the Ministry for the Environment (MfE) periphyton guidelines (MfE 2000) periphyton guidelines, which provide guideline concentrations of DIN and DRP that limit chlorophyll a concentrations to less than 200 mg/m^2 including adjustments according to days of accrual (refer Table 2-5). For example, doubling the average annual accrual period from 20 to 40 days decreases the DIN guideline concentration (for biomass <200 mg/m^2 of chla) from 0.30 to less than 0.04 g/m^3.

The DIN and DRP thresholds provided in the NZ periphyton guidelines (MfE 2000) appear to be overly restrictive (see Snelder et al. 2015, Appendix B in Larned et al. 2015). The reasons for this appear to be that the original research that developed these criteria (Biggs, 2000a) used data from sites at which only nutrients were limited the growth of periphyton biomass (Snelder et al. 2015). In reality,

[1] The term 'accrual' is used rather than "growth" because the rate of accumulation of periphyton is affected by factors that continually reduce biomass as well as by the process of growth through cell division. These include invertebrate grazing, and cell losses through senescence or hydraulic disturbances.
[2] REC geology classes include soft sedimentary (SS), volcanic acidic (VA) and volcanic basic (VB).

periphyton at some Northland sites are likely to be limited by other factors such as adequate substrate and light.

The flow of water required to remove periphyton is stream-dependent (e.g., catchment slope and substrate type), but in New Zealand, this is most commonly defined as being 3times the annual median flow (Biggs, 2000). The annual frequency of 3-times median flow events is called the FRE3 (Clausen & Biggs, 1997). The annual average accrual period is calculated by dividing 365 by FRE3. For example, the annual average accrual period for streams with a FRE3 of 18 and 12 would be 20 (365/18) and 30 (365/12) days, respectively.

Periphyton growth is expected to be greatest during summer months when temperatures are warmer and stream flows are most stable (i.e., longer accrual periods). Thus we would expect most streams to have longer average accrual periods in summer than in. However, seasonal rainfall patterns vary considerably throughout the country, and it is likely that the relationship between summer and annual accrual periods will differ between regions. Moreover, depending on a region's climate, it is uncertain whether average annual accrual periods are a good predictor of summer (or other seasonal) accrual periods. If nuisance periphyton proliferations occur largely in summer months, and average annual accrual periods are not strongly correlated with average summer accrual periods, are annual average accruals a good (or the best) predictor of nuisance periphyton 'pressure' in Northland streams?

1.2 Study objectives

To better understand the potential importance of summer accrual periods in driving nuisance periphyton biomass in Northland hard-bottomed streams, Northland Regional Council engaged NIWA to undertake a study to investigate seasonal variation in the two key drivers of periphyton standing crop, namely (1) accrual period and (2) nutrient concentrations, and to use this data to predict sites with potential nuisance growths of periphyton, and to compare this was available periphyton monitoring data.

The project involved the following components:

a) analysis of seasonal variation of accrual periods and comparison with average annual accrual period

b) determination of nutrient guideline concentrations for <200 mg/m^2 of periphyton biomass, using the NZ periphyton guidelines (MfE 2000) and accrual periods determined in (a)

c) comparison of nutrient guideline values (determined in (b)) with actual measured concentrations (SoE monitoring); and with recently derived nutrient concentration thresholds (Larned et al. 2015) to determine 'potential nuisance' sites

d) comparison of 'potential nuisance' sites (determined in (c)) with available measured chla biomass data.

2 Methods

2.1 General FRE3 methodology

FRE3 is a measure of the frequency of river bed disturbance by increases in flow (Clausen and Biggs, 1997). It is the average annual frequency of freshes/floods more than three times the median flow where the floods/freshes are measured as mean daily flows, and where floods occurring within a specified time period are considered as one flood. It was developed to measure how often periphyton and invertebrate communities would be reset. The Tideda PSIM program developed by M. Duncan (NIWA) has inputs of a record of the mean daily flows, the whole record median flow and period where multiple floods are considered as one. The record is interrogated to find when the flow gets above the median flow and when the flows drops below the median flow a FRE3 event is counted as long as a second event does not occur within the multiple flood period. When the entire record has been interrogated, the number of FRE3 events is divided by the record length in years to give the FRE3 value for the record in units of events/year.

2.2 Sites

Flow data was supplied by NRC for 20 water quality SoE sites that had adequate flow records from nearby sites (Table 2-1). Note that for the two Awanui water quality sites the same flow site (Awanui at School Cut) was used. The 20 sites were selected on the basis of meeting the following criteria: 1) there was a suitable flow record that could be related to the water quality monitoring sites; 2) the flow record was of sufficient duration (ideally >10 years); and, 3) the stream was monitored for periphyton biomass, which limited the streams to those classified as hard bottom substrates. It is noted that much of the stream reaches in Northland are soft bottom streams, which generally do not support nuisance proliferations of periphyton (Snelder et al. 2013).

Table 2-1: List of 20 water quality and corresponding flow monitoring sites used for the FRE3 analysis.

No.	Water quality (WQ) site	WQ Site#	Closest flow site	Flow site#	Duration (years)
1	Awanui at FNDC take	100363	Awanui at School Cut	1316	55
2	Awanui at Waihue Channel	100370	Awanui at School Cut	1316	55
3	Hakaru at Topuni	109021	Hakarau at Topuni Creek Farm	46020	3.9
4	Hatea at Mair Park Foot Bridge	100194	Hatea at Whareora Rd	5538	16
5	Kaihu at Gorge	102256	Kaihu at Gorge	46611	43
6	Mangahahuru at end Of Main Road	100237	Mangahahuru at County Weir	46674	43
7	Mangakahia at Twin Bridges (NIWA)	109096	Mangakahia at Gorge	46618	54
8	Manganui at Mititai Road	102257	Manganui at Permanent Station	46651	51
9	Ngunguru at Coalhill Lane	110603	Ngunguru at Dugmores Rock	4901	45
10	Opouteke at Suspension Bridge	102258	Opouteke at Suspension Br	1046651	29
11	Otaika at Otaika Valley Road	110431	Otaika at Kay	5659	4.6
12	Punakitere at Taheke	105231	Punakitere at Taheke	47595	19
13	Ruakaka at Flyger Road Bridge	105008	Ruakaka at Flyger Rd	5901	30
14	Victoria at Thompsons Bridge	105532	Victoria at Victoria Valley Road	1351	8.5
15	Waiarohia at Second Ave	108359	Waiarohia at Lovers Lane	5527	31
16	Waiharakeke at Stringers Road Bridge	100007	Waiharakeke at Willowbank	3819	45
17	Waipao at Draffin Road Bridge	108941	Waipao at Draffins Rd	46641	33
18	Waipapa at Forest Ranger	101751	Waipapa at Forest Ranger	47804	37
19	Waipoua at SH12 Bridge	103304	Waipoua at SH12	46902	8.2
20	Waitangi at Waimate Road Bridge	103178	Waitangi at Waimate North Rd	3725	3.7

2.3 Calculation of average accrual periods

The number of qualifying flow events (i.e., those >3x annual median flow) were determined using standard procedures (Clausen and Biggs, 1997). This included using a 5-day filter to exclude any 3x median flow events that occurred within 5 days of a previous qualifying event. The time periods that FRE3 statistics were calculated for are summarised in Table 2-3. The median flow for each flow recorder site was used to calculate the number of 'FRE3' events for each time period.

By definition, FRE3 as the average number of qualifying flow event that occur per year, with the *average annual accrual period* calculated by dividing 365 days by the FRE3 value. To extend this approach to determining 'average seasonal FRE3' count and calculation of the corresponding *average seasonal accrual period* we determined the total number of qualifying 'FRE3' flow events (i.e., those >3x median flow and outside the 5-day filter period) for each time period within the entire flow record. The average accrual period for each time period of interest (days) was then calculated by dividing the *total number of days for each time period* by the corresponding *number of qualifying flow events* (i.e., >3x median flow). A worked example is shown for the 'Kaihu at Gorge' site in Table 2-2.

Table 2-2: Example of calculation of average accrual period for Kaihu at Gorge. Average accrual is the total number of days (top row) divided by the total number of qualifying flow events (3x median with 5-day filter) occurring for each time period.

Flow site	Kaihu at Gorge								
	annual	MJJ-ASO	NDJ-FMA	NDJ	DJF	JFM	FMA	MJJ	ASO
Total no. of days	15,621	7,959	7,576	3,895	3,743	3,696	3,640	3,920	3,996
No. of qualifying flow events	603	454	150	86	65	63	66	234	227
Average accrual period (days/events)	26	18	51	45	58	59	55	17	18

Table 2-3: Different monthly intervals used to determine average accrual periods (days). Total number of days divided by the number of qualifying flow events (>3x median).

Time period	No. of months	Abbreviation	'Season'
All months	12	Annual	annual average
Nov, Dec, Jan, Feb, Mar, Apr	6	NDJFMA	summer
May, Jun, Jul, Aug, Sep, Oct	6	MJJASO	winter
Nov, Dec, Jan	3	NDJ	summer
Dec, Jan, Feb	3	DJF	summer
Jan, Feb, Mar	3	JFM	summer
Feb, Mar, Apr	3	FMA	summer
May, Jun, Jul	3	MJJ	winter
Aug, Sep, Oct	3	ASO	winter

2.4 Nutrient concentrations (dissolved inorganic nitrogen and phosphorus)

Nutrient concentrations (limited to DRP and DIN) for all 20 sites were provided by Northland Regional Council (NRC). Nutrient data from January 2002 to September 2015 were used, although approximately half the sites did not have data spanning this entire time period (Table 2-4). The time period selected for the water quality was independent of the flow record period used to calculate accrual periods (up to 40 years of flow record for some sites).

Table 2-4: Summary of water quality sampling periods used to determine annual and seasonal average nutrient concentrations for the 20 water quality sites.

Water quality site	Start date	Finish date	n (samples)
Awanui at FNDC take	Apr-02	Sep-15	161
Awanui at Waihue Channel	Jan-02	Sep-15	160
Hakaru at Topuni	Sep-07	Sep-15	97
Hatea at Mair Park Foot Bridge	Jul-08	Aug-15	101
Kaihu at Gorge	Jul-02	Aug-15	157
Mangahahuru at end Of Main Road	Jul-05	Aug-15	122
Mangakahia at Twin Bridges (NIWA)	Jul-08	Aug-15	84
Manganui at Mititai Road	Jan-02	Sep-15	165
Ngunguru at Coalhill Lane	Nov-11	Aug-15	47
Opouteke at Suspension Bridge	Jan-02	Aug-15	161
Otaika at Otaika Valley Road	Jul-11	Sep-15	66
Punakitere at Taheke	Jan-02	Aug-15	164
Ruakaka at Flyger Road Bridge	Aug-06	Sep-15	110
Victoria at Thompsons Bridge	Jan-02	Sep-15	164
Waiarohia at Second Ave	Jul-05	Sep-15	138
Waiharakeke at Stringers Road Bridge	Aug-06	Aug-15	109
Waipao at Draffin Road Bridge	Jan-07	Sep-15	110
Waipapa at Forest Ranger	Jan-02	May-15	161
Waipoua at SH12 Bridge	Jul-02	Aug-15	158
Waitangi at Waimate Road Bridge	Jan-02	Sep-15	179

The number of monthly DIN and DRP data points between 2002 and 2015 ranged from 47 to 165. Censored data (below detection limit) were entered as half the detection limit value (i.e., a value of <0.002 g/m^3 was entered as 0.001 g/m^3). DIN data was grouped by the same nine seasonal periods used for flow analysis (Table 2-3), while DRP concentrations were grouped by annual and the nominal 6-month summer (Nov to Apr) and winter (May to Oct) periods (given that there was no apparent seasonal variation in median DRP concentrations – refer to Figure 3-8).

2.5 Nutrient guidelines for periphyton growth

The MfE periphyton guidelines (MfE 2000) provide nutrient concentrations (DIN and DRP) for managing periphyton (diatom dominated) abundance to <200 mg/m^2 of chla for different average accrual periods (Table 2-5). The MfE periphyton guidelines use average annual accrual periods calculated with a '0-day filter' whereas in this report we used a 5-day filter. In order to compare 'apples with apples' the annual average accrual periods (derived using a 0-day filter) that appear in the periphyton guidelines (reproduced in column 2, Table 2-5) were converted to 5-day filtered results using the regression derived by Booker (2013).

Table 2-5: NZ periphyton guidelines (MfE 2000) criteria for DIN and DRP for chla concentrations of <200 mg/m² with estimated 5-day filter accrual periods. Grey shading indicates the values used to derive the power regressions (refer to Figure 2-1). Days of accrual is based on the mean value of days of accrual (365/FRE3). Modified FRE3 5-day filter periods are calculated using the regression of Booker (2013).

Annual average FRE3 (0 day filter)[1]	Average annual accrual period (0 day filter)	DIN (g/m³)	DRP (g/m³)	Estimated annual average FRE3 (5-day filter)[1]	Estimated average annual accrual period (5-day filter)[2]
18	20	<0.295	<0.026	11	33
12	30	<0.075	<0.006	9	40
9	40	<0.034	<0.0028	7	53
7	50	<0.019	<0.0017	5.5	67
5	75	<0.01	<0.001	3.7	100
4	100	<0.01	<0.001	2.7	133

[1] 0-day filter includes all flow events >3x median, using a 5-day filter excludes those 3x flow events that occur within 5 day of an early qualifying flow event. The reasoning for this is that <5 days is considered insufficient for the accrual of significant periphyton biomass. [2] FRE3 = 365/average accrual period; average accrual period = 365/FRE3.

The regression curves (power function) between nutrient guideline values and average accrual period (5-day filter values) are shown in Figure 2-1. Using the power regressions, the guideline nutrient concentrations approach a minimum value of 0.01 and 0.001 g/m³ for DIN and DRP (orange dashed line in Figure 2-1), respectively, for average accrual periods (5-day filter) of around 70 to 80 days.

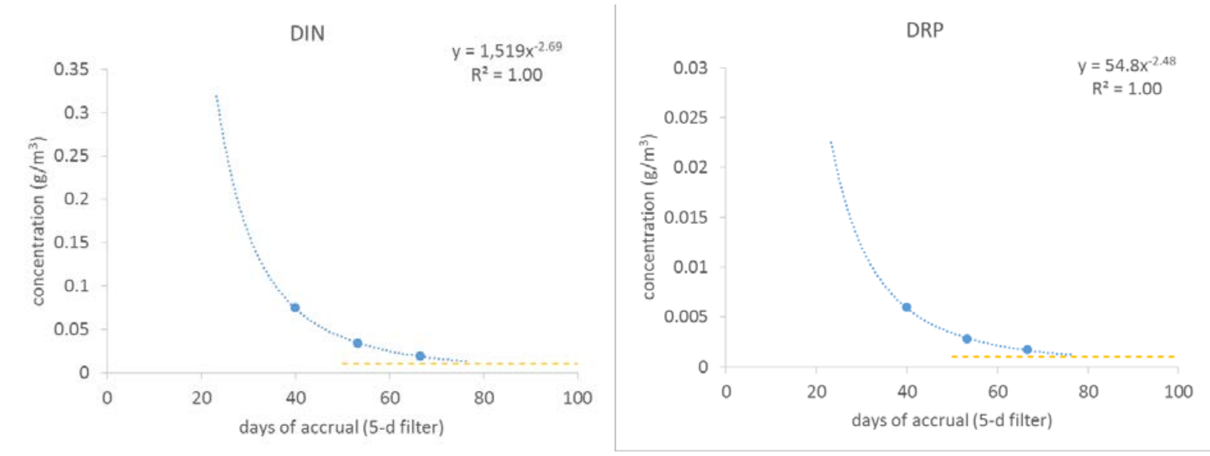

Figure 2-1: Power function regression of nutrient guideline concentrations (DIN left, and DRP right) and average accrual period (days) for <200 mg/m² of chla. Data from MfE (2000) with average accrual periods modified from 0-day to 5-day filtered values using the regression of Booker (2013).

In addition to the periphyton guideline values, Larned et al. (2015) derived nutrient threshold concentrations for REC source-of-flow classes. For the predominant Northland REC source-of-flow class (warm wet, low elevation, WWL), the estimated TN and DRP thresholds corresponding to <200 mg/m^2 chla (92% of the time, or exceeding 8% of the time) were 0.336 and 0.011 g/m^3, respectively. Using the relationship of DIN (site median) = 0.75 x TN (site median) (refer to Appendix B of Larned et al. 2015), the TN threshold corresponds to a DIN concentration of around 0.25 g/m^3. The authors, however, emphasised that there were some significant limitations associated with the derived nutrient criteria and that they should only be used as a provisional guide.

2.6 Comparison with Northland periphyton data

To undertake a preliminary evaluation of the periphyton thresholds (for chla concentrations of <200 mg/m^2) derived from annual and seasonal accrual periods for the selected Northland streams, these were compared with median DIN and DRP concentrations (for seasonal and annual time periods) for the 20 sites provided by Northland Regional Council (NRC). Nutrient data from January 2002 to September 2015 were used, although approximately half the sites did not have data spanning this entire time period. The nutrient concentration statistic used for each period (annual and 6-month summer) was the median (50th percentile) value. Other statistics (for example higher percentile values, or mean values) may be more suitable for undertaking such assessments, but exploration of this was beyond the resourcing of this project.

Potential for nuisance periphyton biomass was indicated for sites where the median concentration (for the multi-year record) exceed the various threshold concentrations (including those derived by Larned et al. 2015). The results of this analysis were then compared with the approximately 15 to 20 months of periphyton monitoring data available for 18 of the 20 river sites. For the purposes of this report, sites with potentially nuisance periphyton biomass were defined as sites that had at least one observation of >200 mg/m^2 of chla. Indicative agreement between 'predicted' and 'measured' nuisance periphyton biomass were then made using the above operational definitions of sites with potential for nuisance periphyton standing crop.

The nutrient concentration statistic used for each period (annual and 6-month summer) was the median (50th percentile) value. The reason for selecting this statistic was primarily 'convention'. Other statistics (for example higher percentile values, or mean values) may be more suitable for undertaking such assessments, but exploration of this was beyond the resourcing of this project.

3 Results and Discussion

3.1 Accrual periods

Average accrual periods for the 19 flow sites are summarised in Table 3-1. The total number of days within each flow period for each site is provided in Table A-1 (Appendix A). The number of qualifying flow events (<3-times median, and occurring >5 days from preceding event) for each flow period and site are given in Table A-2 (Appendix A).

Table 3-1: Summary of average annual and seasonal accrual periods (days) for the 19 Northland flow sites. Hakarau, Otaika and Waitangi shown in bold because these sites have <5 years of data.

Flow site	Time period analysed								
	Annual	MJJ-ASO	NDJ-FMA	NDJ	DJF	JFM	FMA	MJJ	ASO
Awanui at School Cut	23	16	42	36	44	58	51	15	16
Hakarau at Topuni Creek Farm	**30**	**19**	**66**	**61**	**45**	**90**	**71**	**19**	**18**
Hatea at Whareora Rd	29	21	44	50	46	48	39	20	22
Kaihu at Gorge	26	18	51	45	58	59	55	17	18
Mangahahuru at County Weir	35	26	52	53	55	54	51	24	28
Mangakahia at Gorge	21	15	36	33	40	45	39	15	15
Manganui at Permanent Station	35	25	57	53	61	67	61	24	22
Ngunguru at Dugmores Rock	30	22	46	49	53	48	42	21	23
Opouteke at Suspension Br	23	16	39	38	40	41	40	16	17
Otaika at Kay	**37**	**25**	**74**	**62**	**66**	**85**	**89**	**24**	**23**
Punakitere at Taheke	26	18	50	48	54	60	53	16	19
Ruakaka at Flyger Rd	27	19	45	49	45	44	42	19	19
Victoria at Victoria Valley Road	24	17	43	39	38	54	45	16	17
Waiarohia at Lovers Lane	26	21	34	34	34	35	33	20	21
Waiharakeke at Willowbank	38	25	68	63	72	71	72	25	23
Waipao at Draffins Rd	43	28	95	103	93	94	88	27	29
Waipapa at Forest Ranger	23	17	36	35	37	42	36	17	18
Waipoua at SH12	23	15	52	57	48	56	51	13	17
Waitangi at Waimate North Rd	**27**	**18**	**48**	**37**	**40**	**120**	**71**	**19**	**18**

MJJASO = 6 month winter period May through to Oct; NDJFMA = 6 month summer period Nov through to Apr; NDJ = Nov-Dec-Jan; DJF = Dec-Jan-Feb; JFM = Jan-Feb-Mar; FMA = Feb-Mar-Apr; MJJ = May-Jun-Jul; ASO = Aug-Sep-Oct.

To better visualise comparison between different seasonal periods, the data (grouped by season) is shown as box plots using both absolute and relative scales (Figure 3-1 – left and right, respectively). Summary statistics for each seasonal period (including annual) are provided in Table 3-2.

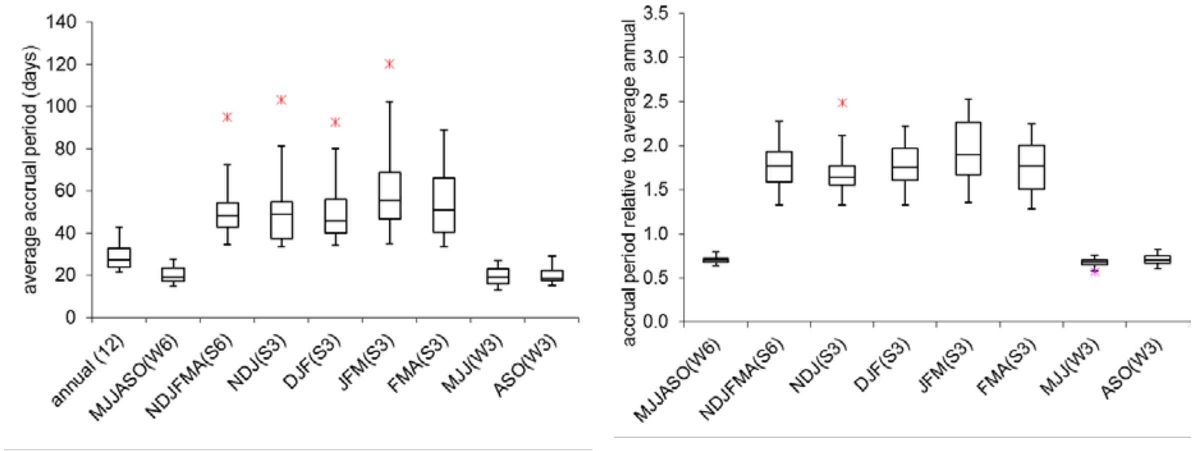

Figure 3-1: Accrual periods grouped by seasonal period - both absolute (left) and relative (to the average annual accrual period, right) values are shown. Refer to Table 3-1 footnote for time period abbreviations. The 'W' and 'S' in parentheses designate nominal winter and summer months – i.e., W6 = six winter months.

Table 3-2: Statistical summary of seasonal accrual period statistics grouped by 'season' (n=19 sites). Both absolute (upper) and relative (to the average annual accrual period, bottom) values are shown.

	Annual	MJJ-ASO(W6)	NDJ-FMA(S6)	NDJ(S3)	DJF(S3)	JFM(S3)	FMA(S3)	MJJ(W3)	ASO(W3)
Absolute values (days)									
Minimum	21	15	34	33	34	35	33	13	15
25th %ile	24	17	43	37	40	47	41	16	17
Median	27	19	48	49	46	56	51	19	19
75th %ile	33	23	55	55	56	69	66	23	22
Maximum	43	28	95	103	93	120	89	27	29
IQR	9	6	12	18	16	22	26	7	5
Relative values (seasonal accrual times relative to the average annual accrual period)									
Median	-	0.70	1.8	1.6	1.8	1.9	1.8	0.68	0.70

Key points:

- In general, the results indicate that periphyton removal from flushing events would be expected to be less frequent (i.e., longer accrual periods) in summer months because of flushing flows occur less frequently in summer.
- Median, average annual accrual periods were: 27, 46-56, and 19 days for annual, summer and winter time periods, respectively.
- In relative terms, based on median values, summer accrual periods (48 days, e.g., NDJFMA) were around 1.8-times greater than average annual values (27 days). Winter accrual periods (19 days, e.g., MJJASO) were 30% lower than the average annual accrual period.

- Across all 19 sites, summer accrual periods were, as expected, greater than average annual accrual values. However, the relative importance of the difference (with respect to accrual of nuisance periphyton biomass in Northland streams) would require a similar analysis to be undertaken in different regions.
- Differences in the accrual periods of the five summer time periods were not statistically significant, and therefore we can probably adequately represent 'summer conditions' using the 6-month Nov to Apr summer period (NDJFMA).

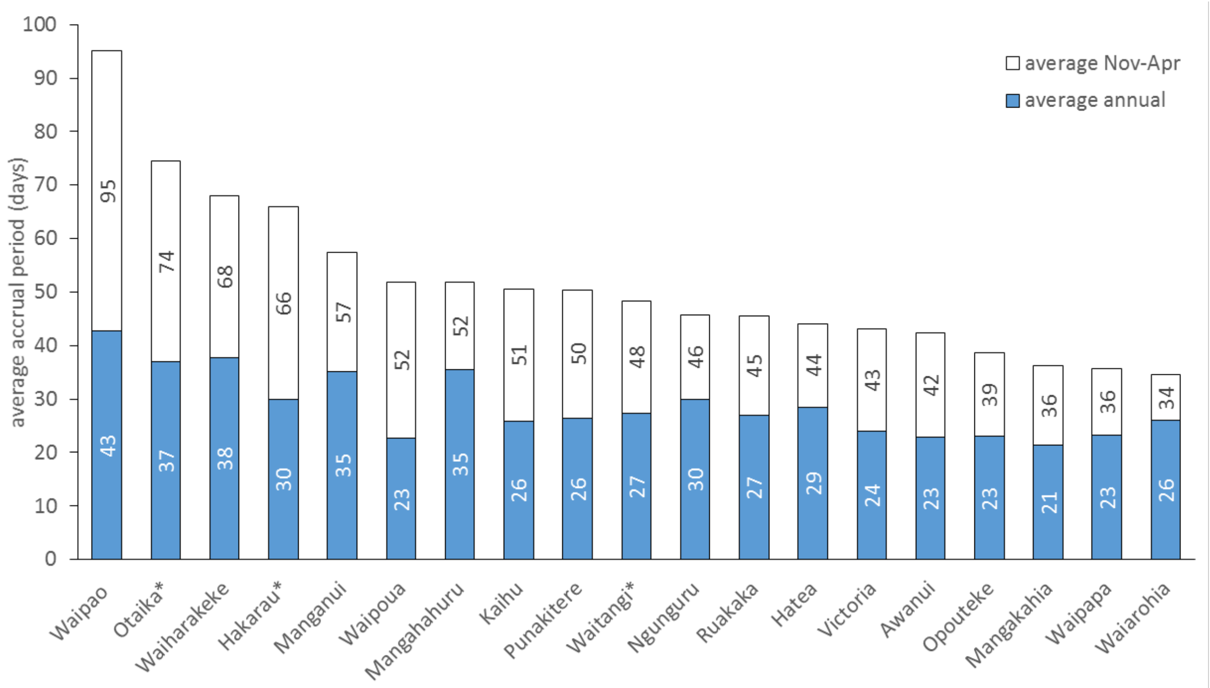

Figure 3-2: Comparison of average annual and average 'summer' (6 month period, NDJFMA) accrual periods for the 19 Northland flow sites. Summer values (combined height of blue and white bars) are shown in black font and average annual values (blue bars) are given in white font. For example, for Waipao, the average annual and summer (NDJFMA) accrual period is 43 and 95 days, respectively. Sites with asterisk indicate <5 years of available flow data.

3.1.1 Correlation of average seasonal and average annual accrual periods

Correlations of both winter and summer seasonal accrual periods against average annual accrual periods are shown in Figure 3-3. The coefficient of determination (R^2) of nominal 6-month winter and summer periods with average annual accrual periods was 0.91 and 0.62, respectively. Including the Waipao, the summer R^2 value increased to 0.72. For 3-month 'winter' periods, the coefficient of determination with annual average accrual periods was 0.91 (MJJ) and 0.71 (ASO). Correlations between annual average and some 3-month summer periods were relatively weak (e.g., FMA, R^2 = 0.4, Figure 3-3). This indicates that for Northland streams, depending on the seasonal period selected, the average annual accrual period may not be a good predictor of certain summer accrual periods. If these summer accrual periods (e.g., NDJ) were better predictors of nuisance periphyton occurrence, then an annual average accrual metric may not be the best approach.

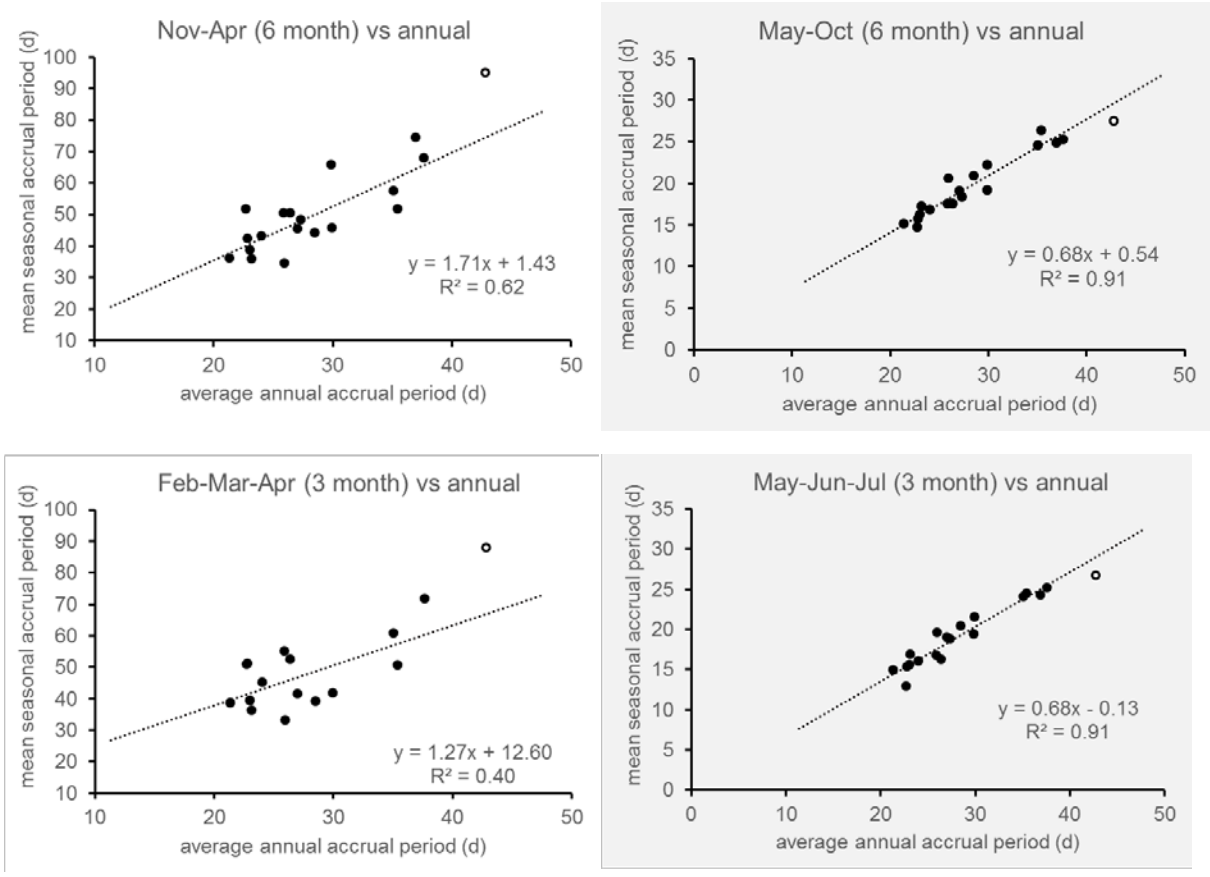

Figure 3-3: Correlations of average seasonal and average annual accrual periods (n=19 sites). Open circle = Waipao, which was excluded as it was spring-fed dominated stream. Shaded and non-shaded figures identify winter and summer seasonal periods, respectively.

Key points:

- The results support the hypothesis that annual average accrual periods may not be good predictors of summer average accrual periods, which are assumed to be key drivers of periphyton biomass in selected Northland streams.
- Although the results show that average summer accrual periods are almost 2-fold larger than average annual accrual periods, there appears to be no equivalent analysis to provide a national context for the Northland results. For example, information is required on average annual and average seasonal (i.e., summer) accrual periods for other regions – including those regions classified as 'productive classes' (e.g., cold and warm dry climate classes) in the NPS-FM, which are permitted to have up to 16% exceedance of 200 mg/m^2 chla (as opposed to 8% for other regions, including Northland).

3.2 Nutrients

3.2.1 Dissolved inorganic nitrogen (DIN)

Mean DIN concentrations for each calendar month at each site are provided in Table 3-3, and the median values for each of the 12 months (i.e., median of each column of Table 3-3) are plotted in Figure 3-4. The figure shows the pronounced seasonal variation in DIN concentrations across most sites, with lower concentrations occurring during dryer summer months. Presumably this reflects the greater input/contribution of nitrate-enriched shallow ground water to total stream flow during the wetter months and possibly higher instream uptake of nutrients during summer low flows (discussed in section 3.3.2). Both these explanations require further investigation. An example of a site showing pronounced seasonal variation in DIN is the Manganui Stream (Figure 3-5, left) and a spring-fed site showing no significant seasonal variation in DIN concentrations is the Waipao Stream (Figure 3-5, right).

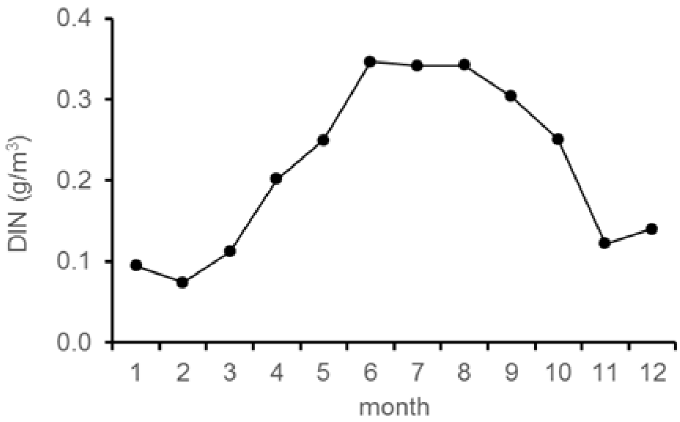

Figure 3-4: Median value of the monthly mean DIN concentrations of the 20 Northland water quality sites highlighting pronounced seasonal variation. 1 = January to 12 = December.

Table 3-3: Mean DIN concentrations (g/m^3) by month for the 20 Northland water quality sites. Maximum time period used was between Jan 2002 and Sep 2015.

Water quality site	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
Awanui at FNDC	0.05	0.02	0.03	0.05	0.06	0.12	0.12	0.10	0.08	0.16	0.03	0.03
Awanui at Waihue Channel	0.11	0.07	0.17	0.19	0.25	0.26	0.30	0.27	0.28	0.26	0.13	0.09
Hakaru at Topuni	0.09	0.11	0.09	0.22	0.27	0.51	0.39	0.42	0.35	0.24	0.16	0.18
Hatea at Mair Park	0.25	0.24	0.39	0.38	0.58	0.53	0.61	0.58	0.45	0.41	0.28	0.33
Kaihu at Gorge	0.10	0.08	0.12	0.22	0.34	0.46	0.50	0.41	0.33	0.32	0.21	0.16
Mangahahuru at Main Rd	0.05	0.06	0.08	0.13	0.17	0.17	0.21	0.24	0.15	0.09	0.09	0.10
Mangakahia at Twin Br’s	0.01	0.01	0.02	0.04	0.11	0.16	0.18	0.17	0.16	0.05	0.04	0.08
Manganui at Mititai Rd	0.06	0.07	0.05	0.12	0.25	0.46	0.48	0.43	0.37	0.32	0.12	0.10
Ngunguru at Coalhill Ln	0.01	0.07	0.10	0.15	0.19	0.15	0.22	0.26	0.19	0.11	0.10	0.12
Opouteke at Suspension Br	0.03	0.03	0.06	0.07	0.14	0.20	0.20	0.18	0.12	0.07	0.04	0.04

Water quality site	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
Otaika at Otaika Valley Rd	1.38	1.43	0.98	1.43	1.27	1.17	1.11	0.90	1.13	1.27	1.65	1.14
Punakitere at Taheke	0.20	0.23	0.34	0.37	0.51	0.56	0.66	0.58	0.51	0.52	0.44	0.29
Ruakaka at Flyger	0.28	0.20	0.29	0.48	0.54	0.73	0.69	0.65	0.56	0.44	0.45	0.40
Victoria at Victoria Valley Rd	0.05	0.02	0.02	0.04	0.03	0.03	0.04	0.03	0.03	0.07	0.03	0.02
Waiarohia at Second Ave	0.11	0.20	0.22	0.33	0.46	0.57	0.60	0.52	0.44	0.40	0.31	0.22
Waiharakeke at Stringers Rd	0.19	0.28	0.19	0.29	0.15	0.16	0.16	0.17	0.12	0.14	0.07	0.18
Waipao at Draffin	2.61	2.57	2.39	2.55	2.41	2.16	2.34	2.44	2.34	3.05	3.10	2.61
Waipapa at Forest Ranger	0.01	0.01	0.01	0.03	0.05	0.05	0.05	0.04	0.04	0.02	0.01	0.02
Waipoua at SH12	0.03	0.02	0.02	0.06	0.04	0.06	0.05	0.06	0.04	0.03	0.02	0.02
Waitangi at Waimate Rd	0.24	0.22	0.25	0.32	0.42	0.43	0.50	0.51	0.45	0.45	0.41	0.33

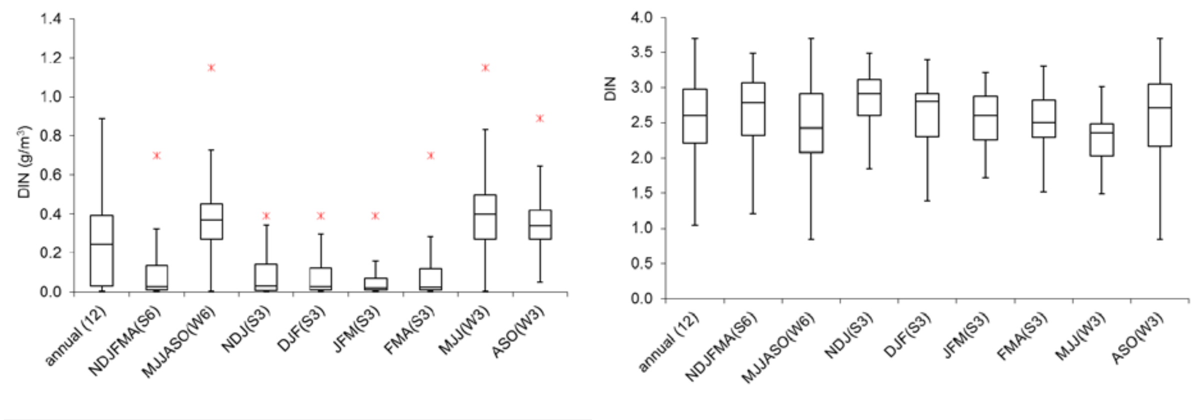

Figure 3-5: Examples of seasonal distribution of DIN at site with (left, Manganui) and without (right, Waipao) a pronounced seasonal trend. Refer to Table 3-1 footnote for time period abbreviations. The 'W' and 'S' in parentheses designate nominal *winter* and *summer* months – i.e., W6 = six winter months.

The distributions of DIN concentrations at the 20 water quality sites for annual and summer (Nov-Apr) periods are summarised in Figure 3-6. Median DIN concentrations for annual, 6 month and 3 month time-periods are presented in Table 3-4. Correlations between seasonal 6 month DIN concentrations and annual median DIN concentrations are shown in Figure 3-7.

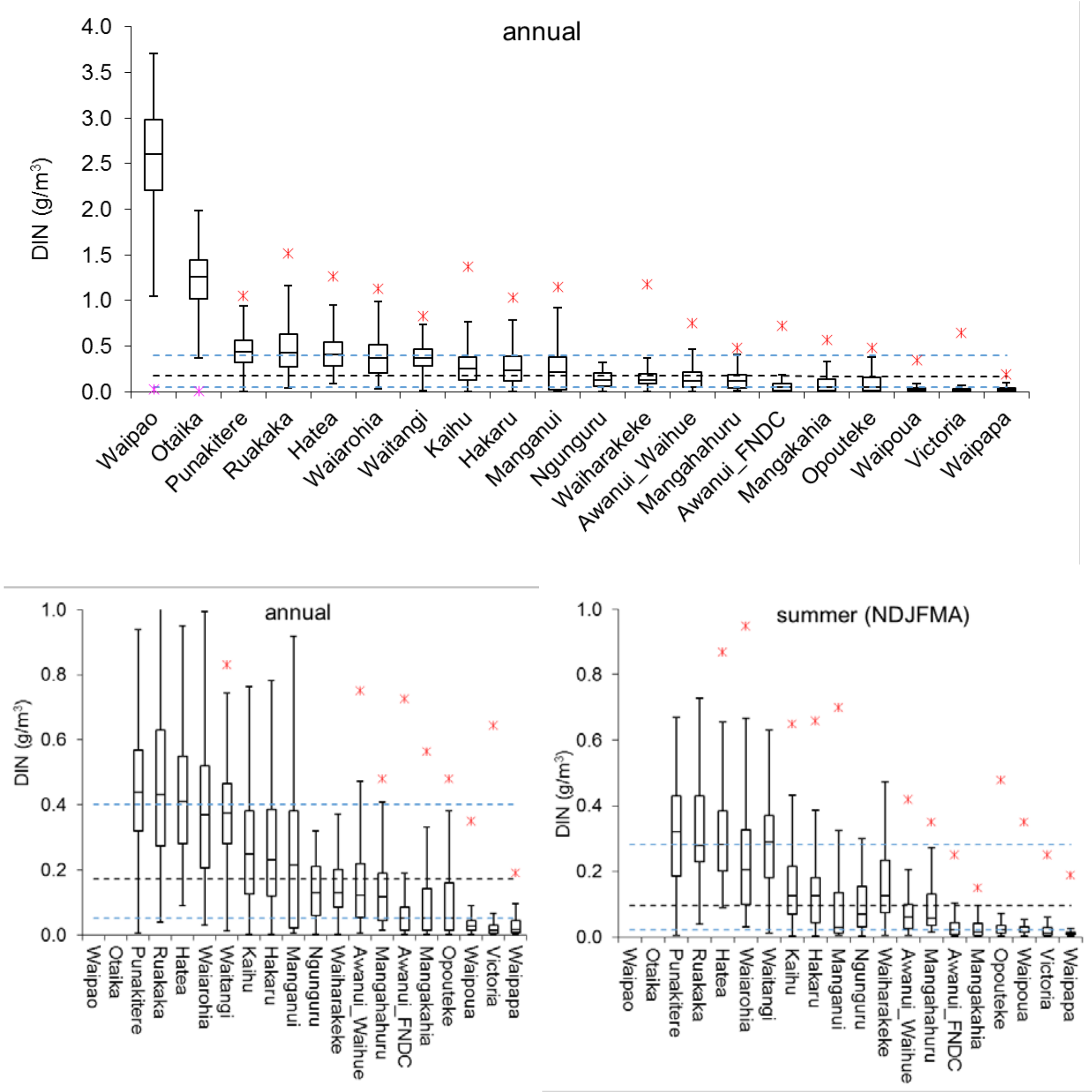

Figure 3-6: Distributions of annual median DIN concentrations (top) for all sites; and comparison of annual (lower left) and summer-NDJFMA (lower right) median DIN concentrations at 18 sites. Waipao and Otaika were not included as there was no seasonal variation at these sites. The black and blue dashed line indicate the 50th percentile and quartiles (25th and 75th) of median DIN concentrations across all sites. The 'median of medians' (black dashed lines) for all sites were 0.17 and 0.10 g/m^3 for annual and summer periods, respectively.

Table 3-4: Median DIN concentrations for the 20 Northland sites that correspond to the seasonal accrual periods.

WQ site	Annual (12)	NDJ-FMA(S6)	MJJ-ASO(W6)	NDJ(S3)	DJF(S3)	JFM(S3)	FMA(S3)	MJJ(W3)	ASO(W3)
Waipao at Draffin	2.604	2.785	2.430	2.910	2.798	2.603	2.505	2.358	2.713
Otaika at Otaika Valley Rd	1.260	1.415	1.145	1.455	1.415	1.260	1.260	1.210	1.105
Punakitere at Taheke	0.438	0.320	0.535	0.350	0.265	0.295	0.320	0.538	0.503
Ruakaka at Flyger	0.430	0.280	0.580	0.350	0.280	0.255	0.263	0.670	0.520
Hatea at Mair Park	0.411	0.283	0.507	0.260	0.230	0.290	0.360	0.560	0.478
Waiarohia at Second Avenue	0.370	0.205	0.510	0.193	0.165	0.148	0.213	0.555	0.465
Waitangi at Waimate Rd	0.375	0.290	0.460	0.333	0.258	0.205	0.265	0.458	0.460
Kaihu at Gorge	0.250	0.125	0.375	0.155	0.090	0.080	0.108	0.400	0.350
Hakaru at Topuni	0.230	0.125	0.360	0.140	0.115	0.095	0.110	0.405	0.340
Manganui at Mititai Rd	0.215	0.028	0.370	0.030	0.026	0.021	0.025	0.398	0.340
Ngunguru at Coalhill Lane	0.130	0.070	0.206	0.070	0.035	0.035	0.070	0.195	0.206
Waiharakeke at Stringers	0.130	0.125	0.135	0.110	0.155	0.180	0.190	0.140	0.133
Awanui at Waihue Channel	0.123	0.060	0.185	0.050	0.050	0.060	0.061	0.175	0.190
Mangahahuru at Main Rd	0.118	0.058	0.160	0.058	0.050	0.048	0.063	0.170	0.145
Awanui at FNDC	0.050	0.020	0.080	0.021	0.021	0.015	0.015	0.085	0.075
Mangakahia at Twin Br	0.050	0.015	0.105	0.020	0.011	0.011	0.011	0.133	0.100
Opouteke at Suspension Br	0.050	0.020	0.136	0.021	0.015	0.015	0.015	0.165	0.075
Waipoua at SH12	0.028	0.015	0.035	0.015	0.015	0.015	0.015	0.045	0.033
Victoria at Victoria Valley Rd	0.015	0.011	0.018	0.013	0.013	0.015	0.011	0.020	0.015
Waipapa at Forest Ranger	0.016	0.009	0.042	0.011	0.009	0.008	0.008	0.051	0.027

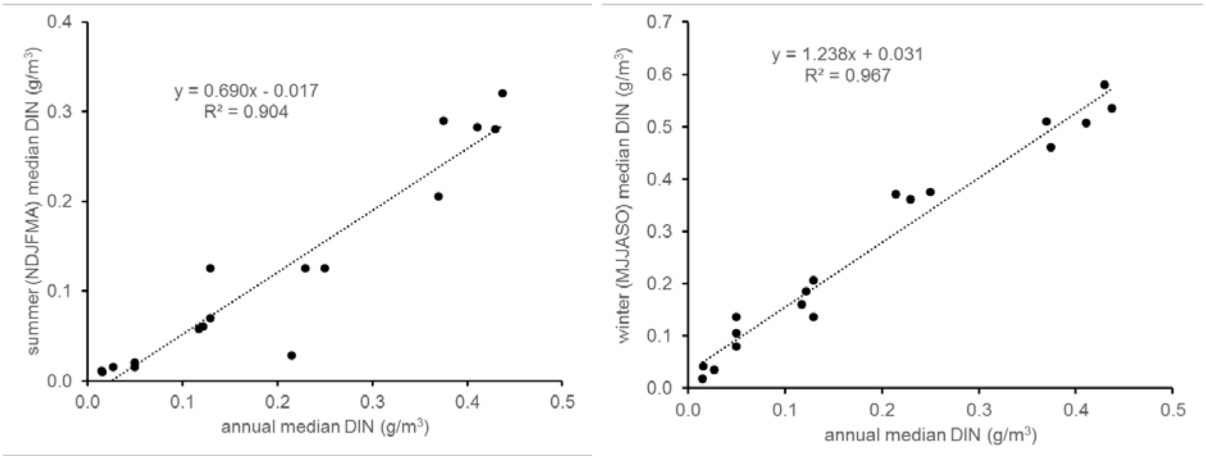

Figure 3-7: Correlation between seasonal (summer, left and winter, right) and annual median DIN concentrations for 18 Northland sites. Waipao and Otaika data were excluded.

Key points (DIN):

- DIN shows strong seasonal trend (high in winter, low in summer) – in contrast to DRP (Section 3.2.2):
    - Exceptions to this were the two sites with the highest DIN, Waipao and Otaika, which showed no apparent seasonal trend.
- Seasonal (winter and summer) median DIN concentrations correlated well with annual medians.
- Summer vs annual correlation more variable – for example annual and summer concentrations for Manganui at Mititai Rd were 0.22 and 0.03 g/m^3, respectively.
- From the slope of the linear regressions:
    - Winter (May-Oct) median DIN concentrations were approximately 1.2-times greater than the annual medians.
    - Summer (Nov-Apr) median DIN concentrations were around 70% of annual medians.

3.2.2 Dissolved reactive phosphorus (DRP)

Mean DRP concentrations for each calendar month (Jan=1 to Dec=12) are provided in Table 3-5, and the median values for each of the 12 month's (i.e., median of each column of Table 3-5) are plotted in Figure 3-8.

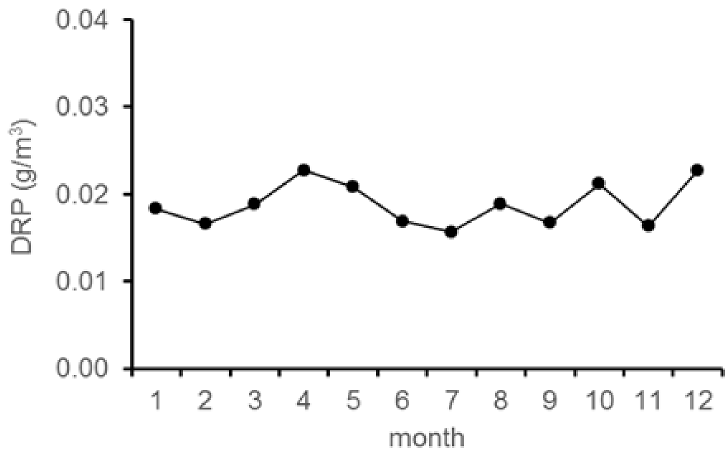

Figure 3-8: Median value of monthly average DRP concentrations of the 20 Northland water quality sites indicating no apparent seasonal variation. Refer to Figure 3-4 to compare with DIN seasonal variation.

Table 3-5: Mean DRP concentrations (g/m^3) by month for the 20 Northland water quality sites. Maximum time period used was between Jan 2002 and Sep 2015.

Water quality site	month											
	1	2	3	4	5	6	7	8	9	10	11	12
Awanui at FNDC	0.017	0.018	0.017	0.023	0.018	0.018	0.016	0.014	0.017	0.019	0.016	0.019
Awanui at Waihue Channel	0.108	0.160	0.139	0.100	0.158	0.064	0.127	0.077	0.090	0.059	0.073	0.094
Hakaru at Topuni	0.065	0.054	0.053	0.060	0.043	0.063	0.034	0.041	0.042	0.040	0.050	0.065
Hatea at Mair Park	0.018	0.010	0.017	0.011	0.013	0.009	0.009	0.009	0.007	0.009	0.009	0.018
Kaihu at Gorge	0.007	0.007	0.006	0.008	0.007	0.010	0.012	0.009	0.012	0.028	0.009	0.035
Mangahahuru at Main Rd	0.010	0.011	0.009	0.008	0.010	0.008	0.010	0.015	0.008	0.008	0.009	0.011
Mangakahia at Twin Br's	0.011	0.005	0.007	0.005	0.020	0.007	0.007	0.008	0.008	0.007	0.006	0.008
Manganui at Mititai Rd	0.036	0.044	0.049	0.037	0.033	0.041	0.034	0.034	0.046	0.045	0.037	0.038
Ngunguru at Coalhill Ln	0.008	0.008	0.013	0.011	0.013	0.010	0.008	0.020	0.013	0.013	0.011	0.016
Opouteke at Suspension Br	0.071	0.052	0.067	0.064	0.091	0.035	0.063	0.049	0.072	0.049	0.042	0.046
Otaika at Otaika Valley Rd	0.014	0.016	0.030	0.020	0.024	0.016	0.014	0.019	0.017	0.018	0.020	0.022
Punakitere at Taheke	0.032	0.041	0.021	0.023	0.034	0.032	0.023	0.020	0.044	0.023	0.023	0.024
Ruakaka at Flyger	0.119	0.090	0.093	0.091	0.083	0.060	0.064	0.100	0.085	0.128	0.108	0.130
Victoria at Victoria Valley Rd	0.070	0.057	0.056	0.057	0.057	0.022	0.024	0.056	0.064	0.048	0.045	0.052
Waiarohia at Second Ave	0.010	0.013	0.010	0.017	0.013	0.015	0.016	0.019	0.011	0.023	0.017	0.011
Waiharakeke at Stringers Rd	0.019	0.017	0.019	0.024	0.015	0.018	0.012	0.013	0.017	0.017	0.014	0.022
Waipao at Draffin	0.024	0.029	0.031	0.032	0.033	0.032	0.023	0.033	0.030	0.031	0.030	0.047
Waipapa at Forest Ranger	0.004	0.004	0.004	0.004	0.005	0.006	0.006	0.006	0.006	0.005	0.005	0.005
Waipoua at SH12	0.016	0.007	0.006	0.026	0.022	0.007	0.007	0.012	0.005	0.011	0.006	0.034
Waitangi at Waimate Rd	0.024	0.016	0.019	0.007	0.007	0.008	0.022	0.014	0.008	0.020	0.009	0.010

The distributions of DRP concentrations for the 20 water quality sites across 12-month and summer 6-month (Nov-Apr) periods are shown in Figure 3-9. Median DRP values for annual, summer (Nov-Apr) and winter (May-Oct) periods are provided in Table 3-6.

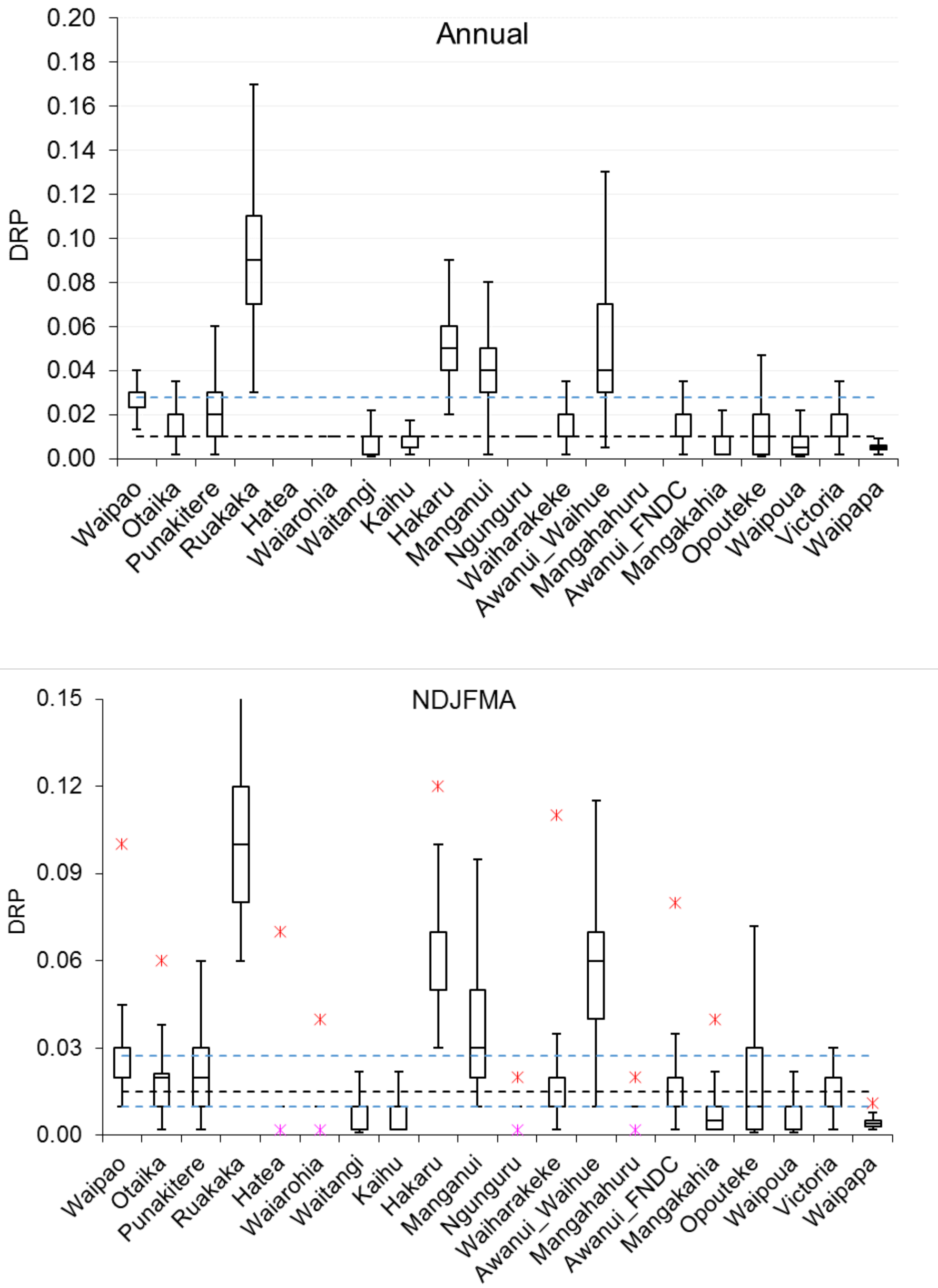

Figure 3-9: Distributions of annual median (upper) and 6-month summer, NDJFMA (lower) DRP concentrations for all sites. The black and blue dashed line indicate the 50th percentile and quartiles of median DRP concentrations across all sites. The 'median of medians' (black dashed lines) for all sites were 0.01 and 0.015 g/m^3 for annual and summer periods, respectively.

Table 3-6: Median DRP concentrations for the 20 Northland sites for annual, summer (NDJFMA) and winter (MJJASO) periods. Note the 3 month duration periods are not shown as seasonal variation in DRP concentrations was not significant.

WQ site	annual	Summer (Nov-Apr)	Winter (May-Oct)
Waipao at Draffin	0.030	0.030	0.030
Otaika at Otaika Valley Rd	0.020	0.020	0.015
Punakitere at Taheke	0.020	0.020	0.020
Ruakaka at Flyger	0.090	0.100	0.075
Hatea at Mair Park	0.010	0.010	0.010
Waiarohia at Second Avenue	0.010	0.010	0.010
Waitangi at Waimate Rd	0.010	0.010	0.010
Kaihu at Gorge	0.010	0.010	0.010
Hakaru at Topuni	0.050	0.050	0.040
Manganui at Mititai Rd	0.040	0.030	0.040
Ngunguru at Coalhill Lane	0.010	0.010	0.010
Waiharakeke at Stringers	0.010	0.020	0.010
Awanui at Waihue Channel	0.040	0.060	0.035
Mangahahuru at Main Rd	0.010	0.010	0.010
Awanui at FNDC	0.020	0.020	0.020
Mangakahia at Twin Br	0.010	0.005	0.010
Opouteke at Suspension Br	0.010	0.010	0.010
Waipoua at SH12	0.005	0.010	0.005
Victoria at Victoria Valley Rd	0.020	0.020	0.020
Waipapa at Forest Ranger	0.005	0.004	0.006

Key points (DRP):

- Sites with the highest DRP concentrations were Ruakaka, Hakaru, Manganui and Awanui (Waihue) with median concentrations of 0.10, 0.05, 0.03 and 0.06 g/m^3, respectively.
- There was no significant seasonal variation in DRP concentrations. DRP concentrations in different seasonal periods were not significantly different from annual DRP concentrations. This may reflect the relative importance of sediment–water column interactions, for example, the equilibrium phosphorus concentration (EPC0) which determines whether the sediment is behaving as a sink or source of water column phosphorus (McDowell et al. 2010).

3.2.3 Nitrogen to phosphorus ratios (DIN:DRP)

Bioavailability of either nitrogen (N) or phosphorus (P) often limits macrophyte and algal growth rates (Schindler et al. 2008). An important bioavailability component is the relative abundance of N and P, indicated by N:P ratios. A conservative approach is to use N:P ratios as indicators of extreme N- or P-limitation (McDowell et al. 2009). Mass-based N:P ratios typically used in New Zealand are <7:1 and >15:1 for N-limitation and P-limitation, respectively (McDowell et al. 2009, MfE 2007). However, as a caveat, measured nutrient concentrations can reflect uptake by plants, and some literature shows that predicting nutrient limitation from measured nutrient ratios is approximate to say the least (Keck and Lepori, 2012).

N:P ratios (DIN:DRP mass-based) over annual, summer (NDJFMA) and winter (MJJASO) periods for the 20 Northland sites are shown in Table 3-7.

Table 3-7: DIN:DRP ratios (mass based) for annual, summer (NDJFMA) and winter (MJJASO) time periods. Ratios derived from median concentration (refer to Table 3-4 and Table 3-6). Blue shading = P-limited sites (N:P >15); green shading = N-limited (N:P <7); unshaded = potentially co-limited (N:P between 7 and 15). NDJFMA = 6 summer months Nov-Apr; MJJASO = 6 winter months May to October.

WQ site	annual (12)	NDJFMA(S6)	MJJASO(W6)
Waipao at Draffin	87	93	81
Otaika at Otaika Valley Rd	63	71	76
Punakitere at Taheke	22	16	27
Ruakaka at Flyger	5	3	8
Hatea at Mair Park	41	28	51
Waiarohia at Second Avenue	37	21	51
Waitangi at Waimate Rd	38	29	46
Kaihu at Gorge	25	13	38
Hakaru at Topuni	5	3	9
Manganui at Mititai Rd	5	1	9
Ngunguru at Coalhill Lane	13	7	21
Waiharakeke at Stringers	13	6	14
Awanui at Waihue Channel	3	1	5
Mangahahuru at Main Rd	12	6	16
Awanui at FNDC	3	1	4
Mangakahia at Twin Br	5	3	11
Opouteke at Suspension Br	5	2	14
Waipoua at SH12	6	2	7
Victoria at Victoria Valley Rd	0.8	0.6	0.9
Waipapa at Forest Ranger	3	2	7

Key points:

- Analysis of data is based on monitored concentrations, which are influenced by instream uptake by instream plant biomass. Accordingly, for streams with high plant biomass (particularly summer months) the indicated nutrient state (i.e., N or P limitation) may reflect instream plant assimilation rather than nutrient ratios supplied to the stream from the catchment. The DIN:DRP ratios for the 20 Northland yielded the following:
- Phosphorus limitation corresponded to sites with highest DIN concentrations (generally >0.3 g/m^3).
- Exception to this was Ruakaka at Flyger which had >0.4 g/m^3 DIN, but contained the highest DRP concentration of 0.119 g/m^3.

- Most of the N-limited sites contained <0.2 g/m^3 of DIN.
- Summary of Table 3-7.

Time period	P-limited (N:P >15)	N-limited (N:P <7)	N:P (7 to 15)
Annual	7	10	3
Summer (NDJFMA)	5	13	2
Winter (MJJASO)	9	5	6

- Consistent with average seasonal patterns in DRP and DIN (Figure 3-4 and Figure 3-8, respectively), summer ratios were more shifted to N-limitation.
- Two sites (Ngunguru and Mangahahuru) shifted from being P-limited in winter to N-limited in summer.
- The number of 'extreme' (i.e., N:P <7) N-limited sites increased from 5 in winter to 13 in summer.
- P-limited sites (over winter and summer) included:
    - Waipao, Otaika, Punakitere, Hatea, Waiarohia, Waitangi and Kaihu.

3.3 Assessment against nutrient–periphyton guidelines

This section is limited to comparison between annual and the nominal six-month summer period between November and April (i.e., NDJFMA).

3.3.1 Annual accrual period

The results for the assessment of median DIN and DRP concentrations using modified periphyton guideline values (based on 5-day filter FRE3 accrual period and MfE 2000) and recently reported (Larned et al. 2015) guideline values for lowland streams (warm wet climate class) are provided in Table 3-8 and Table 3-9, respectively.

Table 3-8: Assessment of median DIN concentrations (all months) against estimated DIN periphyton threshold values (to limit chla to <200 mg/m^2) using average annual accrual periods.

Site (annual)	Limiting nutrient[1]	Average annual accrual (days)[2]	Estimated DIN guideline (modified MfE 2000)[3]	Median DIN conc. (g/m^3) (SoE data)	Exceeds estimated DIN guideline[3]	Exceeds 0.25 g/m^3 DIN (Larned et al. 2015)
Awanui at FNDC	N	23	0.337	0.050	no	no
Awanui at Waihue Channel	N	23	0.337	0.123	no	no
Hakaru at Topuni	N	30	0.163	0.230	yes	no
Hatea at Mair Park	P	29	0.185	0.411	yes	yes
Kaihu at Gorge	P	26	0.240	0.250	yes	yes
Mangahahuru at Main Rd	N/P	35	0.103	0.118	yes	no
Mangakahia at Twin Br	N	21	0.403	0.050	no	no
Manganui at Mititai Rd	N	35	0.106	0.215	yes	no
Ngunguru at Coalhill Lane	N/P	30	0.162	0.130	no	no
Opouteke at Suspension Br	N	23	0.328	0.050	no	no
Otaika at Otaika Valley Rd	P	37	0.092	1.260	yes	yes
Punakitere at Taheke	P	26	0.227	0.438	yes	yes
Ruakaka at Flyger	N	27	0.214	0.430	yes	yes
Victoria at Victoria Valley Rd	N	24	0.294	0.015	no	no
Waiarohia at Second Ave	P	26	0.238	0.370	yes	yes
Waiharakeke at Stringers	N/P	38	0.088	0.130	yes	no
Waipao at Draffin	P	43	0.062	2.604	yes	yes
Waipapa at Forest Ranger	N	23	0.323	0.016	no	no
Waipoua at SH12	N	23	0.341	0.028	no	no
Waitangi at Waimate Rd	P	27	0.207	0.375	yes	yes
Number of sites that exceed DIN guideline					*12*	*8*
Number of sites that exceed DIN guideline and where N maybe limiting nutrient[1]					*5*	*1*

[1] refer to Table 3-7. [2] refer to Table 3-1. [3] refer to Table 2-5 and Figure 2-1. Colour key: orange = guideline exceedance for potentially limiting nutrient; blue = guideline exceedance of non-limiting nutrient (N); yellow = exceedance of nutrient at site that is either N or P limited (i.e., N:P ratio between 7 and 20).

Table 3-9: Assessment of median DRP concentrations (all months) against estimated DRP periphyton guideline values (to limit chla to <200 mg/m²) using average annual accrual periods.

Site (annual)	Limiting nutrient[1]	Average annual accrual (days)[2]	Estimated DRP guideline (modified MfE 2000)[3]	Median DRP conc. (g/m^3) (SoE data)	Exceeds estimated DRP guideline[3]	Exceeds 0.011 g/m^3 DRP (Larned et al. 2015)
Awanui at FNDC	N	23	0.024	0.020	no	yes
Awanui at Waihue Channel	N	23	0.024	0.040	yes	yes
Hakaru at Topuni	N	30	0.012	0.050	yes	yes
Hatea at Mair Park	P	29	0.014	0.010	no	no
Kaihu at Gorge	P	26	0.017	0.010	no	no
Mangahahuru at Main Rd	N/P	35	0.008	0.010	yes	no
Mangakahia at Twin Br	N	21	0.028	0.010	no	no
Manganui at Mititai Rd	N	35	0.008	0.040	yes	yes
Ngunguru at Coalhill Lane	N/P	30	0.012	0.010	no	no
Opouteke at Suspension Br	N	23	0.023	0.010	no	no
Otaika at Otaika Valley Rd	P	37	0.007	0.020	yes	yes
Punakitere at Taheke	P	26	0.016	0.020	yes	yes
Ruakaka at Flyger	N	27	0.016	0.090	yes	yes
Victoria at Victoria Valley Rd	N	24	0.021	0.020	no	yes
Waiarohia at Second Ave	P	26	0.017	0.010	no	no
Waiharakeke at Stringers	N/P	38	0.007	0.010	yes	no
Waipao at Draffin	P	43	0.005	0.030	yes	yes
Waipapa at Forest Ranger	N	23	0.023	0.005	no	no
Waipoua at SH12	N	23	0.024	0.005	no	no
Waitangi at Waimate Rd	P	27	0.015	0.010	no	no
Number of sites that exceed DRP guideline					*9*	*9*
Number of sites that exceed DRP guideline and where P maybe limiting nutrient[1]					*5*	*3*

[1] refer to Table 3-7. [2] refer to Table 3-1. [3] refer to Table 2-5 and Figure 2-1. Colour key: orange = guideline exceedance for potentially limiting nutrient; green = guideline exceedance of non-limiting nutrient (P); yellow = exceedance of nutrient at site that is either N or P limited (i.e., N:P ratio between 7 and 20).

3.3.2 Summer accrual period (Nov-Apr)

Median summer (Nov-Apr, inclusive) concentrations of DIN and DRP for the 20 water quality sites were compared to similar guidelines used for annual accrual periods (section 3.3.1). The same Larned et al. (2015) guidelines were used (i.e., 0.25 and 0.011 g/m^3 for DIN and DRP, respectively), although it is emphasised that these values were derived from the analysis of annual nutrient data. Estimated periphyton guidelines for DIN and DRP were derived from the respective regression curves of modified (FRE3 unfiltered converted to FRE3 5-day filtered data according to Booker 2013) data from MfE (2000) (refer to Table 2-5 and Figure 2-1). Again, it is emphasised that this approach is indicative only, as the original data set (Biggs 2000) is based on average annual accrual periods. In other words, comparing Northland average summer accrual periods with average annual accrual periods used in the NZ periphyton guidelines (MfE 2000) means we are not 'comparing apples with apples'. The result of this is overly conservative (i.e., too low) nutrient guideline concentrations. To explore the use of seasonal accrual periods (any period other than annual), we would need to recalculate the various average seasonal accrual periods for streams used to derive the NZ periphyton guideline values.

The limiting nutrient is based on the median concentration of DIN and DRP for the six-month summer period (Nov to Apr, inclusive). Because some sites showed a strong seasonal trend in DIN (i.e., low in summer – refer to Figure 3-4), a higher proportion of sites exhibited N-limitation. While lower summer DIN concentrations are expected, it is likely that the low concentrations are exacerbated by assimilation into in-stream plant biomass.

The results for the summer period (Nov-Apr) assessment of median DIN and DRP concentrations using modified periphyton guideline values (based on 5-day filter FRE3 accrual period and Biggs 2000) and recently reported (Larned et al. 2015) guideline values for lowland streams (WWL REC class) are provided in Table 3-10 and Table 3-11, respectively.

Table 3-10: Assessment of median DIN concentrations (6-month summer period Nov-Apr) against estimated DIN periphyton guideline values (to limit chla to <200 mg/m²) using average annual accrual periods.

Site (summer)	Limiting nutrient[1]	Average summer accrual (days)[2]	Estimated DIN guideline (modified Biggs 2000)[3]	Median DIN conc. (SoE data)	Exceeds estimated DIN guideline[3]	Exceeds 0.25 g/m³ DIN (Larned et al. 2015)
Awanui at FNDC	N	42	0.064	0.020	no	no
Awanui at Waihue Channel	N	42	0.064	0.060	no	no
Hakaru at Topuni	N	66	0.019	0.125	yes	no
Hatea at Mair Park	P	44	0.057	0.283	yes	yes
Kaihu at Gorge	N/P	51	0.040	0.125	yes	no
Mangahahuru at Main Rd	N	52	0.037	0.058	yes	no
Mangakahia at Twin Br	N	36	0.098	0.015	no	no
Manganui at Mititai Rd	N	57	0.028	0.028	no	no
Ngunguru at Coalhill Lane	N	46	0.052	0.070	yes	no
Opouteke at Suspension Br	N	39	0.081	0.020	no	no
Otaika at Otaika Valley Rd	P	74	0.014	1.415	yes	yes
Punakitere at Taheke	N/P	50	0.040	0.320	yes	yes
Ruakaka at Flyger	N	45	0.053	0.280	yes	yes
Victoria at Victoria Valley Rd	N	43	0.061	0.011	no	no
Waiarohia at Second Ave	P	34	0.111	0.205	yes	no
Waiharakeke at Stringers	N	68	0.018	0.125	yes	no
Waipao at Draffin	P	95	0.007	2.785	yes	yes
Waipapa at Forest Ranger	N	36	0.101	0.009	no	no
Waipoua at SH12	N	52	0.037	0.015	no	no
Waitangi at Waimate Rd	P	48	0.045	0.290	yes	yes
Number of sites that exceed DIN guideline					*12*	*6*
Number of sites that exceed DIN guideline and where N maybe limiting nutrient[1]					*7*	*2*

[1] refer to Table 3-7. [2] refer to Table 3-1. [3] refer to Table 2-5 and Figure 2-1. Colour key: orange = guideline exceedance for potentially limiting nutrient; blue = guideline exceedance of non-limiting nutrient (N); yellow = exceedance of nutrient at site that either N or P limited (i.e., N:P ratio between 7 and 20).

Table 3-11: Assessment of median DRP concentrations (6-month summer period Nov-Apr) against estimated DRP periphyton guideline values (to limit chla to <200 mg/m²) using average annual accrual periods.

Site (summer)	Limiting nutrient[1]	Average summer accrual (days)[2]	Estimated DRP guideline (modified Biggs 2000)[3]	Median DRP conc. (SoE data)	Exceeds estimated DRP guideline[3]	Exceeds 0.011 g/m³ DRP (Larned et al. 2015)
Awanui at FNDC	N	42	0.005	0.020	yes	yes
Awanui at Waihue Channel	N	42	0.005	0.060	yes	yes
Hakaru at Topuni	N	66	0.002	0.050	yes	yes
Hatea at Mair Park	P	44	0.005	0.010	yes	no
Kaihu at Gorge	N/P	51	0.003	0.010	yes	no
Mangahahuru at Main Rd	N	52	0.003	0.010	yes	no
Mangakahia at Twin Br	N	36	0.008	0.005	no	no
Manganui at Mititai Rd	N	57	0.002	0.030	yes	yes
Ngunguru at Coalhill Lane	N	46	0.004	0.010	yes	no
Opouteke at Suspension Br	N	39	0.006	0.010	yes	no
Otaika at Otaika Valley Rd	P	74	0.001	0.020	yes	yes
Punakitere at Taheke	N/P	50	0.003	0.020	yes	yes
Ruakaka at Flyger	N	45	0.004	0.100	yes	yes
Victoria at Victoria Valley Rd	N	43	0.005	0.020	yes	yes
Waiarohia at Second Ave	P	34	0.009	0.010	yes	no
Waiharakeke at Stringers	N	68	0.002	0.020	yes	yes
Waipao at Draffin	P	95	0.001	0.030	yes	yes
Waipapa at Forest Ranger	N	36	0.008	0.004	no	no
Waipoua at SH12	N	52	0.003	0.010	yes	no
Waitangi at Waimate Rd	P	48	0.004	0.010	yes	no
Number of sites that exceed DRP guideline					*18*	*10*
Number of sites that exceed DRP guideline and where P maybe limiting nutrient[1]					*7*	*3*

[1] refer to Table 3-7. [2] refer to Table 3-1. [3] refer to Table 2-5 and Figure 2-1. Colour key: orange = guideline exceedance for potentially limiting nutrient; green = guideline exceedance of non-limiting nutrient (P); yellow = exceedance of nutrient at site that either N or P limited (i.e., N:P ratio between 7 and 20).

Data from Table 3-8 Table 3-11 are summarised in Table 3-12, which indicates what water quality sites may exceed periphyton guidelines based on annual and seasonal (summer) time periods.

Table 3-12: Summary of sites that exceeded (x) indicative periphyton guideline values.

Site Name	Annual period (12 months)			Summer period (Nov-Apr)		
	Limiting nutrient	'modified MfE' guideline	Larned et al. guideline	Limiting nutrient	'modified MfE' guideline	Larned et al. guideline
Awanui at FNDC	N			N		
Awanui at Waihue Channel	N			N		
Hakaru at Topuni	N	x		N	x	
Hatea at Mair Park	P			P	x	
Kaihu at Gorge	P			N/P	x	
Mangahahuru at Main Rd	N/P	x		N	x	
Mangakahia at Twin Br	N			N		
Manganui at Mititai Rd	N	x		N		
Ngunguru at Coalhill Lane	N/P			N	x	
Opouteke at Suspension Br	N			N		
Otaika at Otaika Valley Rd	P	x	x	P	x	x
Punakitere at Taheke	P	x	x	N/P	x	x
Ruakaka at Flyger	N	x	x	N	x	x
Victoria at Victoria Valley Rd	N			N		
Waiarohia at Second Ave	P			P	x	
Waiharakeke at Stringers	N/P	x		N	x	
Waipao at Draffin	P	x	x	P	x	
Waipapa at Forest Ranger	N			N		
Waipoua at SH12	N			N		
Waitangi at Waimate Rd	P			P	x	
Total number of sites		8	4		12	3

Key points:

- Based on annual data, a total of 8 sites exceeded the 'modified MfE' periphyton guideline for the limit nutrient/s, of which:
    - 3 sites were N-limited (Hakaru, Manganui and Ruakaka).
    - 3 sites were P-limited (Otaika, Punakitere and Waipao).
    - 2 site were either N or P limited (Mangahuru and Waiharakeke).
- The limiting nutrient/s exceeded the Larned et al. (2015) DIN and DRP periphyton guideline values of 0.25 and 0.011 g/m^3, respectively, at 4 sites:
    - 3 sites P-limited (Otaika, Punakitere and Waipao); 1 site N-limited (Ruakaka).
- Applying the 'modified MfE' guidelines to summer data as expected, resulted in overly conservative results since the data underpinning the original values is based on average annual accrual periods. A total of 12 sites exceeded the limiting nutrient/s.

- Applying the Larned et al. (2015) annual guideline to the seasonal data resulted in 3 sites exceeding the limiting nutrient guideline (Otaika, Punakitere and Ruakaka).
- The relative merits of the assessments summarised in Table 3-12 will need to be verified using long-term periphyton monitoring data (when this becomes available).

3.4 Preliminary assessment of NRC periphyton monitoring data

Northland periphyton monitoring data for 18 streams are summarised in Table 3-13, and Figure 3-10. The number of exceedances (of 120 and 200 mg/m^2 chla) by month is shown in Figure 3-11. It is emphasised that proper assessment against the NOF periphyton attribute requires at least three years of monthly monitoring data (i.e., n=36). Accordingly, the results of this preliminary assessment of available periphyton monitoring data (n=10 to 18) are indicative only. The exception to this is Hakaru Stream, which already has 4 exceedances of 200 mg/m^2 chla and therefore, regardless of the results of the next 18 months of monitoring, this site will have a 200 mg/m^2 chla exceedance frequency of greater than 8% (1 month in 12).

Table 3-13: Summary statistics for 18 Northland periphyton monitoring sites that correspond to the water quality sites used in this study.

Site Name	number samples	>120 mg/m^2 of chla	% of time chla >120 mg/m^2	>200 mg/m^2 of chla	% of time chla >200 mg/m^2	90th %ile (1/12)[1]	83rd %ile (2/12)[2]
Awanui at FNDC	17	3	18%	1	6%	279	129
Hakaru at Topuni	18	9	50%	4	22%	635	576
Hatea at Mair Park	16	1	6%	0		108	62
Kaihu at Gorge	18	0		0		60	55
Mangahahuru at Main Road	18	0		0		20	12
Mangakahia at Twin Bridges	19	3	16%	0		143	122
Ngunguru at Coalhill Lane	11	0		0		76	67
Opouteke at Suspension Bridge	20	7	35%	1	5%	178	148
Otaika at Otaika Valley Road	15	4	27%	1	7%	197	153
Punakitere at Taheke	16	2	13%	2	13%	276	93
Ruakaka at Flyger Road	18	1	6%	0		77	46
Victoria at Victoria Valley Road	20	0		0		63	37
Waiarohia at Second Avenue	19	3	16%	1	5%	157	129
Waiharakeke at Stringers Road	17	3	18%	2	12%	259	172
Waipao at Draffin Road	15	1	7%	0		100	57
Waipapa at Waimate North Road	10	0		0		33	25
Waipoua at SH12	20	0		0		5	4
Waitangi at Waimate North Road	20	0		0		31	25

[1] 90th percentile (%ile) indicates an average exceedance (i.e., >200 mg/m^2 chla) frequency of 1 month in every 12, note that this should have technically been the 92nd percentile, however this value could not be calculated using the excel MEDIAN function. [2] 83rd percentile (%ile) indicates an average exceedance (i.e., >200 mg/m^2 chla) frequency of 2 months in every 12 – equivalent to 'productive' classes. Red shading indicate sites where results are consistent with 'D' band in the NPS-FM and orange shading indicates sites that have at least one result that >200 mg/m^2 chla.

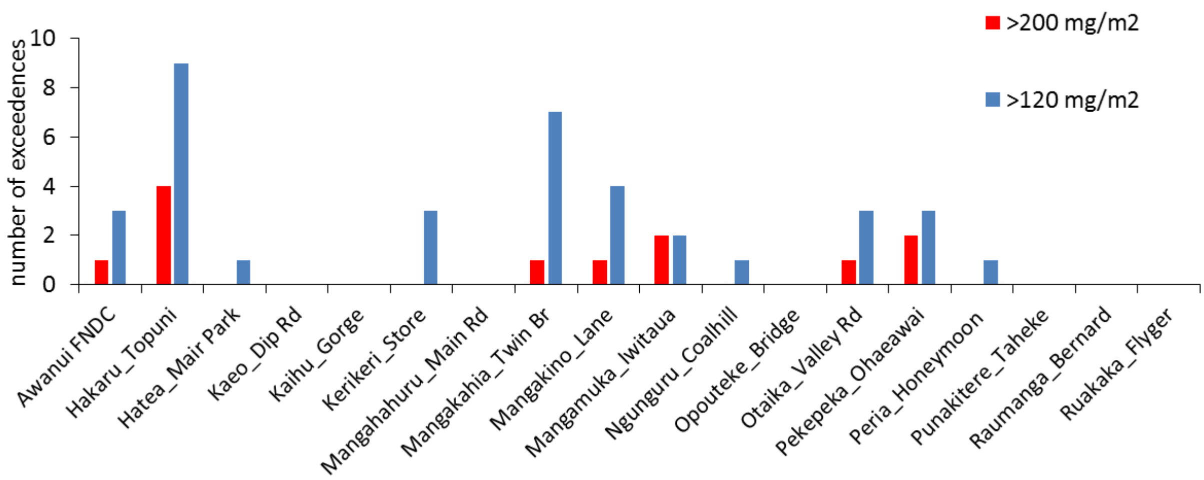

Figure 3-10: Number of observations that exceed chla concentrations of 120 mg/m^2 (blue) and 200 mg/m^2 (red).

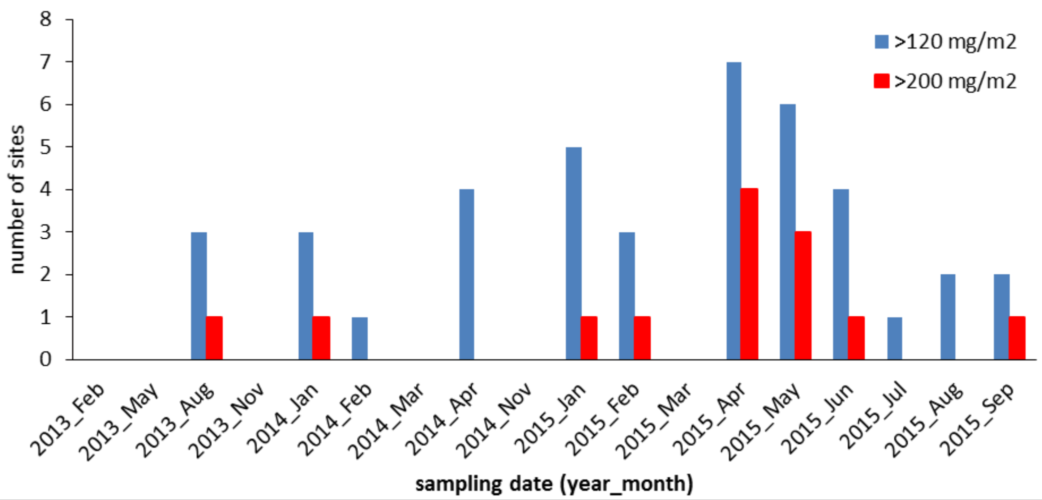

Figure 3-11: Number of periphyton monitoring sites that exceed 120 (blue) and 200 mg/m^2 (red) of chla, grouped by sampling date.

The results from Table 3-12 (assessment of SoE concentration against guidelines) and Table 3-13 (summary of periphyton monitoring results) are brought together in Table 3-14.

Table 3-14: Sites exceeding (x) estimated periphyton guidelines (refer to Table 3-12) compared with periphyton monitoring data. Red and orange shading indicated impacted sites (red = potentially 'D' band) and grey shading highlights where periphyton impacted sites did not coincide with guideline exceedance.

Water quality site	Annual period (12 months)			Summer period (Nov-Apr)		
	Limiting nutrient	'modified MfE' guideline	Larned et al. guideline	Limiting nutrient	'modified MfE' guideline	Larned et al. guideline
Awanui at FNDC	N			N		
Hakaru at Topuni	N	x		N	x	
Hatea at Mair Park	P			P	x	
Kaihu at Gorge	P			N/P	x	
Mangahahuru at Main Rd	N/P	x		N	x	
Mangakahia at Twin Br	N			N		
Ngunguru at Coalhill Lane	N/P			N	x	
Opouteke at Suspension Br	N			N		
Otaika at Otaika Valley Rd	P	x	x	P	x	x
Punakitere at Taheke	P	x	x	N/P	x	x
Ruakaka at Flyger[1]	N	x	x	N	x	x
Victoria at Victoria Valley Rd	N			N		
Wairohia at Second Ave	P			P	x	
Waiharakeke at Stringers	N/P	x		N	x	
Waipao at Draffin[2]	P	x	x	P	x	
Waipapa at Forest Ranger	N			N		
Waipoua at SH12	N			N		
Waitangi at Waimate Rd	P			P	x	
Correct assignment of 'impacted' sites[3]		*4*	*2*		*5*	*2*
Missed assignment of 'impacted' sites[4]		*3*	*5*		*2*	*5*
incorrect assignment of 'impacted' site[5]		*1*	*0*		*5*	*0*

[1] monitoring site at Ruakaka Stream is light limited. [2] Waipao Stream is macrophyte dominated. [3] 'periphyton impacted' sites are defined as having at least one value >200 mg/m² chla (orange and red shading). [4] number of impacted sites that were not identified by exceedance of guideline values (grey shading). [5] Ruakaka and Waipao are not included in this statistic.

Key points:

- 18 of the 20 water quality sites (used to determine accrual periods) had periphyton monitoring data (between 10 and 20 measurements at each site).
- Based on 8% exceedance frequency of 200 mg/m² chla, three sites are potentially classified as 'D band - Hakaru, Punakitere and Waiharakeke. Four additional sites have 1 measurement >200 mg/m², which are Awanui (FNDC), Opouteke, Otaika and Waiarohia.
- If using a 17% exceedance frequency (average of 2 months in 12), as per 'productive' REC classes), Hakaru is the only site that would be classified as band 'D'. A comparison between Northland and 'productive' class streams would be required to get a better understanding of how accrual periods in Northland (annual and seasonal) compare to those in CD and WD productive catchments.
- High periphyton biomass in Northland streams is not limited to summer months. It is unclear if 2015 was an atypical year (with respect to climate), but periphyton biomass appeared to be greatest in April, May and June, which was consistent with 6-years of data analysed for

the Manawatu-Whanganui region (Kilroy et al. 2016). This being the case, focussing on summer accrual periods may not be the best approach (as opposed to mean annual periods).

- Periphyton impacted sites consisted of both N- and P-limited streams.
- The accrual period-based guideline ('modified MfE') resulted in better identification of periphyton impacted sites compared with the Larned et al. (2015) values for lowland streams in warm-wet climates. 'Modified MfE' and Larned et al. (2015) guidelines, respectively, identified 4-5 and 2 (of a total of 7) potentially 'periphyton impacted' streams.
- The use of summer accrual periods (as opposed to annual) resulted in the identification of more impacted sites (5 vs. 4), however, this greater sensitivity to detect 'positives' was at the expense of decreased specificity (i.e., low incidence of false negatives but high incidence of false positives). The number of 'false positives' using summer and annual time periods were 5 and 1, respectively.
- The Larned et al. (2015) periphyton guidelines for DIN and DRP had low sensitivity but high specificity (i.e., high incidence of false negatives and low incidence of false positives).
- 'False negative' sites included Awanui (FNDC), Opouteke and Waiarohia.
- Assuming that the periphyton monitoring sites and associated data are robust, the rather average predictive power from using nutrient guideline concentrations indicates that biomass monitoring is the better approach for assessing the 'eutrophication risk' from stream nutrient concentrations.
- If nutrient guidelines or standards (i.e., attribute states) for managing periphyton are developed, these preliminary results suggest that a best approach is to use guidelines derived from accrual periods. Average annual accrual periods ranged from 21 to 43 days for the 19 Northland streams analysed. Given this variability (2-fold), it is unlikely that a 'one size fits all' periphyton nutrient guideline will be effective for managing periphyton biomass across the Northland region.
- We emphasise that assessment against the NPS-FM periphyton attribute requires at least 3 years of monitoring data. Currently, NRC have approximately 15 to 18 months of monitoring data, and therefore a better picture of periphyton biomass pressure (spatial and temporal) will emerge as the dataset matures.

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Appendix A

Table A-1: Total number of days within each seasonal period for the 19 flow sites.

flow site	Years	Total number of days in each seasonal flow period								
		annual	MJJ-ASO	NDJ-FMA	NDJ	DJF	JFM	FMA	MJJ	ASO
Awanui at School Cut	55	19,954	10,174	9,780	4,873	4,799	4,854	4,907	5,138	5,036
Hakarau at Topuni Creek Farm	4	1,435	710	725	368	361	361	357	368	342
Hatea at Whareora Rd	16	5,959	3,002	2,957	1,552	1,515	1,486	1,405	1,487	1,515
Kaihu at Gorge	43	15,621	7,959	7,576	3,895	3,743	3,696	3,640	3,920	3,996
Mangahahuru at County Weir	43	15,655	7,892	7,763	3,871	3,830	3,857	3,892	3,943	3,949
Mangakahia at Gorge	54	19,714	9,950	9,764	4,937	4,862	4,861	4,827	5,010	4,940
Manganui at Permanent Station	51	18,496	9,310	9,186	4,684	4,631	4,570	4,502	4,666	4,644
Ngunguru at Dugmores Rock	45	16,469	8,250	8,219	4,160	4,085	4,085	4,059	4,123	4,127
Opouteke at Suspension Br	29	10,488	5,222	5,266	2,696	2,633	2,614	2,570	2,634	2,588
Otaika at Kay	5	1,663	844	819	373	394	425	446	460	384
Punakitere at Taheke	19	7,081	3,510	3,571	1,786	1,784	1,799	1,785	1,767	1,743
Ruakaka at Flyger Rd	30	10,816	5,495	5,321	2,705	2,583	2,616	2,616	2,655	2,840
Victoria at Victoria Valley Road	8	3,099	1,549	1,550	828	792	761	722	736	813
Waiarohia at Lovers Lane	31	11,225	5,671	5,554	2,861	2,750	2,733	2,693	2,790	2,881
Waiharakeke at Willowbank	45	16,564	8,269	8,295	4,211	4,195	4,165	4,084	4,203	4,066
Waipao at Draffins Rd	33	11,986	5,999	5,987	2,997	2,968	2,999	2,990	2,985	3,014
Waipapa at Forest Ranger	37	13,544	6,820	6,724	3,397	3,332	3,327	3,327	3,422	3,398
Waipoua at SH12	8	2,978	1,528	1,450	736	722	722	714	799	729
Waitangi at Waimate North Rd	4	1,368	643	725	368	361	361	357	339	304

Table A-2: Number of qualifying flow events within each time period for the 19 sites. Qualifying flows are those that exceeding 3-times the long-term median annual flow, and did not occur within 5 day of the preceding qualifying event.

flow site	Number of qualifying flow events (3x median flow, 5 day filter)								
	annual	MJJ-ASO	NDJ-FMA	NDJ	DJF	JFM	FMA	MJJ	ASO
Awanui at School Cut	584	396	188	98	90	79	92	203	194
Hakarau at Topuni Creek Farm	874	647	231	137	108	84	96	335	322
Hatea at Whareora Rd	48	37	11	6	8	4	5	19	19
Kaihu at Gorge	209	144	67	31	33	31	36	73	70
Mangahahuru at County Weir	603	454	150	86	65	63	66	234	227
Mangakahia at Gorge	442	299	150	73	70	71	77	161	142
Manganui at Permanent Station	923	658	270	148	121	107	125	336	323
Ngunguru at Dugmores Rock	527	380	160	88	76	68	74	194	212
Opouteke at Suspension Br	550	371	180	85	77	85	97	192	181
Otaika at Kay	455	321	136	71	66	63	65	169	151
Punakitere at Taheke	45	34	11	6	6	5	5	19	17
Ruakaka at Flyger Rd	268	200	71	37	33	30	34	109	93
Victoria at Victoria Valley Road	400	289	117	55	58	59	63	140	150
Waiarohia at Lovers Lane	129	92	36	21	21	14	16	46	49
Waiharakeke at Willowbank	432	276	161	83	80	78	81	142	135
Waipao at Draffins Rd	440	327	122	67	58	59	57	167	174
Waipapa at Forest Ranger	280	218	63	29	32	32	34	112	103
Waipoua at SH12	131	104	28	13	15	13	14	62	43
Waitangi at Waimate North Rd	50	35	15	10	9	3	5	18	17