Using empirical relationships to develop nutrient targets for periphyton management

a case study from the Horizons region

Prepared for Dairy NZ and Horizons Regional Council

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Executive summary

Horizons Regional Council's (HRC's) One Plan, the first regional plan for environmental management to be developed in New Zealand, includes targets for the levels of primary production (periphyton biomass, measured as chlorophyll *a* and cover on the streambed) in waterways. The periphyton targets, along with nutrient targets (as dissolved inorganic nitrogen, DIN, and dissolved reactive phosphorus, DRP), were set with the aim of maintaining healthy ecosystems and were applied to 43 River Management Zones within the Horizons region.

In parallel with development and implementation of the One Plan, in 2008, HRC set up a programme of monthly periphyton and nutrient monitoring at river sites representing many of the River Management Zones. The purposes of the programme included assessment of compliance with periphyton targets specified in the One Plan and development of a regional model for predicting periphyton from nutrient concentrations and other environmental variables. Regional models were anticipated to be required for updating the nutrient targets set in the One Plan.

An analysis of seven years of periphyton monitoring data from the Horizons region, in a 2018 joint report between NIWA, HRC and DairyNZ (DNZ) (https://www.manawaturiver.co.nz/wp-content/uploads/2018/12/Periphyton-Environment-Relationships-in-the-Horizons-Region.pdf), identified reasonably strong empirical relationships between chlorophyll *a* and nutrient concentrations when other predictor variables were included. Other predictors included: water temperature (Tmean), stream substrate composition (pccoarse), electrical conductivity (EC) and flow metrics (DaEF – a measure of accrual period). The report included a look-up table (Appendix L) as a tentative suggestion on how the empirical periphyton – environment models could be used to assist in setting nutrient targets. To use the look-up table, a user would select an appropriate combination of predictor values and read off an estimate of the nutrient concentration corresponding to the periphyton target (as Chla_92). The look-up table had the following limitations:

1. the table was based on one of multiple linear models; therefore, variability in periphyton – predictor relationships among models was not accounted for;
2. the table did not include uncertainties around the predictions within the model used;
3. predictor values were restricted to only three choices across the whole range of values, which kept the table to a manageable size but at the expense of omitting combinations relevant to many sites.

The present report was prepared for DNZ and HRC, who requested "greater development of Appendix L into a stand-alone technical report delivering recommended guidance [on the use of the relationships developed in the 2018 report] to recommend instream DIN and DRP concentrations for corresponding periphyton … objectives."

DNZ and HRC also requested that: "If the contractors believe that look-up DIN and DRP concentrations [i.e., the outcome of the guidance developed in the first part of the work] can be recommended for specified chlorophyll *a* outcomes", a further requirement was to: "estimate associated DIN and DRP concentrations for river periphyton outcomes specified in Table E.2 of Schedule E from the operative Horizons One Plan."

The project was carried out in three stages.

In **Stage 1**, criteria based on applicability and statistical performance were used to select models with potential for use in nutrient target setting. Look-up tables were developed for each promising model and used to compare predictions and identify outliers. The outcome of the evaluation was that eight models were initially retained. All models predicted Chla_92 from a combination of at least three of DIN, DRP, DaEF, EC, pccoarse, and Tmean. Only one model included DRP as a predictor.

In **Stage 2**, the practicalities of using the look-up tables generated by the models for setting nutrient targets were considered. In view of the need to take a site-specific approach, it was determined that direct use of the equations was simpler and more transparent than look-up tables. A table of predictor values applicable to each site was compiled.

In **Stage 3**, the eight models from Stage 1 combined with the assessments in Stage 2 were applied to derive suggested DIN targets at specific sites for the management of periphyton chlorophyll *a* against the One Plan targets and the NPS-FM bands in the Horizons region.

A review of DIN targets estimated from the eight models showed that they could be reduced to three models, all of which were generated using data from 2009 to 2016 (therefore incorporating maximum temporal variability). A further model was also suggested because it was the only model including DRP as a predictor. The latter model was not used in the subsequent target assessments.

The sites were divided into four groups for final assessment of DIN targets (Part 2 of the work).

1. **Sites at which current Chla_92 and DIN were both low (< 20 mg/m^2 and <0.1 mg/L, respectively) (14 sites).** Models were not appropriate for deriving DIN targets at these sites. Derived DIN targets for Chla_92 were up to 30 x greater than observed DIN. Furthermore, the predictions were outside the range of dataset. We suggested retaining the current One Plan target or revision to a target closer to observed DIN.

2. **Sites at which current Chla_92 and DIN were both close to the One Plan targets (3 sites).** Current targets were assessed as appropriate.

3. **Sites at which the One Plan chlorophyll *a* target was exceeded (13 sites).** Current DIN targets were appropriate at three sites; revised targets based on the models were suggested for five sites; at three sites, targets closer to current concentrations were suggested; and at the remaining two sites, we suggested reviewing the current chlorophyll *a* target because high EC indicated that these sites are naturally productive and have naturally high periphyton.

4. **Sites at which the One Plan chlorophyll *a* target was met (30 sites).** The DIN target was also exceeded at 17 sites. Revised DIN targets based on the models were suggested at six of these 17 sites. At the remaining 11 sites, targets closer to the observed mean DIN value were suggested. The One Plan DIN target was not exceeded at 13 sites. Revised DIN targets based on the models were suggested for four of these sites, the One Plan target was assessed as appropriate at seven and revision to a target closer to observed DIN at two sites.

The following limitations apply to the use of the empirical models described in this report.

- The models apply only in the Horizons region, and to individual sites.
- Reviews of targets derived using the models are part of the process. Examples are provided. The reviews were important for resolving unexpected or anomalous results.

- the equations are not valid for deriving nutrient targets when the predictors variables at set to values within the ranges and combinations used in the dataset to develop the models. This problem occurs particularly at sites where both chlorophyll *a* and DIN (or DRP) concentrations are currently very low.

The procedure developed for using the models to derive targets was summarised in a flow chart (decision support system). A summary table is provided showing suggested revised DIN targets at all periphyton monitoring sites alongside the current One Plan targets and observed chlorophyll *a* and DIN concentrations. The derived DIN targets are presented in this report, but the spreadsheet, with equations, is also provided to DNZ and HRC to enable refinement of the targets by adjusting predictor values (e.g., based on updated data), and to enable application of the method to new sites.

Two further steps to improve usability of the suggested method and targets are: (1) create bands for targets to take account of uncertainty in both the predictions and measurements (because the derived target concentrations presented are unrealistically precise); and (2) explore the relationship between Chla_92 and maximum chlorophyll *a* so that targets can also be set to be consistent with current SOE reporting (which assesses sites using maximum chlorophyll *a* rather than Chla_92).

1 Introduction

1.1 Background

Horizons Regional Council's (HRC's) regional plan for environmental management (the One Plan, http://www.horizons.govt.nz/about-us/one-plan/) was the first comprehensive regional plan to be developed in New Zealand. One aspect of river management recognised in developing the One Plan was the need to set targets for the levels of primary production in waterways (mainly periphyton: the algae-dominated community growing on the river bed) in order to maintain healthy ecosystems. Periphyton targets adopted for the One Plan were based on those proposed in the New Zealand Periphyton Guideline (Biggs 2000a). The targets were quantified as periphyton biomass measured as chlorophyll *a*, and periphyton cover of the stream bed estimated by visual assessments of cover by mats (> 3 mm thick) and filamentous algae (> 2 cm long) and were "effects-based". In other words, periphyton biomass and cover thresholds were derived from relationships with river ecosystem condition assessed from macroinvertebrate communities (Biggs 2000a), and from research on human perception of desirable periphyton cover (e.g., Suplee et al. 2009). The One Plan also specified nutrient targets (of dissolved inorganic nitrogen, DIN, and dissolved reactive phosphorus, DRP) which were partly based on the ANZECC guidelines (ANZECC 2000). Periphyton and nutrient targets were applied to 43 River Management Zones (with Sub-Zones), established as part of the One Plan "for the purpose of managing water quality, water quantity and activities in the beds of rivers and lakes, defined by catchments and sub-catchments".

In parallel with development and implementation of the One Plan, HRC set up a programme of monthly periphyton and nutrient monitoring at river sites across the region, representing many of the River Management Zones. Since 2008 the original network of 48 sites has expanded to > 60 sites. The monitoring programme had multiple purposes, including assessment of compliance with periphyton targets specified in the One Plan and development of a regional model for predicting periphyton at unmonitored river sites and in response to catchment changes. Regional models were anticipated to be required for updating and refining the nutrient targets set in the One Plan. The periphyton monitoring data are also appropriate for assessing river status against the periphyton attribute of the National Policy Statement for Freshwater Management[1] (NPS-FM, NZ Government 2017)

In the absence of regional models, models developed by Biggs (2000b) have been widely applied in New Zealand for predicting periphyton or for predicting nutrient concentrations to ensure that periphyton biomass remains less than a threshold (e.g., Norton and Kelly 2010). The Biggs (2000b)

[1] Compliance with the NPS-FM is mandatory for regional councils. The policy is based around a National Objectives Framework (NOF) that includes a suite of attributes (defined measures for assessing the state of fresh waters). The NOF must be applied to Freshwater Management Units, which are defined by each regional council.

The periphyton attribute is included in the NPS-FM for protection of the ecological values of waterways and is specified in terms of chlorophyll *a* per square metre of river bed. Bands are ≤50 mg/m^2 (A), >50 ≤120 mg/m^2 (B), >120 ≤200 mg/m^2 (C), and >200 mg/m^2 (D). The metric required for assignment of a river to a band is the 92nd percentile of monthly observations of chlorophyll *a*, based on at least three years of data. Thus, for a site to fall into band D, chlorophyll *a* would exceed 200 mg/m^2 in more than three of 36 monthly surveys.

The periphyton attribute allows for two classes: default and productive. The productive class is allowed one additional exceedance per year, i.e., more than six exceedances over a 36-month period.

Classes are defined according to types in the River Environment Classification (REC). The productive class includes sites at which periphyton is expected to be naturally high because of naturally occurring high background concentrations of nutrients. The productive class is defined by the combination of REC "Dry" Climate categories (i.e. Warm-Dry (WD) and Cool-Dry (CD)) and REC Geology categories that have naturally high levels of nutrient enrichment due to their catchment geology (i.e. Soft-Sedimentary (SS), Volcanic Acidic (VA) and Volcanic Basic (VB)). Therefore, the productive class is defined by the following REC defined types: WD/SS, WD/VB, WD/VA, CD/SS, CD/VB, CD/VA. The default class includes all REC types not in the productive class.

relationships were derived using data from 30 hill-fed, gravel-bed rivers throughout New Zealand. It is understood that the models have a tendency to over-predict (e.g., Kilroy et al. 2017). One potential reason for overpredictions is that Biggs (2000b) dataset covered a narrow range of mean DIN concentration (6 to 232 mg/m^3). The upper limit of the range is commonly exceeded in many rivers, and in those cases the relationships cannot be validly applied for predicting at new sites. In addition, although the rivers in the Biggs (2000b) dataset reasonably represent many New Zealand rivers in terms of their REC classifications, river types covering at least 30% of New Zealand were not represented (Appendix E in Matheson et al. 2012). Thus, development of regional models can be justified.

In 2017 – 18, seven years of periphyton monitoring data from the Horizons region were analysed in a joint project between NIWA, HRC and DairyNZ (DNZ). The report on the analysis was co-authored by all agencies (Kilroy et al. 2018) and explored empirical relationships between environmental variables and periphyton standing crop to predict periphyton abundance in rivers over time and across the region. In addition to nutrient concentrations, predictors included water temperature, stream substrate composition, electrical conductivity (EC) and flow metrics. Reasonably strong empirical relationships for predicting peak periphyton (e.g., annual maximum biomass) were identified in the analysis, especially when site-specific accrual periods were included as predictors.

Kilroy et al. (2018) included a preliminary look-up table in which estimates of the 92nd percentile of chlorophyll *a* (a requirement in the NPS-FM[1]) were derived for multiple combinations of predictor values. The look-up table was presented as Appendix L in that report as a tentative suggestion on how the empirical periphyton – environment relationships (models) could be used to assist in setting nutrient targets in the Horizons region. Appendix L used a relationship developed using data from July 2012 to June 2015 and consisted of predictions of Chla_92 over a range of pre-selected combinations of predictor values based on the ranges of values of the predictor variables. To use the look-up table to suggest a nutrient target, a user would select an appropriate combination of predictor values and read off an estimate of the nutrient concentration corresponding to the periphyton target (as Chla_92). The look-up table was a suggestion only and had the following limitations:

1. the table was based on just one of multiple linear models, and variability in the periphyton – predictor relationships among models was not accounted for;
2. the table did not include uncertainties around the predictions within the model used;
3. predictor values were restricted to only three choices across the whole range of values; this kept the table to a manageable size but at the expense of omitting combinations relevant to some sites.

The present report was prepared for DNZ and HRC, who requested "greater development of Appendix L into a stand-alone technical report delivering recommended guidance [on the use of the relationships developed in the 2018 report] to recommend instream DIN and DRP concentrations for corresponding periphyton Chl-a objectives."

DNZ and HRC also requested that: "If the contractors believe that look-up DIN and DRP concentrations [i.e., the outcome of the guidance developed in the first part of the work] can be recommended for specified chlorophyll *a* outcomes", a further requirement was to: "estimate associated DIN and DRP concentrations for river periphyton outcomes specified in Table E.2 of Schedule E from the operative Horizons One Plan."

1.2 Project scope

Project scope was limited to management of periphyton biomass measured as chlorophyll *a*. In Kilroy et al. (2018) the dependent variables in the relationships were maximum chlorophyll *a* for annual datasets and the 92nd percentile of chlorophyll *a* (as required by the NPS-FM[2]) for multi-year datasets (three years or seven years). The contract for the present analysis specified that the targets should be set for the 92nd percentile of chlorophyll *a* for both the NPS-FM periphyton attribute thresholds and the One Plan targets. In the remainder of this report the abbreviation 'Chla_92' is used to denote the 92nd percentile of chlorophyll *a.*

The One Plan targets do not specify a permitted rate of exceedance: any exceedances breach the target and multiple exceedances over a period are not taken into account in regional State of the Environment (SOE) assessments. Using the 92nd percentile is a pragmatic approach and simplifies the nutrient target setting process by using the same metric as used in the NPS-FM periphyton attribute. The approach precludes use of single-year relationships in Kilroy et al. (2018) for which the dependent variable was annual maximum chlorophyll *a*.

1.3 Report structure

The project was carried out in three stages.

In **Stage 1 (Section 2)**, we reviewed and assessed the models described in Kilroy et al. (2018). We used criteria based on applicability and statistical performance to select models with potential for use in nutrient target setting. This suite of models was generated from data collected over different time periods and using different datasets. Look-up tables similar to those presented in Appendix L of Kilroy et al. (2018) were developed for each model. Predictions generated by the initial suite of models using a constant set of average conditions were compared. Models were evaluated with the aim of narrowing down the suite to a smaller set for use in the trials of target setting. The evaluation included calculating uncertainties (confidence limits) around each prediction.

In **Stage 2 (Section 3)**, the practicalities were considered of using look-up tables generated by the models for setting nutrient targets at sites in the Horizons region, compared with using model equations directly. We also considered use of the models at unmonitored sites.

In **Stage 3 (Section 4)**, the selected suite of models from Stage 1 combined with the predictor values in Stage 2 was applied to derive suggested DIN targets at specific sites for the management of periphyton chlorophyll *a* against the One Plan targets and the NPS-FM bands in the Horizons region. Look-up tables similar to Appendix L were not necessary. Instead, site-specific calculations (in a spreadsheet) were used in which DIN, DRP and other variables, could be altered to obtain estimates of nutrient concentrations corresponding to the One Plan chlorophyll *a* targets and NPS-FM band thresholds at each site. A process for estimating nutrient targets was summarised in a flow chart.

The main outcomes (selection of suitable models, process and outcome of target revision exercise, and main limitations of the method) are summarised in **Section 5**.

BOX 1. A note on terminology and units

Throughout the report we refer to the relationships developed by Kilroy et al. (2018) as "models".

All models discussed in this report predict the 92nd percentile of chlorophyll *a* in milligrams of chlorophyll *a* per square metre of river bed, subsequently abbreviated to **Chla_92**, as specified in the contract for this work.

Throughout the report, the units for dissolved inorganic nitrogen (**DIN**) and dissolved reactive phosphorus (**DRP**) are mg/m^3, which is 1000 x mg/L (the unit used in the One Plan). Using mg/m^3 avoids multiple decimal places.

We made an exception in Section 4.3 (target setting) and Appendix E, where DIN and DRP limits are tabulated in mg/L, for consistency with the published One Plan targets.

2 Stage 1. Review all 2018 models and assess performances

The first step in exploration of the models developed by Kilroy et al. (2018) was to review all the models in the following four steps.

A. Review results of the analyses in Kilroy et al. (2018) and select useful models in terms of their predictive accuracy and structure.

B. Compile look-up tables for predicted Chla_92 (in mg/m^2 of river bed) for combinations of predictor values using models from step A, similar to Appendix L of Kilroy et al. (2018). Use uniform scenarios to enable comparisons; calculate uncertainties.

C. Using the look-up tables developed in step B, examine the effects of specific predictors (EC, DaEF) on predicted Chla_92, in relation to the effects of DIN and DRP.

D. Using the results of steps B and C, compare and evaluate models and look-up tables. Select which could be included in a methodology to be tested for setting nutrient targets in Stage 3 below.

2.1 Step A. Review regression results in Kilroy et al. (2018)

2.1.1 Criteria for potentially useful models

The following criteria were used to define useful models:

1. inclusion of DRP and / or DIN (or closely correlated surrogates) as predictor variables;
2. coefficients of DIN and DRP and other variables that are intuitively sensible (i.e., positive or negative when expected, based on conceptual models of the factors that drive periphyton biomass in rivers);
3. inclusion of a small number of predictors, consistent with the relatively small datasets (i.e., not over-fitted);
4. models developed over time periods relevant to calculation of periphyton state for assessment against the NPS-FM periphyton attribute (i.e., at least three years);
5. good predictive skill; Nash-Sutcliffe Efficiency (NSE)[2] should indicate better than average model performance in cross validation (e.g., using the scale proposed by Li 2016).[3] Models with NSE < 0.55 were not considered.

2.1.2 Overview of models

In Kilroy et al. (2018), regressions were run using subsets of sites in 13 different time periods (seven annual datasets, five three-year datasets and one seven-year datasets), recognising that One Plan

[2] Nash Sutcliffe Efficiency (NSE) is commonly used to assess predictive skill in hydrological models (Nash and Sutcliffe 1970). NSE ranges from -∞ to 1, where the closer the number is to 1, the better model fit. NSE = 1 indicates perfect model fit, 0 indicates that model predictions are as accurate as the mean of the observed data and negative values indicate that the mean is a better predictor than the model. NSE is generally proportional to R^2 but is specifically used to quantify how well a model simulation predicts the outcome variable. As well as testing the correlation between observed and predicted values, NSE accounts for correspondence of values (i.e., the slope and intercept in the relationship). Unlike R^2, NSE can take negative values.

[3] Li (2016) suggested the following scale for model performance: 1. Very poor, NSE < 0.1; 2. Poor, 0.1 ≤ NSE < 0.3; 3. Average, 0.3 ≤ NSE < 0.5; 4. Good, 0.5 ≤ NSE < 0.8; 5. Excellent, NSE > 0.8. Li (2016) used a term VEcv (variance explained by cross validation) rather than NSE. The only difference between the two terms appears to be that VEcv is expressed as a percentage and NSE as a proportion.

target compliance may be reviewed annually, and NPS-FM grading applies to a minimum of three years. All periods ran from July to June, from 2009-10 to 2015-16. All annual models were immediately excluded from further consideration (criterion 4 above). Numbers of sites available for each model run depended on the predictor variables available at each site. Groups were defined based on within-site relationships between periphyton and flow and an assessment of nutrient limitation status. The largest sub-group was the set of sites (maximum $n = 41$) at which an effective flow (EF) was identified (see **BOX 2**). A variable representing mean accrual period (days of accrual - DaEF) was calculated for these sites.

All models included electrical conductivity (EC, in µS/cm) as a predictor (see **BOX 3**), and a variable representing nitrogen (either DIN or TN, see **BOX 4**).

BOX 2. What is an effective flow, how does it relate to 3 x median flow, and how is it measured?

The **effective flow** (EF) at a site is the flow threshold (in multiples of the median flow) that typically causes periphyton to be re-set to low levels. “Low level” means chlorophyll *a* equivalent to cover by thin algal films (e.g., ~9 mg/m^2, Kilroy et al. 2013, but with variability from site to site).

EF is important because it allows calculation of “accrual time”, referred to as **DaEF** (days). DaEF is the mean time in days between events exceeding the EF. Accrual time is an important controller of periphyton biomass: the longer the accrual time, the more likely it is that maximum biomass will be observed. Accrual time can therefore be an important predictor of peak periphyton. Note that maximum biomass is also determined by nutrients and other variables such as light, temperature and substrate.

FRE3 (the annual frequency of floods exceeding **3 x median flow**) is broadly correlated with biological indices in streams (Clausen and Biggs 1997) and 3 x median flow has commonly been assumed to represent EF. Three x median can be a good estimate of EF for some types of river (e.g., Biggs 2000b). However, 3 x median is often not appropriate. Hoyle et al. (2017) showed that the EF at 18 sites in the Horizons region approximated the flow magnitude that mobilises sand and that EF varied from 2 x to 15 x median flow.

EF can be calculated using time series of periphyton and flow data to determine:

- the flow threshold typically associated with low chlorophyll *a* (see Hoyle et al. 2017); or
- the flow threshold associated with accrual periods that explain the highest proportion of variance in chlorophyll *a* (Kilroy et al. 2018).

Another way to estimate an effective flow at a site is to estimate the flow magnitude that moves sand. For details, refer to Hoyle et al. (2017).

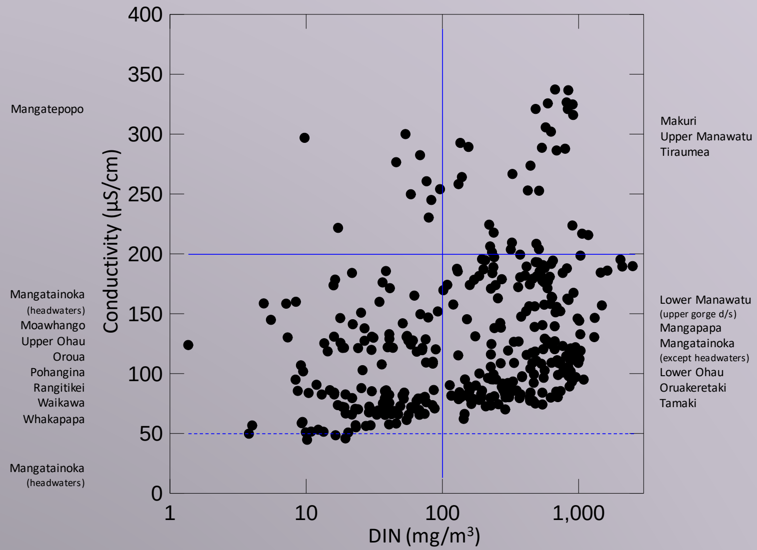
It is not always possible to identify an effective flow. This could be because stable substrate and little fine sediment favours growth of periphyton that resists removal, or because periphyton biomass is always very low. Non-natural flow regimes, or frequently changing bed substrate could also prevent identification of a characteristic EF.

BOX 3. What drives electrical conductivity (EC) and how does it affect periphyton?

Electrical conductivity (EC) was identified by Kilroy et al. (2018) as the strongest predictor of peak chlorophyll *a* in the Horizons region. All models selected for target-setting included EC. This implies that EC must be taken into account when setting nutrient targets even though it cannot be managed.

EC across rivers is usually strongly correlated with total molar concentrations of major ions (e.g., calcium, sodium, etc.). Major ion composition reflects catchment geology and proximity to the sea. For example, rivers draining limestone catchments have high EC from high calcium concentrations; EC in coastal rivers may reflect high sodium concentrations. EC tends to be characteristic at a site with variation over time due to flow effects (e.g., dilution of ions at high flows).

DIN (> 1000 mg/m^3) has a measurable effect on EC values. The plot below shows that annual mean EC and annual mean DIN were weakly correlated in the Horizons region (r = 0.32). The upward slope at the lower edge of the scatter plot likely represents the influence of DIN on EC (<100 µS/cm, r = 0.61, n = 144). Variable EC above 100 µS/cm is likely mainly attributable to other factors. Based on work by Likens et al. (1970), an increase of 1000 mg/m^3 DIN was equivalent to an increase in conductivity of about 12 µS/cm. Thus, EC is likely to be relatively stable within defined flow regimes.



Plot of EC against DIN. Each point is an annual average at a site. DIN values are the geometric mean (log-transformed) and EC values are the arithmetic mean. Horizons region rivers in each quadrant (separated by the blue lines) are listed.

Rivers with higher EC generally support higher algal biomass and are more productive than rivers with low EC. The effect may be caused by the higher nutrient concentrations associated with higher EC (as above). Earlier NZ studies showed that EC appeared to be linked to species composition, with taxa forming the highest biomass occurring at higher EC (Biggs and Price 1987, Biggs 1990). Another cause of the pattern is likely linked to the strong effect of alkalinity (which is correlated with conductivity) in structuring diatom communities (Kelly et al. 2008).

Further investigations into EC – biomass – community composition relationships using data from different regions and geological settings could advance understanding the role of EC in modifying nutrient – periphyton relationships. Refer to Section 6.4.5 in Kilroy et al. (2018) for more discussion.

BOX 4. DIN versus TN as the nitrogen variable

Dissolved inorganic nitrogen (DIN) is a measure of soluble forms of N in a filtered water sample. DIN typically comprises mostly nitrate-nitrogen, but includes nitrite-N and ammonium-N. In the Horizons region, concentrations of ammonium-N can be elevated below waste-water treatment plants and may lead to higher than expected chlorophyll *a* in periphyton (Kilroy et al. 2018b).

Total nitrogen (TN) is a measure of all nitrogen in an unfiltered water sample including DIN, organically bound N, and the N in suspended particulate organic and inorganic material.

Relationships between instream N concentrations and benthic chlorophyll *a* are typically stronger with TN than with DIN, presumably because TN partly reflects benthic chlorophyll *a*. TN includes algae sloughed from periphyton and so there is some circularity in the relationship.

DIN is preferred to TN as a predictor representing N supply, because DIN limits are specified in both the One Plan and the NPS-FM. DIN is the form of nitrogen that is directly available for uptake by periphyton. However, TN is commonly used to represent N supply in other parts of the world (e.g., USA) (see Dodds 2003).

In the Horizons region, DIN and TN are strongly correlated. DIN concentrations can be estimated from TN and vice versa, using the equations:

$$\mathrm{Log_{10}DIN} = -1.478 + 1.435\ (\mathrm{log_{10}TN}) \qquad \textit{(Eq. 1)}$$

$$\mathrm{Log_{10}TN} = 1.136 + 0.65\ (\mathrm{log_{10}DIN}) \qquad \textit{(Eq. 2)}$$

($n = 260$, adjusted $R^2 = 0.95$, mean square error = 0.022, 0.010; DIN and TN are geometric means in mg/m^3).

The equations exclude data from two sites on the Porewa River (upstream and downstream of the waste-water treatment discharge). TN at the Porewa River sites was relatively high (>850 mg/m^3) yet comprised <9% DIN. Across all other sites, TN contained? about 50% DIN on average. Note that the proportion of DIN in TN generally increases with TN concentration. Very high TN is usually mostly DIN, whereas low TN often comprises mostly organic N.

In some periods, the best model included a term for mean temperature (hereafter Tmean) or a substrate variable (pccoarse or pcsand[4]). DaEF was also a predictor. Only one of the models deemed promising for development of look-up tables included DRP as a predictor (Table 2-1).

About 30% of the sites did not have an associated flow record and relationships derived using the whole dataset and excluding a flow variable, but including DIN, were generally weak. However, models including TN, EC and pccoarse as predictors, but no flow variable, performed reasonably well across 56 to 58 sites in three-year and the seven-year time periods. The three strongest of these models were included as promising models, to expand site coverage (Table 2-1).

[4] Substrate variables were calculated using visual estimates of the percentage cover of the stream bed by bedrock, boulders, large cobbles, small cobbles, large and small gravels, sand and silt. Pccoarse was calculated as the sum of large cobbles, boulders and bedrock.

Note that even though DIN and TN were strongly correlated, the all-sites relationships including TN consistently performed better than those including DIN. Refer to **BOX 4**.

A further model was included because of good predictive ability across a set of 14 sites at which EFs were poorly defined or undefinable, with the strongest model in 2009-16. The 14 sites included headwaters, and sites in the Makotuku and Mangapapa Rivers.

In summary, eight regression models of those developed by Kilroy et al. (2018) met the criteria for inclusion in the first suite of models. Predictor variables were: DIN or TN, EC, DaEF, pccoarse, Tmean and DRP. All selected models are subsequently referred to using the letters A to H (Table 2-1).

- Models A to D applied to sites at which an effective flow was identified (see BOX 2).
- Models E, F and G applied to all sites; nitrogen concentrations are represented by TN (see BOX 3) and no flow variable was included as a predictor.
- Model H was developed from a small group of sites (n = 14) at which periphyton was identified by Kilroy et al. (2018) as insensitive to flow.

Models E to H did not include a flow variable. We assumed that inclusion of pccoarse with a positive coefficient may have carried some information about flow because pccoarse at the sites with flow data was positively correlated with variables representing flow variability.

In models C and D, pccoarse had a negative coefficient, which is counter-intuitive because we expect more persistent periphyton at sites with stable substrate. However, in the Horizons dataset, pccoarse and Chla_92 were negatively correlated, reflecting upstream – downstream patterns that were also captured by the variable Tmean. Therefore, both pccoarse and Tmean probably reflected altitude rather than direct effect of either variable on periphyton biomass.

Only one model (B) included DRP as a predictor. Therefore, ability to develop DRP targets was limited.

No selected models were derived from data collected in the first three years of the monitoring programme unless the data were combined into a seven-year dataset (2009-16, July 2009 to June 2016). The models derived from data in 2009-12 and 2010-13 and using DIN as the nitrogen predictor had low predictive skill (Table 2-1). The differences highlighted that multiple years of monitoring are required to obtain robust models that represent relationships between periphyton and other variables under average conditions (**BOX 5**).

Table 2-1: Regression models assessed as most promising for deriving in-stream nutrient criteria. Letters in the left-hand column are used to identify the models in the remainder of the report. The dependent variable was the 92nd percentile of chlorophyll *a* (Chla_92). Suitability was based on inclusion of DIN and/or DRP as predictors, expected coefficient signs (positive or negative) and NSE > 0.55. Grey-shaded cells indicate models that did not meet these criteria: these models are shown for comparative purposes. Under model statistics, R^2 is the adjusted R^2 of the original regression relationship. The mean square error is used to adjust back-transformed values and compute confidence intervals when predicting the estimate of chlorophyll *a*. RMSD indicates the accuracy of predictions as assessed from leave-one-out cross-validation (it indicates the difference between observed and predicted values). Under DIN, * indicates that the variable used was TN rather than DIN. DIN and TN are strongly correlated and DIN can be predicted from TN and vice versa using Equations 1 and 2 in BOX 4. **Models included in the final selection are in bold type (see Section 5)**.

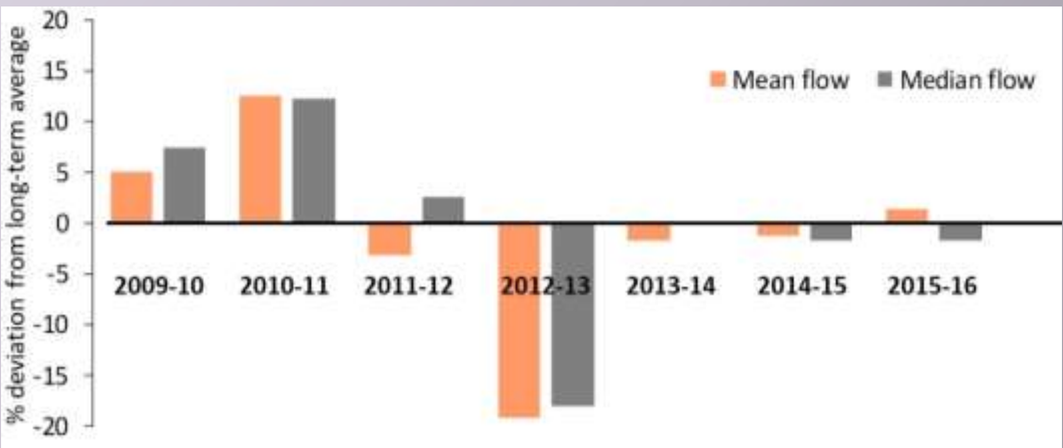
			Coefficients of intercept and predictor variables (with transformation and units)								Model statistics			
		No. of sites	Intercept	daEF	EC	DIN (or TN*)	Temp.	Pccoarse	DRP	%sand				
				log_{10}	sqrt	log_{10}			log_{10}		R^2	Mean squared error	Nash-Sutcliffe Efficiency (NSE)	Root mean squared deviation (RMSD)
Model	Period	*n*		days	µS/cm	mg/m³	°C	%	mg/m³	%				
Sites at which an effective flow (EF) was identified, DIN as predictor														
	2009-12	36	-1.218	0.305	0.090	0.562				-1.218	0.61	0.115	0.20	0.410
	2010-13	37	-2.033	0.469	0.088	0.278	0.073		0.358	-2.033	0.66	0.081	0.30	0.357
A	2011-14	40	-2.002	0.564	0.126	0.280	0.056				0.77	0.059	0.68	0.258
B	**2012-15**	**40**	**-1.939**	**0.524**	**0.106**	**0.323**	**0.040**		**0.334**		**0.79**	**0.050**	**0.70**	**0.239**
C	2013-16	40	-0.995	0.547	0.106	0.336		-0.005			0.77	0.053	0.67	0.245
D	**2009-16**	**42**	**-0.897**	**0.485**	**0.097**	**0.413**		**-0.007**			**0.74**	**0.061**	**0.58**	**0.276**
All sites, TN as predictor instead of DIN and no flow predictors														
E	2010-13	51	-1.642		0.045	0.981*		0.009			0.72	0.062	0.59	0.258
F	2012-15	56	-1.303		0.085	0.671*		0.008			0.71	0.061	0.58	0.257
	2013-16	56	-1.441		0.091	0.603*		0.011		0.030	0.68	0.063	0.51	0.264
G	**2009-16**	**58**	**-1.444**		**0.084**	**0.726***		**0.008**			**0.74**	**0.053**	**0.64**	**0.240**
Flow-insensitive sites at which effective flow only weakly or not identified, DIN as predictor														
H	**2009-16**	**14**	**-1.921**		**0.113**	**0.816**		**0.017**			**0.87**	**0.0397**	**0.63**	**0.464**

BOX 5. Variability in models from different time periods

Models developed by Kilroy et al. (2018) using data collected in the early years of the monitoring programme were weaker than those developed from 2012 onwards. What caused the differences?

A likely explanation is that rainfall and river flows varied across years. The frequency and duration of floods can influence both nutrient concentrations and periphyton biomass. Therefore, models developed from data collected during wet years may differ from those using data collected during average or dry years.

The graph below shows the result of a comparison of annual flows with nine-year averaged flows. Mean and median flows in 2009-10 and 2010-11 were respectively ~5% and >10% higher than the nine-year average (i.e., wetter than average). Mean and median flows in 2012-13 were ~19% lower than the nine-year median (i.e., drier than average). Flows were close to the long-term averages in the other four years.



Average deviations from long-term (2008-18) mean and median flows in the Horizons region, 2009-10 to 2015-16. Years from July to June. Averages of 28 flow records (excluding regulated flows).

Kilroy et al. (2018) found that the weakest periphyton – environment models (i.e., lowest r2 and low NSE) were in 2009-10 and 2010-11 (wet years), followed by 2012-13 (dry year). Models from 2009-12 were also weak. The strongest models derived from multi-years datasets included the dry year (2012-13).

This result suggests stronger models in the average years (i.e., higher variance explained and better predictive ability) than in the wet or dry years.

In general, the multi-year datasets encompassing average conditions also yielded better models than the annual datasets, presumably because the longer time-series resulted in better averaging of hydrological conditions.

2.2 Step B. Develop look-up tables for evaluating models

The equations identified as promising in Table 2-1 were used to generate lookup look-up tables of estimates of Chla_92 for a defined set of predictor values. Predictor values (Table 2-2) were based on ranges of each predictor variable set out in Table 2-3. Histograms for DaEF, EC, DIN, DRP, Tmean and pccoarse are presented in Appendix B.

Each look-up table included all combinations of the predictor values in Table 2-2. The maximum number of predictor variables included in a model was five, including DRP but excluding pccoarse (model B). The maximum number of combinations (excluding DIN) was therefore 288. At least 20 concentrations of DIN were included, depending on the range of DIN observed over the period and sites from which the data were derived.

Table 2-2: Values of predictor variables used to generate estimates of chlorophyll *a* under different conditions, for setting nutrient targets. DRP values included the One Plan targets of 6, 10 and 15 mg/m^3. For models E, F and G, TN was converted to DIN using the relationships in BOX 4.

Predictors	Units	Values used in scenarios					
DaEF	days	20	50	75	100		
EC	µS/cm	50	100	150	200	250	300
DIN	mg/m^3	approximately 20 concentrations, from 20 to >1000, including the One Plan targets					
Tmean	C	10	12.5	15			
Pccoarse	%	20	30	45	60		
DRP	mg/m^3	5	6	10	15		

Table 2-3: Mean values (with ranges) of predictor variables encountered in the dataset in each period. Note that under DaEF the accrual periods in regulated rivers have been omitted as the high values skew the means; however, DaEF at these sites was included in the analysis. The numbers shown for DIN and DRP are averages and ranges of geometric means over the period of interest. The ranges for the two small groups of sites for which look-up tables were generated are shown at the bottom of the table (i.e., sites at which only a weak or no effective flow was identified (see Section 3 in Kilroy et al. 2018), and sites assessed as P-limited at low flows on the basis of DIN : DRP ratios (see Section 4 in Kilroy et al. 2018)). The dependent variable was the 92nd percentile of chlorophyll *a*. **Models included in the final selection are in bold type (see Section 5).**

Model	Period	No. sites n	DaEF (days)	EC (µS/cm)	DIN or TN* (mg/m³)	Tmean (°C)	Pccoarse (%)	DRP (mg/m³)	Chla_92 (mg/m²)
Sites at which an effective flow (EF) was identified, DIN as predictor									
A	**2011-14**	40	82 (12.4 - 563)	130 (51 - 324)	136 (9.8 - 858)	12.7 (8.5 - 15.5)	33 (1 - 61)	9.4 (4.4 - 21)	73 (2.8 - 321)
B	**2012-15**	**40**	**78 (12.6 - 280)**	**133 (52 - 328)**	**126 (6.9 - 983)**	**12.8 (8.6 - 15.1)**	**37 (4 - 63)**	**9.9 (5.3 - 28)**	**72 (2.7 - 273)**
C	**2013-16**	40	76 (11.6 - 281)	134 (51 - 333)	145 (7.7 - 951)	13 (9.1 - 15.4)	40 (4 - 65)	10.1 (4.9 - 30)	62 (2 - 263)
D	**2009-16**	**42**	**66 (11.8 - 618)**	**132 (50 - 321)**	**153 (9 - 951)**	**12.7 (8.8 - 15.1)**	**34 (2 - 61)**	**10.1 (4.4 - 23)**	**74 (2.2 - 253)**
All sites, TN as predictor instead of DIN and no flow predictors									
E	2010-13	51	-	136 (50 – 321)	559* (64 – 1507)	12.5 (8.3 – 15.9)	29 (0.8 – 60)	16.0 (3.8 – 174)	77 (2.9 – 355)
F	2012-15	56	-	133 (52 – 328)	529* (64 – 1601)	12.7 (8.6 – 15.2)	36 (18 – 71)	16.1 (5.3 – 215)	75 (2.7 – 273)
G	**2009-16**	**58**	-	**130 (50 – 321)**	**570* (64 – 1785)**	**12.5 (8.6 – 15.0)**	**34 (2 – 62)**	**15.5 (4.4 – 187)**	**68 (2.2 – 253)**
Flow-insensitive sites at which effective flow only weakly or not identified, DIN as predictor									
H	**2009-16**	**14**	-	**97 (50 – 269)**	**309 (14 – 964)**	**11.5 (8.9– 15.0)**	**42 (16 – 62)**	**15.6 (5.2 – 49.4)**	**69 (8.2 – 253)**

2.3 Step C. Compare predictions under uniform conditions

An initial comparison of the different models was carried out by predicting Chla_92 using each model at the One Plan DIN targets of 70, 110, 167 and 444 mg/m^3. Other variables were set at approximately average values (DaEF, 30 days; EC, 150 µS/cm; Tmean, 12.5 °C; pccoarse, 30%). Four DRP concentrations were included for model B.

Ranges and means of predictor values for model H were more restricted because of the small dataset, and average values were selected accordingly (Table 2-2).

To assess the potential influence of EC, DaEF and DRP on Chla_92 we compared predictions of Chla_92 along gradients of DIN and the second predictor (such as EC), with other predictors set at average values.

The effects of Tmean and pccoarse were smaller (see coefficients in Table 2-1) and were not evaluated in the same way. Note that the pccoarse had both positive and negative coefficients (discussed above, Section 3.1.2).

2.3.1 Quantifying uncertainties within each model

Every prediction from each model is associated with a range of uncertainty around the estimate. In this exercise, we considered that the 95% confidence interval (CI) was an appropriate measure of uncertainty[5]. We calculated the back-transformed 95% CI around each estimate using the modified Cox method for calculating CI for the mean of a log-normal distribution as (Olssen 2005):

$$10 \wedge \text{Estimate} + S^2/2 \pm 2.2 \sqrt{[(S^2/n) + (S^2 * S^2)/2(n-1)]}$$

where S^2 is the mean squared error of the model, residuals and n is the number of samples used to derive the model.

2.3.2 Comparison of predictions

Predicted Chla_92 corresponding to mean DIN concentration of 70 mg/m^3 ranged from 29 to 55 mg/m^2 and of 444 mg/m^3 ranged from 87 to 108 mg/m^2 (Table 2-4). These ranges included all the predictions by Model B when DRP concentrations were set at 5 to 15 mg/m^3.

Models in which TN was substituted for DIN[6] returned lower predicted Chla_92 under equivalent conditions than models in which DIN was used directly except at the highest DIN concentration (444 mg/m^3) (Table 2-4).

- Mean predicted Chla_92 for DIN = 70 mg/m^3 using models E, F and G was 34 mg/m^2 compared to 49 mg/m^2 using models A to D (i.e., ~35% lower on average using models E to G than using models A to D).

[5] Conventional statistical treatment of uncertainty is to use 95% confidence and 95% prediction intervals. The 95% confidence interval (CI) is the range around the estimate in which there is a 95% probability that another estimate would fall if it was derived from a new subset of predictions from the same population. The 95% prediction interval (PI) is the range around the estimated value in which there is 95% probability that a single new predicted value would fall (from the same population). The PI is always larger than the CI

[6] TN corresponding to the DIN targets of 70, 110, 167 and 444 mg/m^3 was, respectively, 206, 284, 379 and 750 mg/m^3 (from Equation 2 in BOX 3).

- At DIN = 444 mg/m^3, mean predicted Chla_92 was 92 and 94 mg/m^2 from models A to D and E to G, respectively (i.e., predictions from models A to D were ~4% lower on average than models E to G).

Predictions using model H reflected conditions at sites in the dataset. Chla_92 was low when DIN concentrations were low because dataset included sites in headwaters where both DIN and Chla_92 was typically low. There is some circularity here: consistently low chlorophyll *a* also presumably leads to lack of effect of high flows because there is rarely enough periphyton to be removed.

The 95% confidence intervals were on average (all models) approximately ± 20% of the estimate.

2.3.3 Effect of different predictors

Plots showing predictions of Chla_92 vs DIN in the different models with EC, DaEF and DRP set at a range of values are shown in Appendix C.

Increases in Chla_92 when holding DIN and other predictors constant and doubling EC from 100 to 200 ranged from ~60 % (model E) to ~300% (model A).

Chla_92 predicted using model A to D increased by about 45% as DaEF doubled from 20 to 40 days. There was a relatively small difference between models. For example, at DIN = 400 mg/m^2, predicted Chla_92 with DaEF = 20 days, EC = 150 µS/cm, DRP = 10 mg/m^3 and Tmean = 12.5 °C or Pccoarse = 30% was 54, 55, 57 and 66 mg/m^2, in models A, B, C and D, respectively. Increasing DaEF to 40 days returned 79, 79, 83 and 93 mg/m^2 respectively.

DRP was a predictor in model B only. Model B predicted an increase in Chla_92 of about 40% with a three-fold increase in DRP concentration from 5 to 15 mg/m^3. A three-fold increase in DIN from 200 to 600 mg/m_3 led to approximately the same percentage increase.

The main differences between models were:

- the effect of EC on Chla_92 was predicted to be greater using models A and H than in other models (first set of plots in Appendix C);
- The effect of EC on Chla_92 differed between model E and other models in that the effect of EC was more uniform along the EC gradient, and generally smaller, leading to higher predicted Chla_92 at low EC (up to 150 µS/cm) and lower predicted Chla_92 at higher EC (200 µS/cm and over) than in other models.
- Predicted Chla_92 using model H was lower than in other models with DIN < ~200 mg/m^3, but with DIN > 200 mg/m^3 was higher than in other models under the same conditions. This pattern of predictions would have been influenced by the small dataset.

Table 2-4: Predicted Chla_92 using all models listed in Table 2-1 under a standard set of conditions and variable DIN and DRP with 95% confidence intervals. The estimates are shown in bold type, followed by lower and upper 95% confidence limits. DIN and DRP were set at the targets in Table E.2 in the One Plan. Predictors other than DIN were set at approximately median values: DaEF = 30 days, EC = 150 µS/cm, Tmean = 12.5 °C; % coarse = 30%. Predictions from models in which TN was used as a predictor rather than DIN were made for TN equivalent to the target DIN values, estimated using Equation 1. Grey type indicates predictions outside the range of DIN in the dataset. Blue type indicates variable DRP as well as DIN. Alternate DIN levels are shaded to aid reading the table.

				DIN = 70 mg/m³			DIN =110 mg/m³			DIN = 167 mg/m³			DIN = 444 mg/m³		
				Est.	95% CI		Est.	95% CI		Est.	95% CI		Est.	95% CI	
Model	Site characteristics	Flows	DRP		lower	upper		lower	upper		lower	upper		lower	upper
Sites at which an effective flow (EF) was identified, DIN as predictor															
A	2011-14	average-dry		**55**	46	66	**63**	52	75	**70**	59	84	**90**	77	111
B	2012-15	average-dry	5	**40**	34	47	**46**	39	55	**53**	45	63	**73**	62	86
B	2012-15	average-dry	6	**43**	36	50	**49**	42	58	**57**	48	67	**77**	66	92
B	2012-15	average-dry	10	**51**	43	60	**59**	50	69	**67**	57	79	**92**	78	109
B	2012-15	average-dry	15	**52**	49	68	**67**	57	79	**77**	65	91	**105**	89	124
C	2013-16	average		**52**	44	62	**61**	51	72	**70**	59	83	**97**	82	115
D	2009-16	average		**50**	42	60	**56**	51	73	**72**	60	86	**108**	90	130
All sites, TN as predictor instead of DIN and no flow predictors															
E	2010-13	average		**29**	25	35	**40**	34	47	**53**	45	63	**104**	89	123
F	2012-15	average-dry		**40**	34	46	**49**	41	57	**58**	50	68	**90**	77	105
G	2009-16	average		**34**	29	39	**43**	37	49	**53**	46	61	**87**	75	100
Flow-insensitive sites at which effective flow only weakly or not identified, DIN as predictor															
H	2009-16	average		**33**	18	23	**34**	29	38	**54**	48	62	**167**	146	191

2.4 Step D. Model evaluation

The eight models evaluated had a range of predictive skill (NSE from 0.58 to 0.72, Table 2-1). The plots in Appendix C highlighted that two may be outliers.

- Model E produced predictions with a different pattern from those of the two related models (F and G), arising from different coefficients (Table 2-1). Model E was derived from the 2010-13 dataset, which included both a wet year and a very dry year (see BOX 4) and was the only model considered from this dataset. Although the shape of the predictions along EC and DIN gradients differed from those in other models, predictions at average EC were similar. NSE was 0.59 and at the low end of the range. On that basis, model E could be the first to be dropped.

- With DIN > 200 mg/m^3, model H predicted higher Chla_92 at higher levels of DIN and a stronger response to EC than other models. Model H applied only to a small set of sites and a different response was expected. Model H could provide useful additional predictions at sites where models E, F and G (using TN instead of DIN) apply. NSE was reasonable at 0.63.

Apart from possibly treating model E as an outlier, there was no real basis for selecting one model over another. Models E, F and G had widest applicability because they covered all sites with data on TN concentrations, EC and bed substrate. However, models E, F and G did not include a variable to represent accrual period, which is one of the more important controllers of periphyton abundance. Furthermore, models E, F and G were not the best models in terms of predictive skill. Omitting better models (i.e., models A, B and C) ignores more accurate predictions, even if their applicability is narrower.

Consequently, at this stage, our approach was to trial the suite of eight models for setting DIN targets corresponding to maintaining Chla_92 below the One Plan targets at the periphyton monitoring sites. The models were expected to indicate a range of targets. Examination of the results, such as testing the effect of removing one or more models from the suite, could justify reducing the number of models further.

3 Stage 2. Practicalities of setting nutrient targets at individual sites

3.1 Direct use of equations rather than look-up tables

Look-up tables that include predictions of chlorophyll *a* for all possible combinations of variables could quickly become cumbersome, especially if multiple models are adopted (Section 2.4). Other disadvantages are that assessing variability of predictions across models and accounting for uncertainty around the predictions in each model add further complexity.

Because the intention in the present exercise was to set targets for individual sites, we considered that direct use of the model equations was a simpler and more practical approach than look-up tables. Direct use of the equations also facilitates inclusion of prediction uncertainties.

3.2 Assigning predictor values

Direct use of the equations requires that the user has prior knowledge of an appropriate value for each predictor at the site(s) of interest.

We analysed the datasets to assess variability over time of each predictor (DaEF, Tmean, EC, pccoarse) at each monitoring site. A summary of the outcome follows. The detailed data are not shown.

- **DaEF** at most sites, as expected, varied from year to year depending on weather conditions (see Box 5). DaEF was more stable when calculated over multiple years (i.e., lower coefficient of variation).
- **Tmean** and **EC** were generally stable over time, especially when calculated over three-year periods. We expect site-specific values because Tmean and EC generally depend on stable features of the catchment (i.e., altitude and geology, respectively) (see Box 3 for more on EC).
- In general, we expect mean values of pccoarse over 12 months or longer to remain stable, and the mean value was assumed to be characteristic at a site. Large floods can reorganise a riverbed, leading to successive surveys with an intervening flood returning different substrate assessments, including **pccoarse**. River flows tend to remove finer fractions deposited in floods, and generally return to a more typical equilibrium condition. Therefore, there may be short-term fluctuations in composition, especially of the finer fractions.

A table of predictor values was compiled based on long-term means and is presented in Appendix D.

3.3 Assigning predictor values to unmonitored sites

The tables of predictor values applied only to sites already in the periphyton monitoring programme. Other sites could be included if it was possible to obtain estimates of the required predictors (one or more of: EC, DaEF, Tmean, pccoarse).

EC and Tmean could be obtained easily in, for example, a year of monthly spot measurements, or by deploying loggers.

In theory, a single site visit may be sufficient to estimate typical pccoarse. The method used would need to be the same as that used at the periphyton monitoring sites.

Estimation of DaEF requires time-series of periphyton and river flow data, or field surveys to enable estimation of the flows required to mobilise sand (see BOX 2 and Hoyle et al. 2017). Research is underway to develop a national classification of effective flows. Additional steps to estimate DaEF would require river flow data. Modelled river flow data can be generated for ungauged reaches (Booker and Woods 2014). Accuracy at the reach scale in the Horizons region is not known.

4 Stage 3. Nutrient targets for compliance with One Plan chlorophyll *a* targets and NPS-FM periphyton bands

The second part of the project was: "If the contractors believe that look-up DIN and DRP concentrations can be recommended for specified chlorophyll *a* outcomes estimate associated DIN and DRP concentrations for river periphyton outcomes specified in Table E.2 of Schedule E from the operative Horizons One Plan." We considered that going through the exercise of using the models to suggest nutrient targets would be a useful way to assess whether the model predictions were robust enough to set nutrient targets.

Table E-2 of the One Plan is a list of 43 Water Management Zones in the Horizons region, with their subzones. Targets (i.e., outcomes) are specified for each zone for periphyton, DIN and DRP, among other water quality variables. All the Water Management Zones are listed in Appendix E in the present report, along with the periphyton monitoring sites representing each Water Management Zone (if applicable – not all zones have a periphyton site). Where sites represent one or more subzones within a zone, the subzones are also listed. In each case, the One Plan targets for chlorophyll *a*, DRP and DIN are shown.

Below we outline a process for defining DIN targets to achieve the chlorophyll *a* targets, initially using all eight models selected in Section 3. The process was applied to the periphyton monitoring sites representing Water Management Zones in the Horizons region. The outcomes were reviewed, with the aim of further reducing the number of models required. DRP was not included in the assessment at this stage (see below).

4.1 Assumptions made during target setting

The following assumptions were made.

1. The targets for chlorophyll *a* in Table E-2 of the One Plan (Appendix E in this report) have been set using effects-based criteria. That means that the chlorophyll *a* targets represent thresholds above which detrimental effects on the river ecosystem, and / or recreational and cultural values are expected. Refer to Biggs (2000a) and Snelder et al. (2013) for more on derivation of effects-based periphyton thresholds.

2. The 92^{nd} percentile of chlorophyll *a* (Chla_92) is an appropriate metric for assessing compliance with the One Plan periphyton (chlorophyll *a*) targets.

3. The One Plan targets at each site also represent the objectives (bands) in the NPS-FM periphyton attribute because the targets of 50, 120 and 200 mg/m^2 chlorophyll *a* are equivalent to NPS-FM objectives of periphyton attribute bands A, B and C, respectively.

4. The DIN (and DRP) targets listed in Table E.2 of the One Plan and Appendix E in this report were intended to approximate multi-year median (or geometric mean) concentrations that would be expected to maintain periphyton within the targets.

5. The appropriate nutrient targets should be set so as to ensure that Chla_92 meets the target, but without being too restrictive, i.e., the revised DIN and DRP targets should not be set substantially lower than concentrations estimated to correspond to the chlorophyll *a* target.

6. A priority was to look first at sites at which the targets have been exceeded (see Appendix E).

4.2 A process for nutrient target setting

A procedure for estimating appropriate DIN targets at the Horizons periphyton monitoring sites was arrived at in an iterative process and took into account current Chla_92 and DIN concentrations at each site and the initial results in the target-setting trial (Figure 4-1). Following the procedure required access to:

- the list of Horizons water management zones and periphyton sites, showing One Plan targets, observed values for Chla_92, DRP and DIN, and applicable models (from Table 2-1) at each site (**Appendix E**);
- the table in **Appendix D** showing values of predictors at each site;
- the **Excel spreadsheet** (provided separately) with calculations of model predictions for a single set of predictor values, along a gradient of DIN, including the 95% confidence interval. Calculations for all models are on the same sheet, arranged so that predictor values can be rapidly pasted into each. An example of one model in the spreadsheet is shown in Figure 4-2.

A similar procedure would apply to DRP targets but only model B included DRP as a predictor, and DIN was also included. One approach would be to generate estimates of DRP corresponding to the Chla_92 target at each site while holding DIN at its mean value. This has not yet been included in this report.

In the final procedure (Figure 4-1), the sites were divided into four groups for the assessment, using data averaged over the seven-year dataset.

1. **Sites at which current Chla_92 and DIN were both low (< 20 mg/m^2 and <0.1 mg/L, respectively)**. This group of sites emerged as a group following the first round of target-setting using all of the models (see below).
2. **Sites at which current Chla_92 and DIN or Chla_92 and DRP were close to the One Plan targets.** In Figure 4-1 we suggest that the appropriateness of current targets could be based on the ranges of nutrient concentrations observed in three-year datasets over the period of monitoring. On average DIN varied over a range of 60% of the mean and DRP 30%. The current target would be appropriate if (a) the chlorophyll *a* target is within 10% of being met, and (b) observed DIN and DRP are within half the observed range (respectively, 30% and 15%) of the current nutrient targets. For example, if the DIN target is 0.444 mg/L, observed values of 311 – 577 mg/L would suggest that the current target is reasonable. A range is suggested because both DIN and DRP vary naturally across years, as shown in Appendix D. Plus or minus 10% of observed chlorophyll *a* is suggested because this is well within the typical range of chlorophyll *a* sampling variability (Kilroy et al. 2013).
3. **Sites at which the One Plan chlorophyll *a* target was exceeded.** Here exceedance was taken as more than 10% over the target.
4. **Sites at which the One Plan chlorophyll *a* target was met.** Group 4 included sites at which the current the DIN (or DRP) target was either met or exceeded.

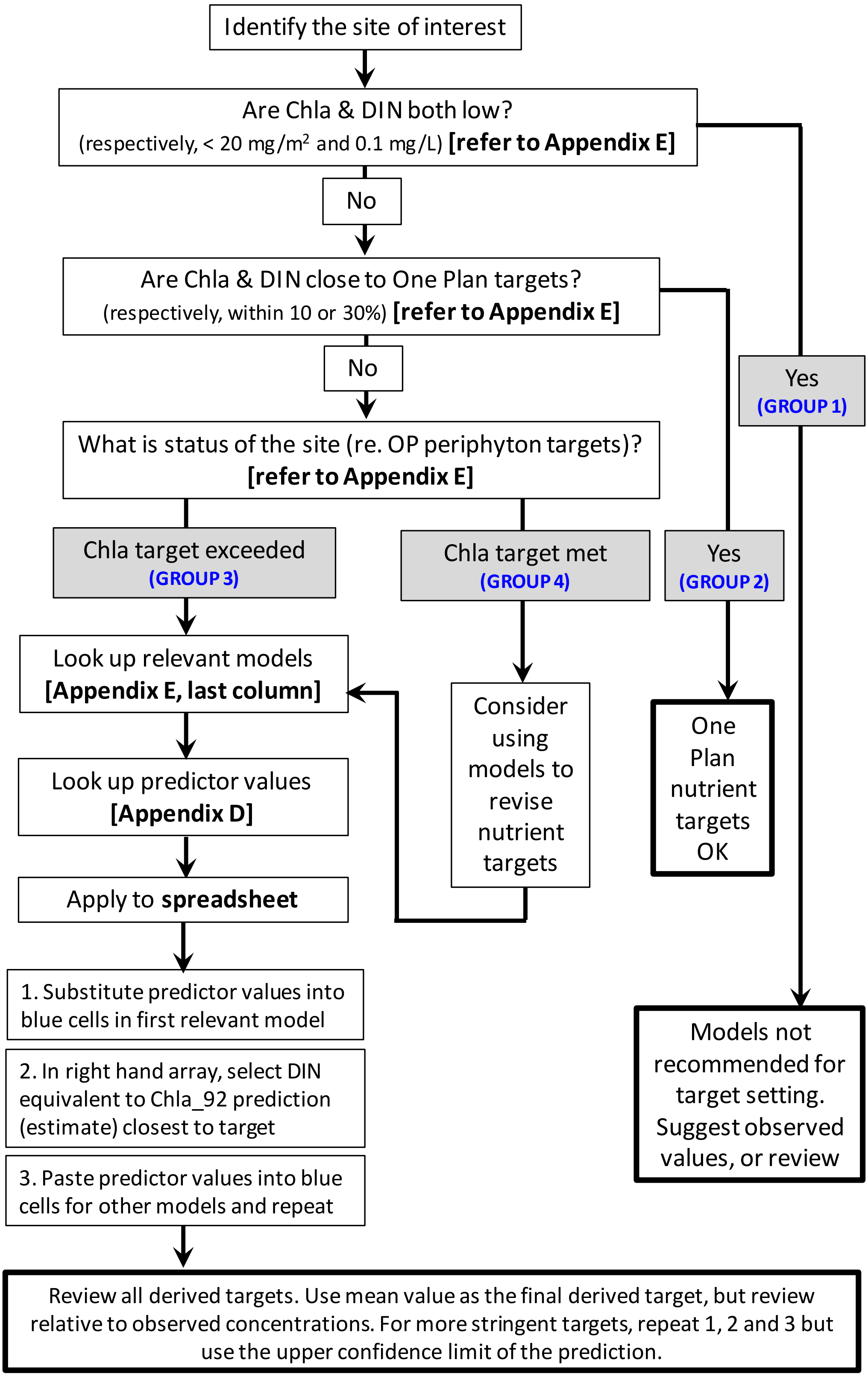
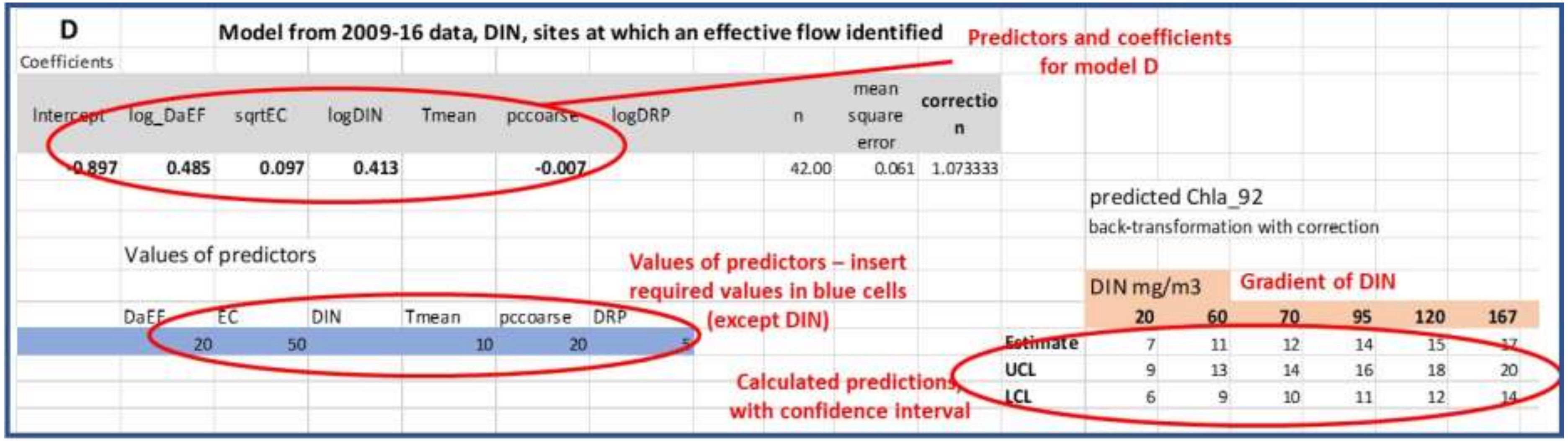


Figure 4-1: Flow chart outlining the process for setting site-specific nutrient targets for periphyton management in the Horizons region. Use of the method requires access to Appendix E (table of sites with current targets and current Chla_92, DRP and DIN), and Appendix D (predictor values and their stability over time). Steps 1, 2 and 3 in the lower left-hand column refer to calculations made on the spreadsheet of relationships, an example of which is shown in Figure 4-2.



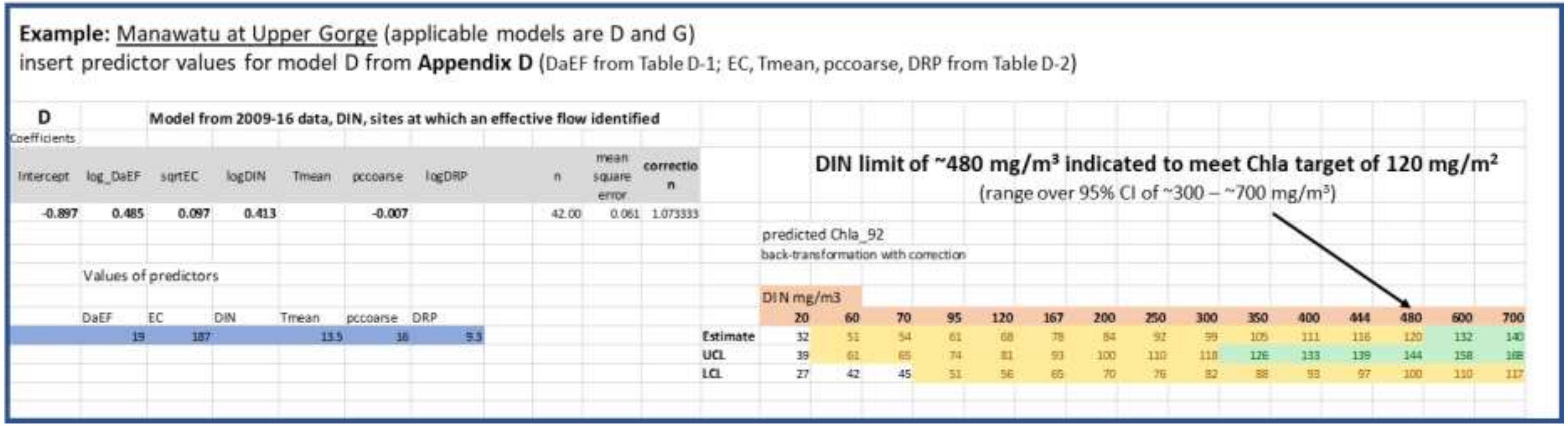


Figure 4-2: Example of use of spreadsheet for setting site-specific nutrient targets. In the final spreadsheet the four selected models are on the same sheet in order B, D, G, H. Values of predictors at the site of interest (from Appendix D) are pasted into the blue cells, and the Chla_92 predictions (with Upper and Lower Confidence Limits) are calculated automatically. Conditional formatting of the predictions allows easy identification of Chla_92 thresholds of 50, 120 and 200 mg/m^2. The DIN values can be adjusted if needed to get to the exact thresholds. Note that the DIN gradient shown includes the current One Plan DIN targets (70, 110, 167 and 444 mg/m^3).

In the following, the Chla_92, DIN and DRP data (i.e., concentrations) used in comparisons with the One Plan targets were calculated from the periphyton and nutrient dataset from July 2009 to June 2016. DIN and DRP data are geometric means (equivalent to the median value) and all concentrations are in mg/L (i.e., consistent with the One Plan).

Sites are referred to by their abbreviated names (as in Appendix E) for brevity.

4.3 Results of target setting trial with examples of reviews

A summary of the outcome for all sites is provided in Section 4.3.5 below, following the results and discussion for each group of sites.

4.3.1 Group 1. Low observed Chla_92 and DIN

The criteria for low Chla_92 (< 20 mg/m2) and low DIN (<0.1 mg/L) were met at 14 sites. At all these sites, the model generated DIN concentration equivalent to the Chla_92 target was at least six times the observed DIN concentration (average 21 times). Overall, this exercise showed that models are not the best way to derive new targets in this situation. The issues are:

- using the models to predict DIN equivalent to very high Chla_92 at a site with typically low Chla_92 assumed that other predictors such as low EC or low accrual times continued to control Chla_92 below the predicted target;
- attributing all of the change in Chla_92 to DIN forced combinations of conditions that were outside range of the original dataset. For example, in the dataset, mean DIN was never > 0.6 mg/L with mean EC < 90 µS/cm and DIN was never > 0.05 mg/L with EC < 75 µS/cm (this was the case at eight sites (see orange-shaded cells in the EC column in Table 4-1);
- sites at which observed DIN was below the current DIN target included headwater sites with low or no catchment development. Setting DIN targets substantially higher than observed values at these sites could have consequences for nutrient enrichment of downstream sites as well as for the sites themselves.

It is suggested that DIN targets at sites shaded in Table 4-1 could be retained at their current concentrations or reduced to be closer to the currently observed concentrations. Alternatively, the One Plan chlorophyll *a* target could be reviewed.

4.3.2 Group 2. Observed chlorophyll *a*, DIN or DRP close to targets

Data from three sites (makakahi_ham, manawatu_opik, porewa_us_hun) indicated that the current DIN targets were appropriate, using the criteria outlined above.

[Note that data from two sites indicated that current DRP targets were appropriate (mangatainoka_ds_db, mangatainoka_ds_pah). There were no sites where both current nutrient targets were appropriate using the criteria in Section 5.2.]

Note that the process in Figure 4-1 does not preclude identifying other sites (in Groups 2 to 4 below) where current One Plan DIN or DRP targets appear to be appropriate.

4.3.3 Group 3. Chlorophyll *a* target exceeded

The One Plan chlorophyll *a* target was exceeded (i.e., Chla_92 at least 10% greater than the target) at 13 sites. The derivation of revised DIN targets at the 13 sites is shown in Table 4-1. Most of the revised targets indicated lower thresholds than the current DIN concentrations. The revised targets suggested that the current targets ranged from appropriate to too lenient or too restrictive, as discussed below.

The derived DIN targets at six sites (highlighted in Table 4-1) were anomalous and required review. One anomaly was that derived DIN targets from the models were up to an order of magnitude lower than observed concentrations even though the chlorophyll *a* targets were exceeded by ~100% or less. A second anomaly was that, despite the One Plan chlorophyll *a* target being exceeded, the DIN target derived from the models was higher than observed DIN at those sites.

Reviews of the six sites follow. The reviews went through the following steps:

1. check predictor variable values from Appendix D (were there errors? Would a range have been more appropriate rather than a single value?)
2. were predictions very variable and were outliers dropped correctly?
3. was there anything about the site that might have caused an incorrect predictor value to be applied, or important predictors to be omitted? Or any other unusual conditions?

Tiraumea at Ngaturi, Makuri at Tuscan Hills

Two sites at which current One Plan DIN targets appeared to be too lenient (tiraumea_nga and makuri_tuscan) both had high observed DIN that easily exceeded the targets. However, DIN targets derived from the models to meet the One Plan chlorophyll *a* targets were very low (0.07 and 0.08 mg/L).

- The predictors EC, Tmean, DRP were relatively stable over time with CV < 6% except for DRP at tiraumea_nga for which the CV was 12%. Therefore, in most cases using mean values from Appendix D for deriving the targets was appropriate. DaEF was more variable over time at both sites (CV > 15%)
- At both sites, DIN corresponding to the One Plan chlorophyll *a* target varied across models by a factor of at least six times. One outlier value was dropped at tiraumea_nga, for model E. Model E also produced the highest target at makuri_tuscan.
- These two sites had highest EC (~300 µS/cm) of all sites. In the original dataset, sites with EC > 250 µS/cm generally had DIN > 0.2 mg/L. In terms of their geology (see LSC column in Appendix E), the two sites are in the productive class of the NPS-FM periphyton (although they are not classified as productive because that also requires a CW or WW climate classification; in see footnote in Section 2.1). High EC (and therefore high productivity) is a direct result of catchment geology and cannot be managed.

Because of high EC and naturally high productivity, setting revised DIN targets at much lower concentrations than both the current targets may be unrealistic. In these case, re-evaluation of the chlorophyll *a* target (given natural productivity) may be justified. An option would be to follow the method set out in the NPS-FM periphyton attribute and use the 84^{th} percentile of chlorophyll *a* at productive sites (i.e., Chla_84 instead of Chla_92) (NZ Government 2017).

Table 4-1: DIN corresponding to One Plan chlorophyll *a* targets derived from periphyton - environment relationships at monitoring sites divided into four groups. Refer to Section 5.2 for explanation of groups 1 to 4. Exceedances based on the 92nd percentile of chlorophyll *a* calculated using data from 2009 to 2016. Criteria were derived using all eight available models (depending on applicability) following the process in Figure 5-1. Targets corresponding to Chla_92 estimates only are shown. The spreadsheet also calculates 95% confidence intervals, allowing targets to be set for the UCL at the periphyton target (more restrictive, lower DIN targets), or the LCL at the periphyton target (more lenient, high DIN targets).

If the estimates are taken to represent variability in response, then a pragmatic approach would be to take the average values of all the estimates as the target, after removing outliers. The mean value in the penultimate right-hand column is the mean derived DIN target (recognising that there are confidence limits around that mean, and the UCL may be considered to be more appropriate). The right-hand column shows the mean derived target using from models D, G and H only, all of which were generated using from 2009 to 2016 (see Table 3-1). The main discrepancy between the two means is highlighted in blue-shaded cells (mangatepopo_gi) (see text). Columns showing the targets derived from models A, C, E and F, and the overall mean value, are grey-shaded as they were not in the final selection. Models D, G and H were selected as the final models. *Model B was also selected because it had highest predictive skill of all models and was the only one to include DRP as a predictor. It has not been tested for DRP target setting at this stage.

In the EC column, orange and lilac shaded cells show sites with EC < 75 and 75 - 90 µS/cm respectively. At these low EC values, DIN never exceeded, respectively, 0.05 and 0.6 mg/L. Therefore, estimates of higher DIN targets (last column) are outside the range of the dataset. Targets in grey lettering in the right-hand column are not recommended. Refer to text. Under “Derived DIN target”, reviews were carried out on sites with dark grey-shaded cells (see text).

Note that the targets derived for the porewa_ds_hun from models E, F and G will be incorrect because the TN – DIN relationship did not apply to these site (see BOX 4 in Section 3).

Site Abbreviation	Group	Current One Plan targets			Observed values				Models	DIN in each model corresponding to the One Plan Chl a target (mg/L)								Derived DIN target, all	Derived DIN target, D, G, H
		Chl a (mg/m²)	DRP (mg/L)	DIN (mg/L)	Chla_92 (mg/m²)	DRP (mg/L)	DIN (mg/L)	EC (µS/cm)		A	B*	C	D	E	F	G	H		
makakahi_doc	1	120	0.010	0.444	5	0.007	0.028	56	E-H					0.6	>1.1	>1.1	0.55	0.84	0.83
mangatainoka_lars	1	50	0.006	0.070	16	0.006	0.038	57	A-G	>1.1	>1.1	>1.1	>1.1	0.185	0.46	0.46		0.79	0.78
mangatainoka_putara	1	50	0.006	0.070	2	0.005	0.014	50	E-H					0.18	0.532	0.532	0.195	0.36	0.36
mangatepopo_gi	1	50	0.006	0.070	13	0.008	0.018	213	A-G	>1.1	>1.1	>1.1	0.02	0.045	0.015	0.021		0.49	**0.02**
mangawhero_doc	1	50	0.006	0.070	11	0.015	0.011	61	E-H					0.12	0.24	0.24	0.105	0.18	0.18
ohau_gladstone	1	50	0.006	0.070	7	0.009	0.040	69	E-H					0.24	0.6	0.58	0.32	0.77	0.67
oroua_almadale	1	120	0.010	0.167	16	0.010	0.057	115	A-G	>1.1	>1.1	>1.1	>1.1	0.7	>1.1	>1.1		1.04	**1.1**
oroua_apiti	1	120	0.010	0.167	8	0.007	0.049	73	A-G	>1.1	>1.1	>1.1	>1.1	0.95	>1.1	>1.1		1.08	1.1
pohangina_mais	1	120	0.010	0.110	15	0.013	0.038	129	A-G	>1.1	>1.1	>1.1	>1.1	0.56	1	1		0.99	**1.05**
pohangina_pir	1	50	0.006	0.070	10	0.006	0.033	70	E-G					0.171	0.35	0.35		0.29	0.35
rangitikei_puk	1	50	0.006	0.070	14	0.007	0.021	78	A-G	>1.1	>1.1	>1.1	0.9	0.15	0.27	0.28		0.70	0.59
tamaki_res	1	50	0.006	0.070	11	0.010	0.046	69	E-G					0.185	0.331	0.331		0.28	0.33

Site Abbreviation	Group	Current One Plan targets Chl a (mg/m²)	DRP (mg/L)	DIN (mg/L)	Observed values Chla_92 (mg/m²)	DRP (mg/L)	DIN (mg/L)	EC (µS/cm)	Models	DIN in each model corresponding to the One Plan Chl a target (mg/L) A	B*	C	D	E	F	G	H	Derived DIN target, all	Derived DIN target, D, G, H
waikawa_nmr	1	120	0.01	0.167	13	0.011	0.046	82	A-G	>1.1	>1.1	>1.1	>1.1	0.7	>1.1	>1.1		1.04	1.1
whanganui_ds_gen	1	50	0.006	0.070	15	0.028	0.012	91	E-G					0.135	0.202	0.212		0.18	0.21
makakahi_ham	2		0.010	0.444	117	0.078	0.293	106	E-H										
manawatu_opik	2		0.010	0.444	121	0.015	0.521	173	A-G										
porewa_us_hun	2		0.010	0.110	124	0.016	0.044	269	E-G										
makotuku_rae	3	50	0.006	0.070	96	0.008	0.285	92	E-H					0.115	0.150	0.170	0.095	0.13	0.13
makotuku_us_rae	3	50	0.006	0.070	132	0.010	0.305	98	E-H					0.180	0.275	0.290	0.195	0.24	0.24
makuri_tuscan	3	120	0.010	0.110	245	0.009	0.822	321	A-G	<0.02	0.060	0.070	0.110	0.128	0.034	0.045		0.07	0.08
manawatu_ds_pncc	3	120	0.010	0.444	253	0.017	0.587	185	A-G	0.295	0.295	0.600	0.400	0.523	0.620	0.625		0.48	0.51
manawatu_hop	3	120	0.010	0.444	168	0.022	0.300	211	A-G	0.385	0.295	0.600	0.350	0.541	0.518	0.541		0.46	0.47
manawatu_weber	3	120	0.010	0.167	162	0.017	0.203	269	E-H					0.323	0.175	0.205	0.205	0.20	0.21
mangatainoka_pahiatua	3	120	0.010	0.444	135	0.007	0.890	108	E-H					0.624	>1.1	>1.1	0.5	0.83	080
mangawhero_ds_oha	3	50	0.006	0.070	70	0.021	0.175	92	E-H					0.128	0.180	0.198	0.110	0.15	0.15
mangawhero_pakihi	3	50	0.006	0.070	69	0.013	0.192	96	A-G	0.125	0.080	0.110	0.140	0.110	0.134	0.152		0.12	0.15
moawhango_waiouru	3	120	0.010	0.110	178	0.009	0.009	142	E-G	0.075	0.095	0.050	0.078	0.480	0.770	0.770		0.33	0.42
porewa_ds_hun	3	120	0.010	0.110	145	0.016	0.086	272	E-G					0.330	0.165	0.200		0.23	0.20
tiraumea_nga	3	120	0.010	0.444	208	0.010	0.571	297	A-G	0.029	0.090	0.090	0.095	0.234	0.092	0.110		0.08	0.10
waitangi_ds_wai	3	120	0.010	0.110	172	0.052	0.438	179	E-G					0.577	0.740	0.740		0.69	0.74
kumeti_tr	4	50	0.006	0.070	18	0.010	0.536	83	A-G	>1.1	>1.1	1.1	0.46	0.37	0.895	0.89		0.85	0.68
makotuku_sh49	4	50	0.006	0.070	34	0.010	0.191	77	E-H					0.24	0.4	0.41	0.24	0.32	0.32
manawatu_tc	4	120	0.010	0.444	31	0.010	0.246	180	A-G	>1.1	>1.1	>1.1	1	0.545	0.64	0.64		0.88	0.82
manawatu_ug	4	120	0.010	0.444	42	0.010	0.444	186	A-G	1	>1.1	0.8	0.46	0.64	0.79	0.79		0.80	0.63
manawatu_us_pncc	4	120	0.010	0.444	70	0.013	0.300	173	A-G	1	1	1	0.58	0.7	1	1		0.90	0.79
mangapapa_troup	4	120	0.010	0.444	30	0.013	0.214	122	E-H					1	>1.1	>1.1	0.4	0.68	0.75
mangatainoka_ds_db	4	120	0.010	0.444	105	0.008	0.826	119	A-G	0.7	0.9	0.95	0.7	0.59	>1.1	>1.1		0.86	0.9

Site Abbreviation	Group	Current One Plan targets Chl a (mg/m²)	DRP (mg/L)	DIN (mg/L)	Observed values Chla_92 (mg/m²)	DRP (mg/L)	DIN (mg/L)	EC (µS/cm)	Models	DIN in each model corresponding to the One Plan Chl a target (mg/L) A	B*	C	D	E	F	G	H	Derived DIN target, all	Derived DIN target, D, G, H
mangatainoka_ds_pah	4	120	0.010	0.444	103	0.011	0.872	121	A-G	0.444	0.5	1.1	0.8	0.465	0.895	0.895		0.73	0.85
mangatainoka_huk	4	120	0.010	0.444	21	0.007	0.572	77	A-G	>1.1	>1.1	>1.1	>1.1	0.79	>1.1	>1.1		1.06	1.1
mangatainoka_scarb	4	120	0.010	0.444	51	0.006	0.951	92	A-G	>1.1	>1.1	>1.1	>1.1	0.64	>1.1	>1.1		1.03	1.1
mangatainoka_sh2	4	120	0.010	0.444	113	0.007	0.804	112	A-G	>1.1	>1.1	>1.1	1.1	0.545	>1.1	>1.1		1.02	1.1
mangatainoka_us_pah	4	120	0.010	0.444	70	0.010	0.823	113	A-G	0.9	1	>1.1	>1.1	0.527	>1.1	1.1		0.98	1.1
mangatainoka_us_tir	4	120	0.010	0.444	85	0.008	0.746	120	A-G	0.4	0.7	1	0.7	0.49	0.95	0.98		0.75	0.84
mangatera_ds_dan	4	120	0.010	0.444	75	0.188	1.232	187	E-G					0.68	0.79	0.79		0.75	0.79
mangatera_us_dan	4	120	0.010	0.444	36	0.044	0.285	153	E-G					1.05	>1.1	>1.1		**1.08**	**1.1**
mangawhero_us_oha	4	50	0.006	0.070	49	0.016	0.147	86	E-H					0.16	0.29	0.3	0.167	0.23	0.23
ohau_haines	4	120	0.010	0.110	72	0.008	0.288	85	A-G	>1.1	>1.1	>1.1	>1.1	1	>1.1	>1.1		1.09	1.1
ohau_sh1	4	120	0.010	0.110	21	0.010	0.192	78	A-G	>1.1	>1.1	>1.1	>1.1	0.86	>1.1	>1.1		1.07	1.1
oroua_awahuri	4	120	0.010	0.444	55	0.020	0.740	164	E-G					0.67	1	0.98		0.88	0.98
oroua_ds_fei	4	120	0.010	0.444	95	0.017	1.324	171	E-G					0.67	1.1	1.1		0.96	1.1
oroua_us_fei	4	120	0.010	0.444	40	0.017	0.142	141	E-G					0.89	>1.1	>1.1		**1.03**	**1.1**
oruakeretaki_sh2	4	120	0.010	0.444	38	0.014	0.732	101	A-G	>1.1	>1.1	>1.1	>1.1	0.79	>1.1	>1.1		1.06	1.1
rangitikei_man	4	120	0.010	0.110	33	0.008	0.037	124	A-G	>1.1	>1.1	>1.1	>1.1	0.35	0.6	0.6		**0.85**	**0.80**
rangitikei_mk	4	120	0.010	0.110	58	0.013	0.044	171	A-G	0.3	0.5	0.5	0.35	0.5	0.64	0.64		**0.49**	**0.49**
rangitikei_one	4	120	0.010	0.110	40	0.009	0.043	156	A-G	0.7	0.9	0.6	0.42	0.61	0.95	1		**0.74**	**0.71**
tamaki_ste	4	120	0.010	0.444	14	0.009	0.275	79	A-G	>1.1	>1.1	>1.1	1.0	>1.1	>1.1	>1.1		**1.09**	1.1
tokiahuru_kar*	4	50	0.006	0.070	49	0.051	0.007	126	E-G					0.21	0.265	0.285		**0.25**	**0.29**
tokomaru_hb	4	50	0.006	0.070	32	0.007	0.050	78	E-H					0.17	0.331	0.331	0.195	**0.26**	**0.26**
waitangi_us_wai	4	120	0.010	0.110	94	0.031	0.270	168	E-G					0.64	0.94	0.895		0.83	0.895
whakapapa_ds_gen	4	50	0.006	0.070	20	0.024	0.025	130	E-G	0.22	0.065	0.14	0.17	0.071	0.055	0.068		**0.11**	**0.12**

Porewa d/s Hunterville STP

A third site where the current target appeared to be too lenient was porewa_ds_hun. The new DIN target was derived from models E, F and G, using TN, and the conversion back to DIN was done assuming that DIN is 9% of TN at this site (see BOX 4). The new revised target turned out to be just lower than current DIN at porewa_us_hun, at which the chlorophyll *a* target was more or less met (see Section 4.3.2).

Manawatu at Hopelands

- All predictors (DaEF, EC, Tmean, DRP) were relatively stable over time with CV < 10%. Therefore, the single values from Appendix D were appropriate.
- Model predictions of the DIN concentration associated with Chla_92 at the One Plan target of 120 mg/m^2 ranged from 0.295 to 0.600 mg/L. Lowest DIN was close to observed DIN of 0.3 mg/L and was from Model B, which included DRP as a predictor set at the average value of 0.022 mg/L.
- There was nothing unusual about the site except for low EF (1.5 x median flow) and therefore low mean DaEF of only 16 days. If we assume that peak chlorophyll *a* is attained at longer accrual periods (e.g., 20 days) then DIN corresponding to 120 mg/m^2 Chla_92 was about 0.20 mg/L using Model B.
- Note that Chla_92 could be driven by DRP at this site. The site was assessed as likely to be P-limited or limited by N or P in Kilroy et al. (2018). Mean DRP was high, at 0.022 mg/L. Setting DIN at the current mean value and adjusting DRP in Model B, with DaEF = 20 days indicated that DRP of less than 0.015 mg/L would be required to achieve Chla_92 below the target of 120 mg/m^2.

It was concluded that an appropriate DIN target could be close to the current mean value (0.30 mg/L). The current DRP target of 0.010 is likely to be appropriate.

Moawhango at Waiouru

- EC was moderately stable over time (CV 12%), Tmean was stable (CV 2%) and DRP was variable (CV 56%) (Appendix D).
- Models A to D (which included DaEF as a predictor) returned low DIN targets (within the range of observed DIN, 0.05 mg/L). However, models E, F and G (which did not include DaEF) indicated that a DIN target of 0.67 mg/L was consistent with observed Chla_92 of 178 mg/m^2. Observed DIN was over an order of magnitude lower (0.009 mg/L).
- The site is unusual because the river flow is regulated. EF assignment was uncertain, but regardless of EF, periods between high flows were very long (over one year). The relatively high observed Chl_92 appears to be driven mainly by accrual period rather than nutrients. Thus, models E, F and G are likely inappropriate because they include no flow predictor.

A suggested DIN target would be associated with a long accrual period and should be set near to the observed value, because any additions of DIN would likely result in increased chlorophyll *a*.

Waitangi at d/s Waiouru STP

- EC and Tmean were stable over time in the Waitangi Stream (CV ≤ 10%), therefore the mean values in Appendix D were appropriate. No flow data were available.
- Predictions were consistent over models E, F and G.
- The site is unusual because the source of Waitangi Stream is a wetland only 5 km upstream from the monitoring site. The site is also downstream of a waste-water treatment plant discharge. Doubling of Chla_92 compared to a site upstream of the discharge (see Appendix E) was likely to be due to the discharge as both DIN and DRP were higher at the downstream site, with a greater difference in DIN than DRP. The current DIN target is evidently too restrictive (given compliance with the chlorophyll *a* target at the upstream site). The current value there (0.27 mg/L) may be a better guide to an appropriate target than the model output.

The current mean DIN value at the upstream site is suggested as an appropriate DIN target.

4.3.4 Group 4. Chlorophyll *a* target met

The One Plan chlorophyll *a* target was met at 30 sites. At sites where Chla_92 met the current target but DIN exceeded the target, the current target applied to periphyton management only could be interpreted as too restrictive. In these cases, output from the models may suggest a more lenient target that still allows periphyton to be managed within the required chlorophyll *a* target. The assumption is that other factors will continue to control chlorophyll *a* so that it stays within the target as DIN increases.

Six sites had a combination of low to moderate DIN and low EC (highlighted Table 4-1), which meant that predictions in some cases were outside the range of the dataset. At all other sites, the nutrient targets derived from the models indicated that the current targets could be increased by 65% (mangatainoka_ds_pah) to over 130% (oruakeretaki_sh2). A few sites required a review because of anomalous results.

Mangatainoka d/s Pahiatua STP, Mangatera d/s Dannevirke STP, Oroua d/s Feilding STP

Three sites were anomalous in that the derived DIN target was less than observed DIN despite the chlorophyll *a* target being met. All three were downstream of waste-water treatment plant discharges. The result implied that the models over-estimated Chla_92 at these sites: on average, for a given DIN concentration.

- The predictor EC was stable over time at all three sites. Tmean was more variable at mangatera_ds_dan (CV > 13%) than at the other two sites (CV < 8%). DRP was variable at all three sites (CV of 32%, 16% and 28% respectively). Only mangatainoka_ds_pah had flow data, and here, DaEF was variable over the time periods (CV = 18%).
- There was moderate variability across the models. For example, at mangatainoka_ds_pah, DIN equivalent to the chlorophyll *a* target (120 mg/m^2) ranged from 0.44 to 1.1 mg/L across models A to G.
- The raw data at this site showed that Chla_92 exceeded the chlorophyll *a* target in two three-year periods, suggesting that the lower DIN target may be appropriate. The raw data at oroua_ds_fei showed a similar pattern (i.e., exceedances of the target in three

three-year periods). There were no exceedances in any three-year periods at mangatera_ds_dan. However, Chla 92 was close to the target in three three-year periods (>99 mg/m^2). At all three sites, mean DIN varied across multi-year periods, and the lowest DIN concentration did not correspond to the lowest Chla_92.

At all three sites it appears that Chla_92 over the seven-year period was relatively low, presumably due to periodic low chlorophyll *a* at these sites. At the same time, mean observed DIN was relatively high. Thus, after examining the raw data, the anomaly can be understood. For target setting, a practical approach would be to set the DIN target close the observed mean values.

Waitangi u/s Waiouru STP

Although a derived target of 0.83 mg/L DIN was indicated at waitangi_us_wai, an increase in DIN to 0.438 at waitangi_ds_wai resulted in Chla_92 greater than the target of 120 mg/m^2. A more appropriate target for both sites would be the current DIN concentration at waitangi_us_wai (see Section 6.3.2 above).

4.4 Final model selection and outcomes

Using all eight models to obtain a derived target (then subject to revision) is time consuming. We therefore looked for ways to reduce the number of models, to obtain a similar result. One option was to restrict models to those developed from the longest dataset (2009-16, models D, G and H) because these models integrated temporal variation better than the three-year models.

Mean derived targets (regardless of whether they were accepted in the review above) were re-calculated using only the results from models D, G and H. The outcome was that derived targets based on models D, G and H were close to or identical to those derived from all eight models, with one exception (mangatepopo_gi) (Table 4-1). In that case, mean DIN from models D and G made more sense as a target than the mean of models A to G, because the derived target was close to the observed DIN concentration.

Accordingly, models D, G and H were selected as the most appropriate models for ongoing use. Assessments of DIN targets at all sites using these models are summarised in Table 4-2.

The above assessment was of DIN targets only because all the models in Kilroy et al. (2018) included DIN or TN as a predictor, but only one model with good predictive skill included DRP as a predictor. That model (model B in Table 2-1) was therefore included in the calculation spreadsheet that accompanies this report so that it can be used for future calculations.

Note that the derived DIN targets in Table 4-2 are shown in mg/L to to two decimal places and vary slightly between sites. In view of uncertainty around the targets (quantified by the 95% confidence interval), setting targets with such precision cannot be justified. There are also uncertainties around measuring both chlorophyll *a* (e.g., Kilroy et al. 2013) and nutrient concentrations. The next step, if the targets are considered realistic, is therefore to create broader target bands. We assume that such a step would be implemented following discussion with both DNZ and HRC.

An additional step may also be adaptation of the method to set DIN targets that apply to One Plan chlorophyll *a* targets as currently interpreted for SOE reporting (see Section 1.2). In other words, the relevant chlorophyll *a* metric would be maximum chlorophyll *a* rather than Chla_92. The selected models were developed to predict Chla_92. Therefore, a logical initial step would be to explore the relationship between Cha_92 and maximum chlorophyll *a* and apply an adjustment.

Table 4-2: Summary of outcome of DIN target setting exercise. Recommendations in the right-hand column are based on the data and the model predictions. Options are: retain current OP target (current target); use observed concentration as a guide (observed); consider revising target based on the derived concentration (derived, with revised target in bold under "derived targets"). Refer to text for discussion on other options at four sites. Sites in order of group (as in Figure 4-1), then alphabetically by site abbreviation. Refer to Appendix E for full site names.

Site abbreviation	Chla_92 (mg/m^2)		DIN (mg/L)		EC (µS/cm)	Derived targets D, G, H	Comment on current One Plan target	Recommendation
	OP target	Obs.	OP DIN target	Obs. DIN				
Group 1								
makakahi_doc	120	5	0.444	0.03	56	0.83	lenient	observed
mangatainoka_lars	50	16	0.07	0.04	57	0.78	OK	current target
mangatainoka_putara	50	2	0.07	0.01	50	0.36	OK	current target
mangatepopo_gi	50	13	0.07	0.02	213	0.02	OK	current target
mangawhero_doc	50	11	0.07	0.01	61	0.18	OK	current target
ohau_gladstone	50	7	0.07	0.04	69	0.67	OK	current target
oroua_almadale	120	16	0.167	0.06	115	1.1	lenient	observed
oroua_apiti	120	8	0.167	0.05	73	1.1	OK	current target
pohangina_mais	120	15	0.11	0.04	129	1.05	OK	current target
pohangina_pir	50	10	0.07	0.03	70	0.35	OK	current target
rangitikei_puk	50	14	0.07	0.02	78	0.59	OK	current target
tamaki_res	50	11	0.07	0.05	69	0.33	OK	current target
waikawa_nmr	120	13	0.167	0.05	82	1.1	lenient	observed
whanganui_ds_gen	50	15	0.07	0.01	91	0.21	OK	current target
Group 2								
makakahi_ham	120	117	0.444	0.519	106		OK	current target
manawatu_opik	120	121	0.444	0.52	173		OK	current target
porewa_us_hun	120	145	0.11	0.085	272		OK	current target
Group 3								
makotuku_ds_rae	50	218	0.07		93			
makotuku_rae	50	96	0.07	0.285	92	**0.13**	restrictive	derived
makotuku_us_rae	50	132	0.07	0.305	98	**0.24**	restrictive	derived
makuri_tuscan	120	245	0.11	0.822	321	0.08	lenient?	review chl target
manawatu_ds_pncc	120	253	0.444	0.587	185	0.51	near derived	current target
manawatu_hop	120	168	0.444	0.3	211	0.47	near derived	current target
manawatu_weber	120	162	0.167	0.203	269	0.21	near derived	current target
mangatainoka_pahiatua	120	135	0.444	0.89	108	**0.80**	restrictive?	derived
mangawhero_ds_oha	50	70	0.07	0.175	92	**0.15**	restrictive	derived
mangawhero_pakihi	50	69	0.07	0.192	96	**0.15**	restrictive	derived
moawhango_waiouru	120	178	0.11	0.009	142	0.42	lenient	observed
porewa_ds_hun	120	145	0.11	0.086	272	0.2	lenient	Porewa us target

Site abbreviation	Chla_92 (mg/m²) OP target	Chla_92 (mg/m²) Obs.	DIN (mg/L) OP DIN target	DIN (mg/L) Obs. DIN	EC (µS/cm)	Derived targets D, G, H	Comment on current One Plan target	Recommendation
tiraumea_nga	120	208	0.444	0.571	297	0.1	lenient?	review chl target
waitangi_ds_wai	120	172	0.11	0.438	179	0.74	restrictive	u/s obs as target
Group 4								
kumeti_tr	50	18	0.07	0.536	83	0.68	restrictive	observed
makotuku_sh49	50	34	0.07	0.191	77	0.32	restrictive	observed
manawatu_tc	120	31	0.444	0.25	180	**0.82**	restrictive?	derived?
manawatu_ug	120	42	0.444	0.44	186	**0.63**	restrictive	derived?
manawatu_us_pncc	120	70	0.444	0.30	173	0.79	OK	current target
mangapapa_troup	120	30	0.444	0.21	122	**0.75**	restrictive?	derived?
mangatainoka_ds_db	120	105	0.444	0.826	119	**0.9**	restrictive	derived
mangatainoka_ds_pah	120	103	0.444	0.872	121	0.85	restrictive	observed
mangatainoka_huk	120	21	0.444	0.572	77	1.1	restrictive	observed
mangatainoka_scarb	120	51	0.444	0.951	92	**1.1**	restrictive	derived
mangatainoka_sh2	120	113	0.444	0.804	112	1.1	restrictive	observed
mangatainoka_us_pah	120	70	0.444	0.823	113	**1.1**	restrictive	derived
mangatainoka_us_tir	120	85	0.444	0.746	120	**0.84**	restrictive	derived
mangatera_ds_dan	120	75	0.444	1.232	187	0.79	restrictive	observed
mangatera_us_dan	120	36	0.444	0.29	153	**1.1**	restrictive?	derived
mangawhero_us_oha	50	49	0.07	0.147	86	0.23	restrictive	observed
ohau_haines	120	72	0.11	0.288	85	1.1	restrictive	observed
ohau_sh1	120	21	0.11	0.192	78	1.1	restrictive	observed
oroua_awahuri	120	55	0.444	0.74	164	**0.98**	restrictive	derived
oroua_ds_fei	120	95	0.444	1.324	171	1.1	restrictive	observed
oroua_us_fei	120	40	0.444	0.14	141	1.1	OK	current target
oruakeretaki_sh2	120	38	0.444	0.732	101	**1.1**	restrictive	derived
rangitikei_man	120	33	0.11	0.04	124	0.8	lenient?	current target
rangitikei_mk	120	58	0.11	0.04	171	0.49	lenient?	current target
rangitikei_one	120	40	0.11	0.04	156	0.71	lenient?	current target
tamaki_ste	120	14	0.444	0.28	79	1.1	OK	current target
tokiahuru_kar*	50	49	0.07	0.01	126	0.29	lenient?	observed
tokomaru_hb	50	32	0.07	0.05	78	0.26	OK	current target
waitangi_us_wai	120	94	0.11	0.27	168	0.895	restrictive	observed
whakapapa_ds_gen	50	20	0.07	0.03	130	0.12	lenient?	observed

5 Summary of outcomes of model testing and target revision

5.1 Model selection

The process described in Sections 2, 3 and 4 resulted in a final selection of three models for DIN target-setting (Table 5-1), out of the eight initially tested (Table 2-1). An additional model (B) was included in the final selection because it was the only model including DRP as a predictor. The models used five predictors in addition to DIN or TN and DRP (Table 5-1).

Table 5-1: Equations for final selection of models for potentially setting nutrient targets in the Horizons region. Each model applies to certain sites (last column). Refer to Table 5.2 for explanations of variables in the equations. R^2 and NSE indicate the strength of the models. See Section 3 for more explanation.

Model	Equation	R^2	NSE	Applies to:	Notes
D	$Log_{10}Chla\_92 = -0.987 + (0.485 * log_{10}DaEF) + (0.097 * \sqrt{EC}) + (0.413 * log_{10}DIN) - (0.004 * pccoarse)$	0.74	0.58	Sites with a flow record, at which an EF identified (see BOX 2 in Section 3)	
G	$Log_{10}Chla\_92 = -1.444 + (0.084 * \sqrt{EC}) + (0.726 * log_{10}TN) + (0.008 * pccoarse)$	0.74	0.64	All sites with TN data (TN converted to DIN during calculation)	Uses TN rather than DIN No flow variable
H	$Log_{10}Chla\_92 = -1.921 + (0.113 * \sqrt{EC}) + (0.816 * log_{10}DIN) + (0.017 * pccoarse)$	0.87	0.63	Sites with a flow record, classed as insensitive to flow	Applies to small group of sites.
B	$Log_{10}Chla\_92 = -2.002 + (0.524 * log_{10}DaEF) + (0.106 * \sqrt{EC}) + (0.323 * log_{10}DIN) + (0.04 * Tmean) + (0.334 * log_{10}DRP)$	0.79	0.70	Sites with a flow record, at which an EF identified.	The only model with DRP as a predictor.

5.2 Method for evaluating and revising targets

The process of using the models to set DIN targets was summarised in a flow chart (see Section 5.2), which was arrived at iteratively during the model testing stages. The process started by dividing the sites currently included in the Horizons periphyton monitoring programme into four groups, depending on their current Chla_92 and nutrient concentrations (Table 5-3).

Although the project originated from the look-up table presented in Appendix L of Kilroy et al. (2018), the methodology we decided on for setting revised DIN targets in the Horizons region did not use look-up tables. Look-up tables were used in the evaluation and comparison of models (Section 2.2), but we considered that a simpler approach for target-setting at individual sites was to use the model equations directly.

Table 5-2: Variables used in the models selected for nutrient target setting.

Variable type	Variable name	Units	Explanation / description	More information
Dependent (what we are predicting)	Chla_92	mg/m^2	The 92nd percentile of chlorophyll *a* calculated over data collected from July 2009 to June 2016	
Explanatory (predictor variables)	DIN	mg/m^3	Dissolved inorganic nitrogen (the sum of nitrate and nitrite-nitrogen and ammoniacal nitrogen), geometric mean	See BOX 4 in Section 4
	DRP	mg/m^3	Dissolved reactive phosphorus, geometric mean	
	TN	mg/m^3	Total nitrogen, geometric mean	See BOX 4 in Section 4
	DaEF	days	Days of accrual based on the flow (in multiples of median flow) most effective at removed periphyton to a low level	See BOX 2 in Section 4
	EC	µS/cm	Electrical conductivity, mean	See BOX 3 in Section 4
	pccoarse	%	Percentage of coarse substrate (large cobbles, boulders and bedrock) on the stream bed, determined from visual assessments, mean	See footnote 6, Section 4.1.2
	Tmean	°C	Mean water temperature, calculated from monthly spot measurements of water temperature	

Table 5-3: Division of the Horizons periphyton monitoring sites into groups. Refer to Section 5.2 for more details.

Group	Description	Notes
1	Sites at which current DIN was low (<0.1 mg/L) and Chla_92 was also low (< 20 mg/m^2)	Thresholds based on the data
2	Sites at which current Chla_92 and DIN or Chla_92 and DRP were close to the One Plan targets	Refer to Section 4.2 for criteria defining “close to targets”
3	Sites at which the One Plan chlorophyll *a* target was exceeded	Chla_92 assumed to be appropriate metric
4	Sites at which the One Plan chlorophyll *a* target was met (DIN target exceeded or met)	Focus on DIN for the current assessments

Direct use of the models required prior knowledge of values of predictor variables at each site. These values were provided (Appendix D) for all periphyton monitoring sites.

5.3 Suggested revised targets

Revised DIN targets based on the output from the models were suggested at 15 of the 60 periphyton monitoring sites[7] in the Horizons region. At all 15 sites, the suggested revised target was higher than the current One Plan target, which was apparently too restrictive.

Retaining the current One Plan target was suggested for 24 sites.

[7] There were 61 sites in total, but no nutrient data were available at one (makotuku_ds_rae).

Revision of the target to a DIN concentration closer to the observed value was suggested at 17 sites, where the current target was either too lenient or too restrictive, but the model-generated targets were too high.

At two sites, we suggested reviewing the current chlorophyll *a* target because high EC indicated that these sites are naturally productive.

The remaining two sites were downstream of discharges. The suggestion was that the DIN target at both pairs of sites (upstream and downstream) should be set at around the concentration at the upstream site.

A summary of the suggested revised targets is provided in Section 4 (Table 4-2). The spreadsheet used to derive the targets is also provided to DNZ and HRC to enable refinement of the targets by adjusting predictor values (e.g., based on updated data), and to enable application of the method to new sites.

We expect that these outcomes of the project (i.e., the derived targets) will now be discussed with DNZ and HRC. For example, the revised targets are unrealistically precise. Small variations from site to site are difficult to justify given variability in observed nutrient concentrations and known low precision in measurements of chlorophyll *a* (Kilroy et al. 2013). A further issue is that the targets relate to Chla_92, which is the relevant metric for grading a site against the NPS-FM periphyton attribute. The contract requirements specified use of Chla_92 as the periphyton metric, but SOE assessments in the Horizons region are based on maximum values. The simplest way to adapt the method to set targets relevant to SOE reporting would be to develop relationship(s) to enable conversion of predicted values of Chla_92 to maximum chlorophyll *a*.

5.4 When to use the models and when not to use them

- The models and methodology described in this report apply to site-specific target setting, because each includes at least two other predictors in addition to DIN (or DRP).

- The models apply only to sites within the Horizons region. Of the four models in the final selection (Table 5-1), only model G applies to all sites across the region. Use of models B and D is restricted to sites with a flow record at which an effective flow has been identified. Use of model H is restricted to a small group of sites which have been identified as having periphyton that is largely insensitive to the effects of high flows.

- The models appear to work best for estimating or confirming nutrient (DIN) targets when applied to sites at which the chlorophyll *a* is already exceeding the chlorophyll *a* target.

- An important limitation of use of the models is that they do not produce sensible targets when applied to sites that already have low chlorophyll *a* and low nutrient concentrations (i.e., both well below the lowest targets currently in place). In that situation, forcing predictions of chlorophyll *a* well above biomass currently observed at the site, but holding other predictors constant, usually results in unrealistically high DIN targets. Such predictions are generally outside the range of data combinations used to develop the model, and therefore are unreliable.

- In common with predictors made using regression models in general, it is stressed predictions are reliable only when the predictor variables are set to values within the ranges and combinations used in the dataset to develop the models. This applies especially to predictions at low-nutrient sites (see above) but could be an issue in other situations such as naturally productive sites (see Section 4.3.3).
- All model results should be reviewed in light of current DIN and chlorophyll *a* concentrations and targets. To understand apparently anomalous results, it may also be necessary to look at values of other predictors such as EC and DaEF. Examples of target DIN reviews are provided in Section 5

6 Conclusions

In this study we explored the feasibility of using empirical regression models derived by Kilroy et al. (2018) for reviewing and setting nutrient (mainly DIN) concentration targets for management of periphyton in the Horizons region. The present analysis was limited to DIN (and not DRP) because DIN was the primary nutrient predictor of periphyton in the earlier analysis.

The outcome of the analysis was that a subset of four of the models developed by Kilroy et al. (2018) were selected as possibly useful for setting nutrient targets in the Horizons region. Three of the models were used to suggest revision of DIN targets at some of the Horizons periphyton monitoring sites, for consideration by DNZ and HRC. We determined that the best method for using the models was not through look-up tables. We considered that a simpler approach for target-setting at individual sites was to use the model equations directly.

Another outcome of the analysis was development of a decision-support framework as a guide to use of regression models for setting nutrient targets for periphyton management. The framework (the flow chart in Figure 4-1) requires that current nutrient and chlorophyll *a* concentrations at each site are taken into account (where data are available).

Limitations to the use of the models are:

- they apply only in the Horizons region, and to individual sites;
- a review of all targets derived using the models should be made as part of the process, in particular for resolving unexpected or anomalous results;
- the equations are not valid for deriving nutrient targets when the predictors variables at set to values within the ranges and combinations used in the dataset to develop the models. This problem occurs particularly at sites where both chlorophyll *a* and DIN (or DRP) concentrations are currently very low.

Two further steps to improve usability of the suggested method and targets are: (1) create bands for targets to take account of uncertainty in both the predictions and measurements (because the derived target concentrations in Table 4-2 are unrealistically precise); and (2) explore the relationship between Chla_92 and maximum chlorophyll *a* so that targets can also be set to be consistent with current SOE reporting (which assesses sites using maximum chlorophyll *a* rather than Chla-92).

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Suplee, M.W., Watson, V., Teply, M., McKee, H. (2009) How green is too green? Public opinion of what constitutes undesirable algae levels in streams. Journal of the American Water Resources Association, 45(1): 123-140.

Appendix A Project requirements (from the contract)

The wording from the contract with Dairy NZ is reproduced below, for reference.

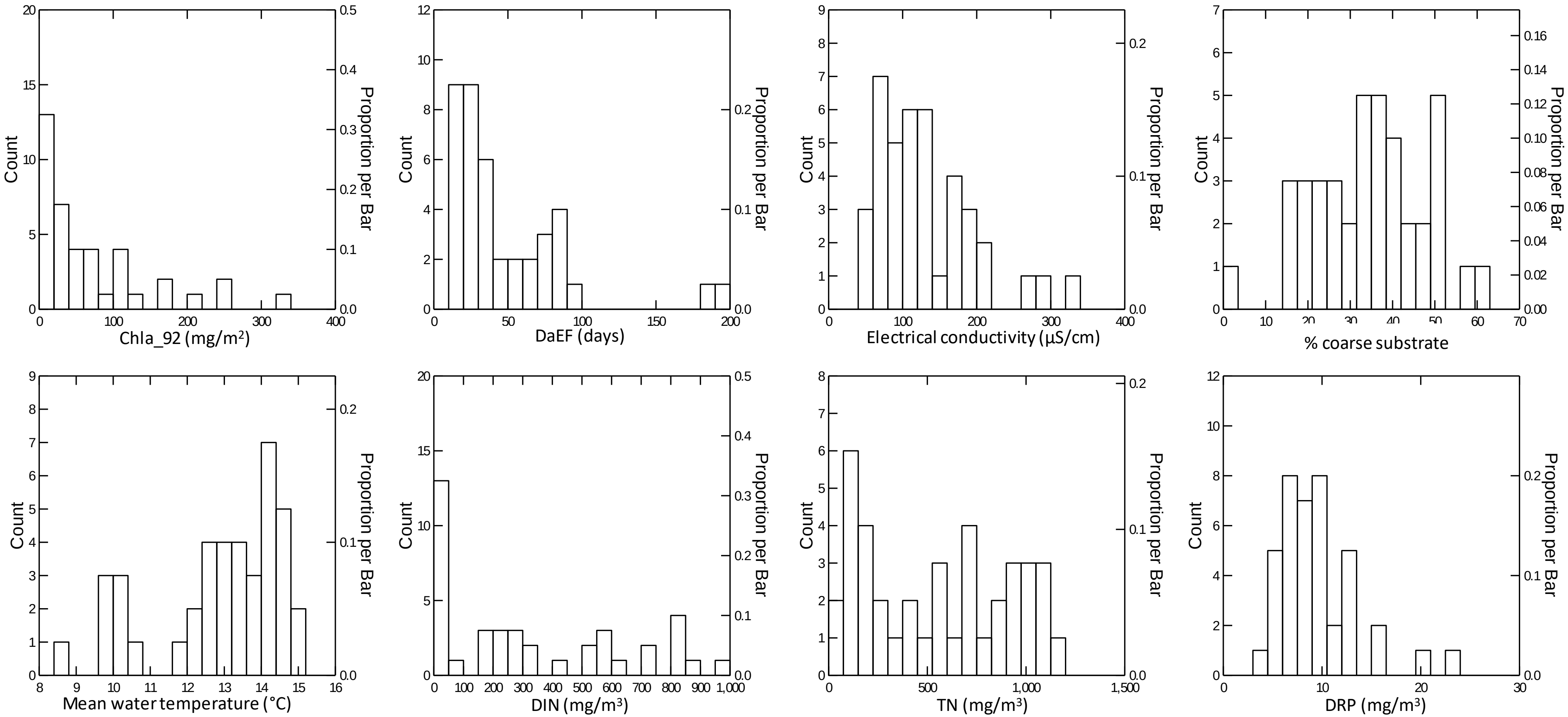
> DairyNZ (DNZ) and Horizons Regional Council (HRC) contracted NIWA to undertake an analysis of regional periphyton data accumulated by HRC since 2009 at over 60 stations in 2017/18, delivering a technical report co-authored by all agencies (e.g., Kilroy et al., 2018). The technical report explored empirical relationships between environmental variables and periphyton standing crop to predict periphyton abundance in rivers over time and across the region, split into three objectives:
>
> 1. Significance and strength of relationships between environmental factors and periphyton standing crop (various %iles, of Chl-a and % cover);
> 2. The effect of periphyton sampling resolution on environmental driver analysis in Objective 1;
> 3. Classification of stations on basis of environmental drivers of periphyton.
>
> Kilroy et al (2018) also delivered tentative look-up tables recommending corresponding environmental conditions supporting varying periphyton 92nd% Chl-a estimates across the Horizons region (i.e., utilising the July 2012 to June 2015 best-performing multiple regression equation for log-10 transformed 92nd Chl-a).
>
> DNZ and HRC request greater development of Appendix L into a stand-alone technical report delivering recommended guidance on the use of the Kilroy et al. (2018) to recommend instream DIN and DRP concentrations for corresponding periphyton Chl-a objectives - notably, those periphyton objectives are likely to be as per Schedule E table E-2 in the Horizons One Plan.
>
> The contractor will explore the ability to develop nutrient (DIN, DRP) look-up tables to manage to objectives on periphyton Chla (92^{nd} %) for the Horizons region, utilising findings from Kilroy et al. (2018) as the basis of recommendations.
>
> Kilroy et al. (2018) made a tentative effort in Appendix L, which is to be further explored, recommending how the various relationships included in Kilroy et al. (2018) should be treated for the objective of developing regional look-up tables to derive nutrient concentration targets for associated periphyton 92^{nd} % Chl-a outcomes across the Horizons region.
>
> The report is likely to need to consider whether to use one or several of the relationships defined in Kilroy et al. (2018), including if several, how to approximate those (e.g., whether to create envelopes of look-up DIN and DRP concentration for any 92^{nd} % Chl-a outcome, covering a span of likely median DIN and DRP from those various relationships).
>
> Recommendations are to be delivered in a technical report and should extend to the Contractor's suggested use and limitations placed on such look-up tables to avoid their misuse in managing to periphyton objectives in the Horizons One Plan.
>
> If the contractors believe that look-up DIN and DRP concentrations can be recommended for specified 92nd% Chl-a outcomes, from Kilroy et al (2018), then the Contractors will be requested to estimate associated DIN and DRP concentrations for rivers periphyton outcomes

specified in Table E.2 of Schedule E from the operative Horizons One Plan - requesting confirmation of periphyton outcomes from Horizons Regional Council project team members.*

*For reference, the technical report and its recommended look-up tables for instream nutrients will then be progressed into an exercise converting any corresponding DIN and DRP concentration recommended, whether as median or some other percentile, into a corresponding annualised DIN and DRP load. That exercise will involve the Contractor and Land Water People (LWP Ltd).

Appendix B Distributions of values of predictor variables

Each histogram in the following plots shows the distribution of values of a predictor variable in the seven-year time periods. Extremely high values were omitted for DaEF (>200 days), and DRP (>30 mg/m^3) so that the bulk of the data can be seen more clearly.



Appendix C Plots of predicted Chla_92 against DIN for assessment of the effects of EC, DaEF and DRP

The following plots illustrate how predictions of Chla_92 differed among models for given concentrations of DIN, with other variables included in the models held constant at approximately average values.

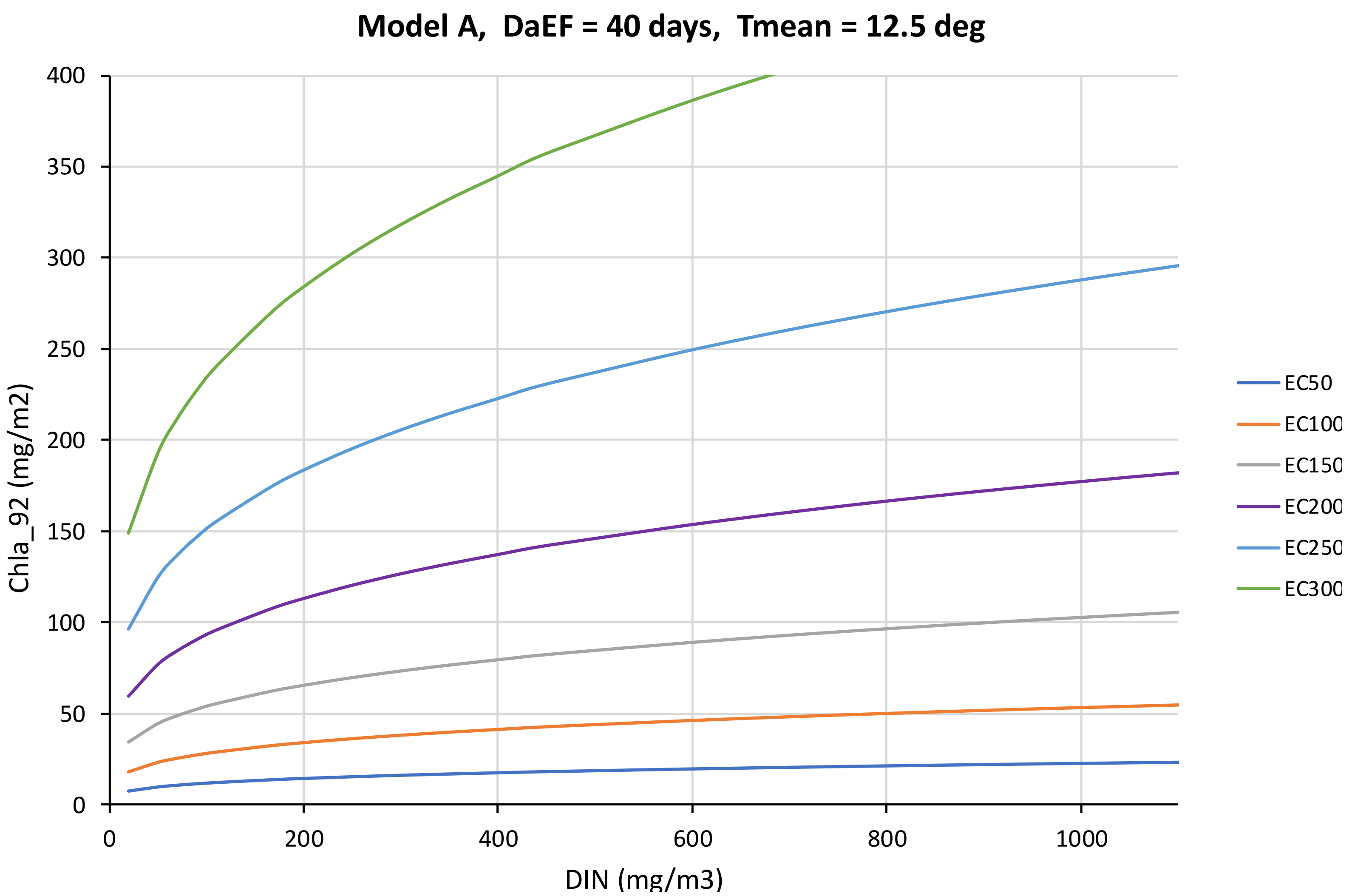
All axes are the same, to aid comparisons. On the horizontal axis DIN ranges from 0 to 1100 mg/m^3, and on the vertical axis, Chla_92 ranges from 0 to 400 mg/m^2. Both ranges extend just beyond the ranges in the datasets.

In models E, F and G, TN was a predictor rather than DIN. In these cases, DIN on the horizontal axes was predicted from TN using Equation 1 in BOX 4. The range of 0 to 1100 mg/m^3 DIN was equivalent to a TN range of 0 to 1400 mg/m^3 TN.

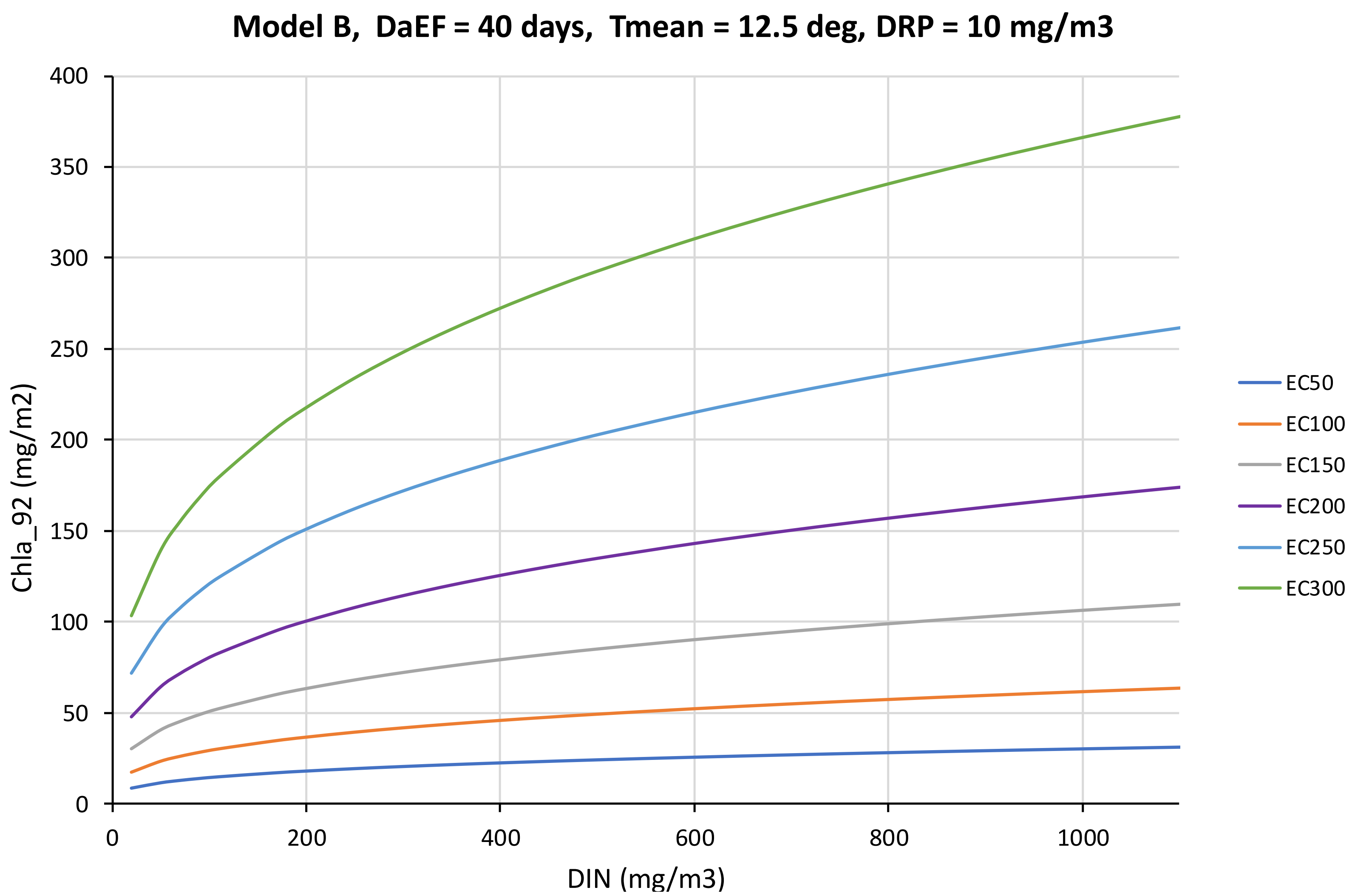
For reference, a summary of the eight models follows.

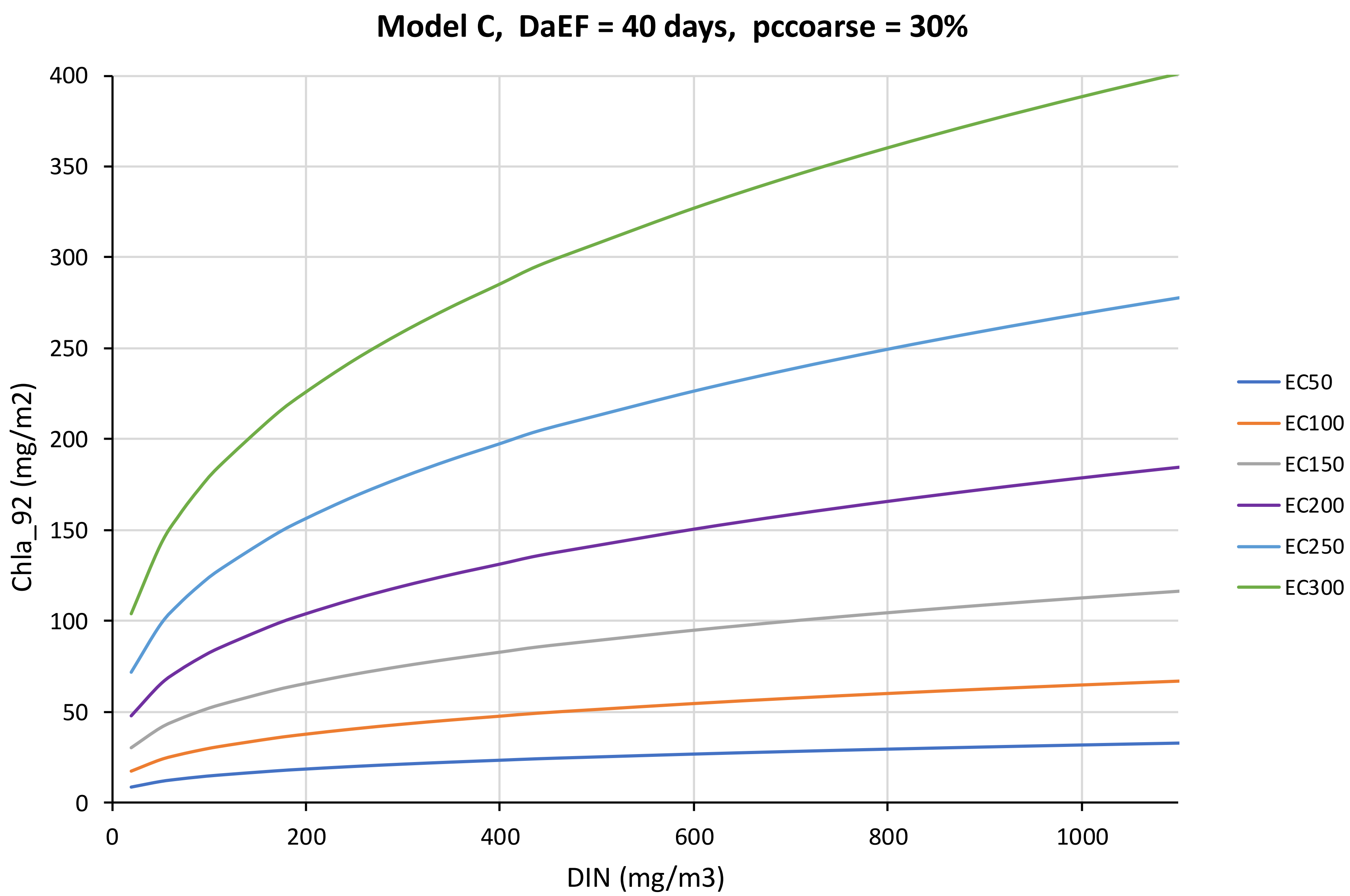
			Predictor variables					
Model	**Years**	**N of sites**	**DaEF**	**EC**	**DIN or TN***	**Temp.**	**Pccoarse**	**DRP**
A	**2011-14**	40	Y	Y	Y	Y		
B	**2012-15**	40	Y	Y	Y	Y		y
C	**2013-16**	40	Y	Y	Y		Y	
D	**2009-16**	42	Y	Y	Y		Y	
E	**2010-13**	51		Y	Y*		Y	
F	**2012-15**	56		Y	Y*		Y	
G	**2009-16**	58		Y	Y*		Y	
H	**2009-16**	14		Y	Y		Y	

Effect of EC

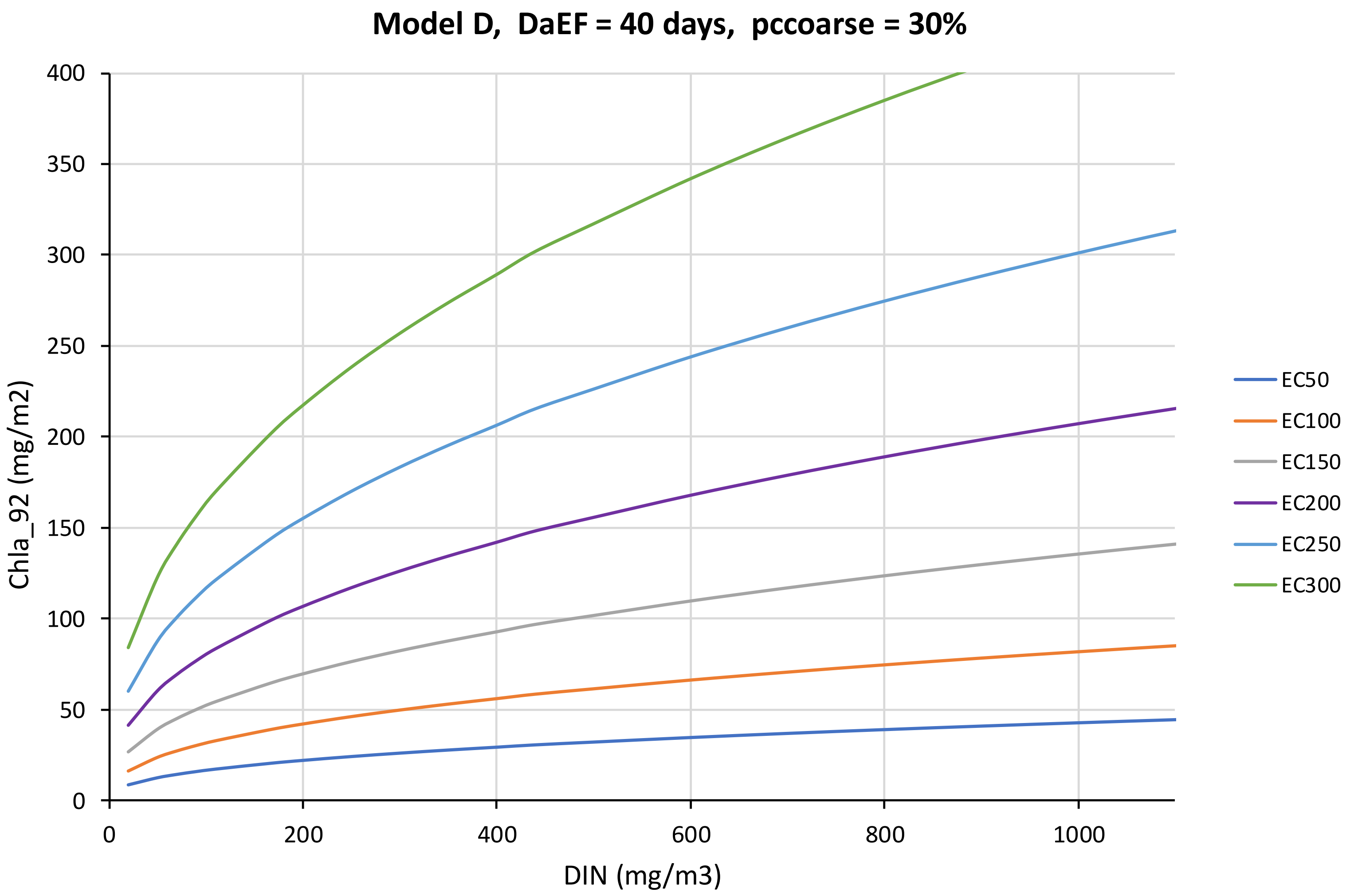


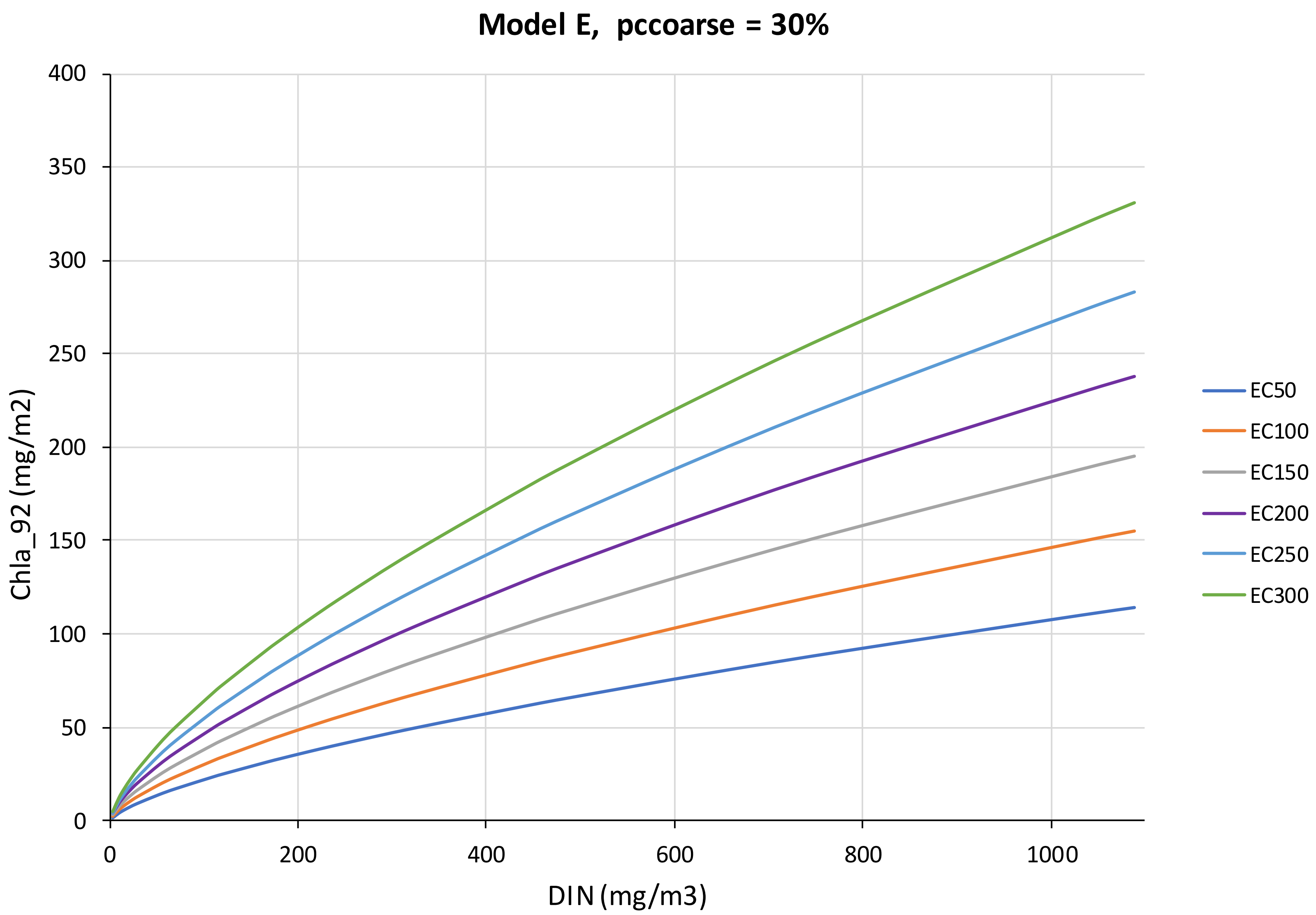
Model A, DaEF = 40 days, Tmean = 12.5 deg
Chla_92 (mg/m2)
400
350
300
250
200
150
100
50
0
0
200
400
600
800
1000
DIN (mg/m3)
EC50
EC100
EC150
EC200
EC250
EC300

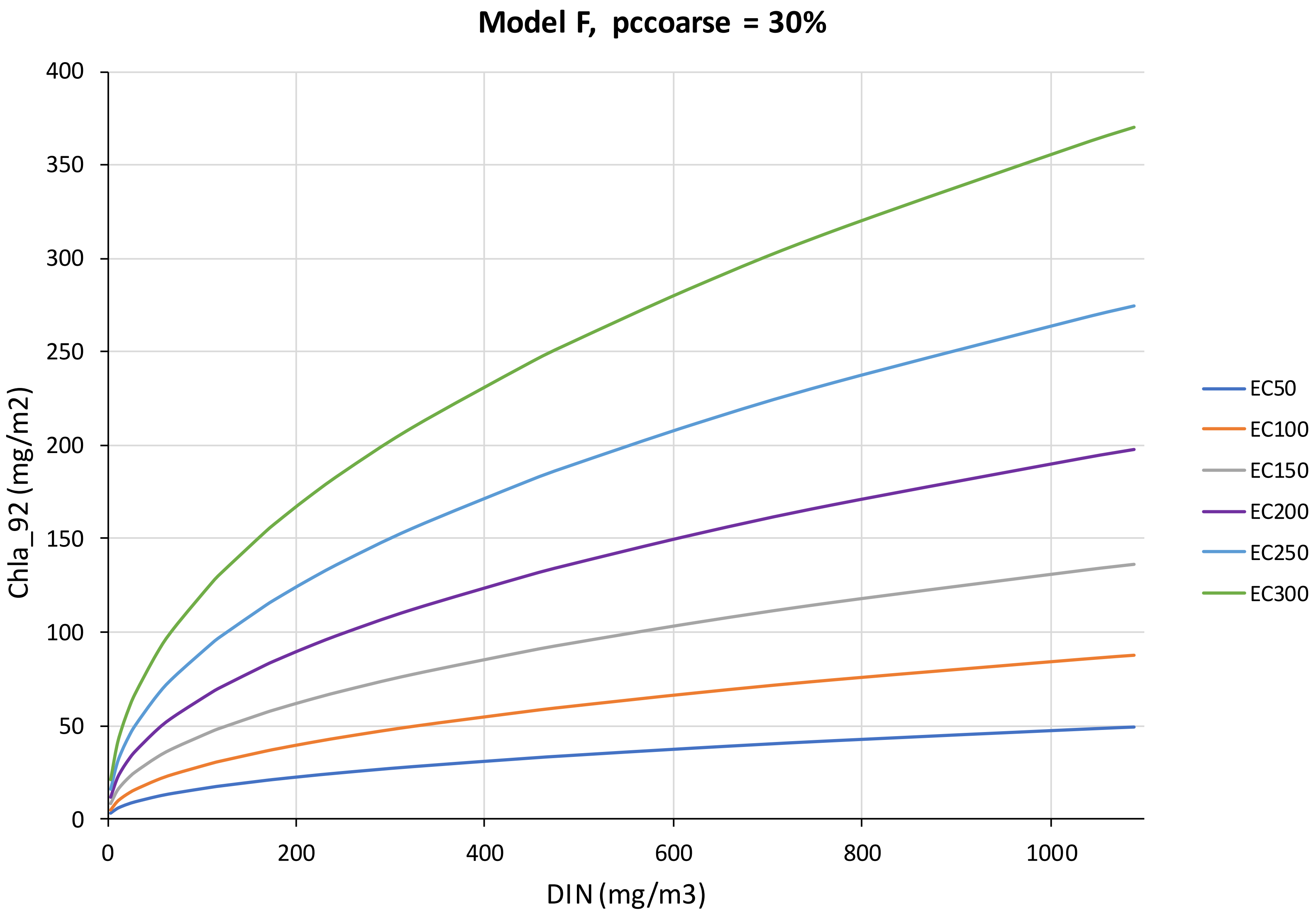

Model B, DaEF = 40 days, Tmean = 12.5 deg, DRP = 10 mg/m3
Chla_92 (mg/m2)
400
350
300
250
200
150
100
50
0
0
200
400
600
800
1000
DIN (mg/m3)
EC50
EC100
EC150
EC200
EC250
EC300



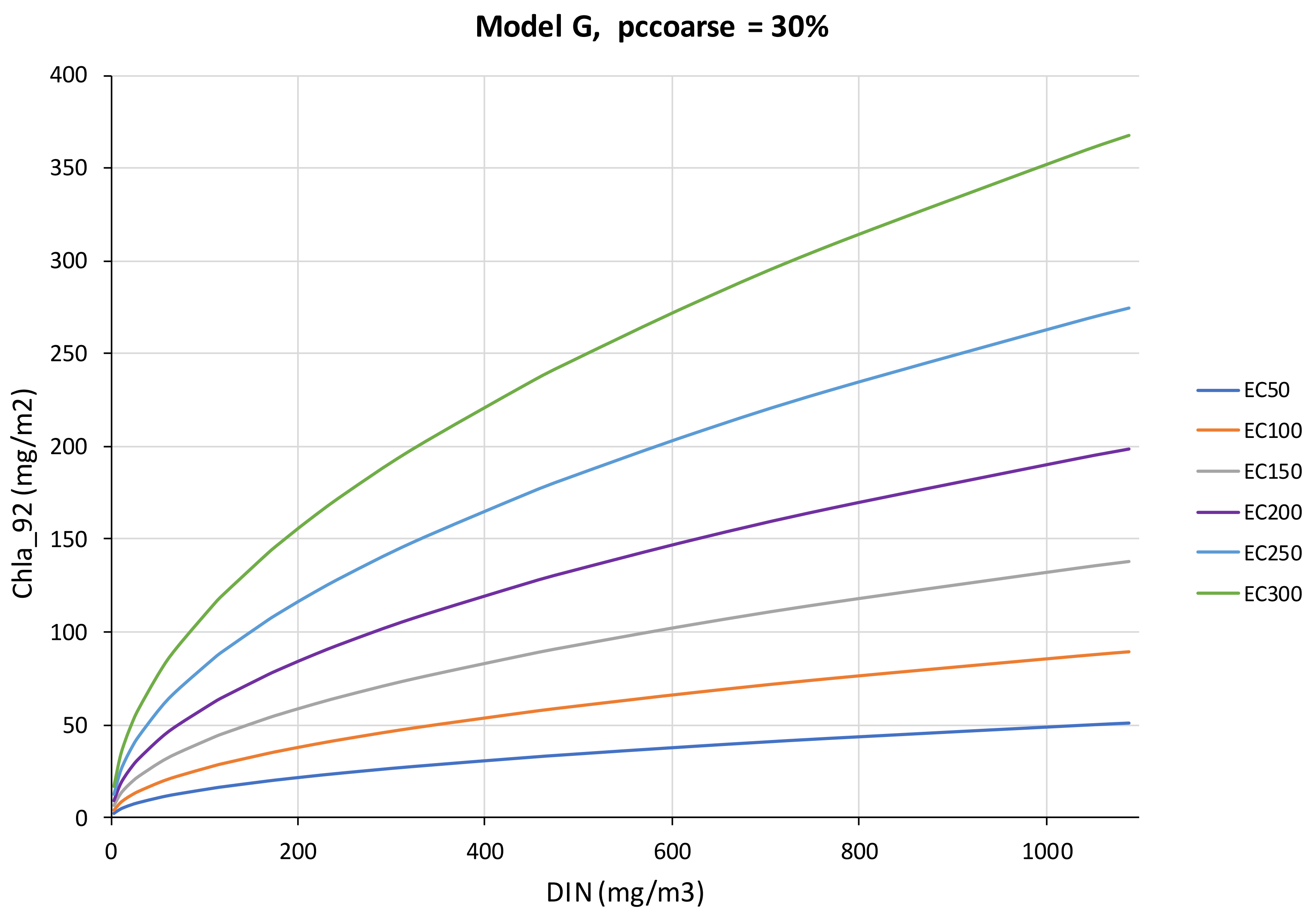
Model C, DaEF = 40 days, pccoarse = 30%
Chla_92 (mg/m2)
400
350
300
250
200
150
100
50
0
0
200
400
600
800
1000
DIN (mg/m3)
EC50
EC100
EC150
EC200
EC250
EC300


Model D, DaEF = 40 days, pccoarse = 30%
400
350
300
250
200
150
100
50
0
Chla_92 (mg/m2)
0
200
400
600
800
1000
DIN (mg/m3)
EC50
EC100
EC150
EC200
EC250
EC300

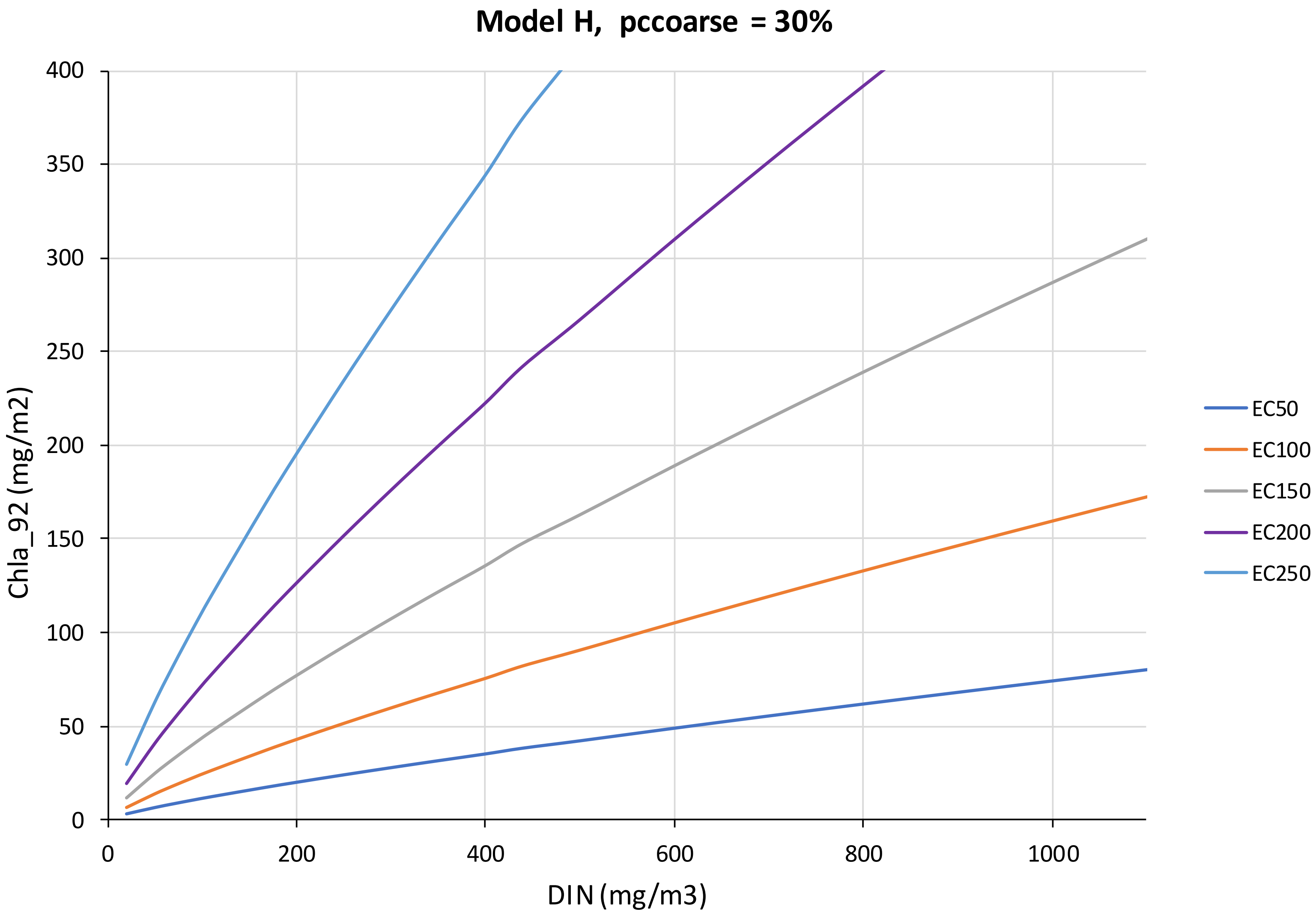

Model E, pccoarse = 30%
Chla_92 (mg/m2)
400
350
300
250
200
150
100
50
0
0
200
400
600
800
1000
DIN (mg/m3)
EC50
EC100
EC150
EC200
EC250
EC300



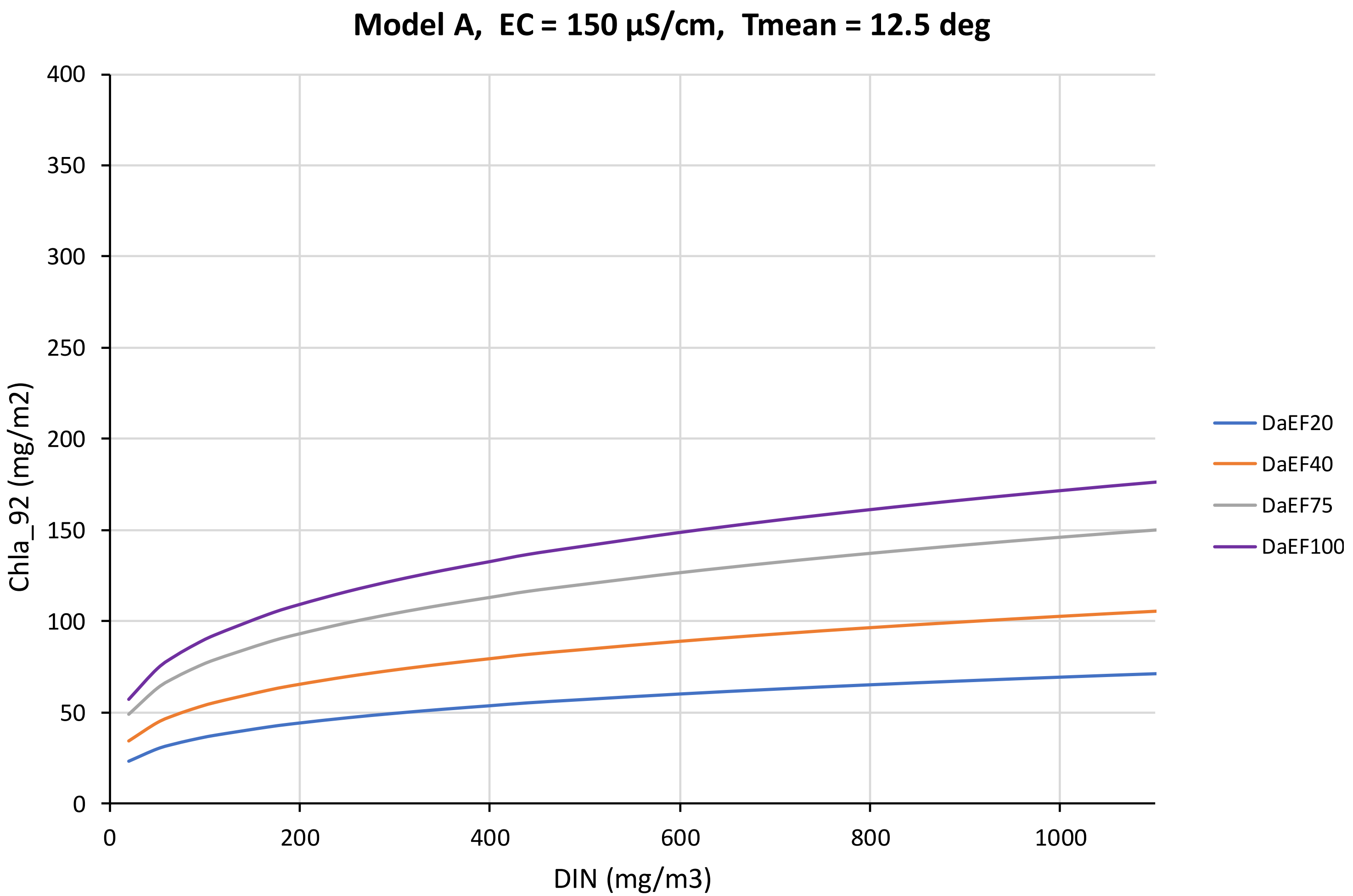
Model F, pccoarse = 30%
400
350
300
250
200
150
100
50
0
Chla_92 (mg/m2)
0
200
400
600
800
1000
DIN (mg/m3)
EC50
EC100
EC150
EC200
EC250
EC300

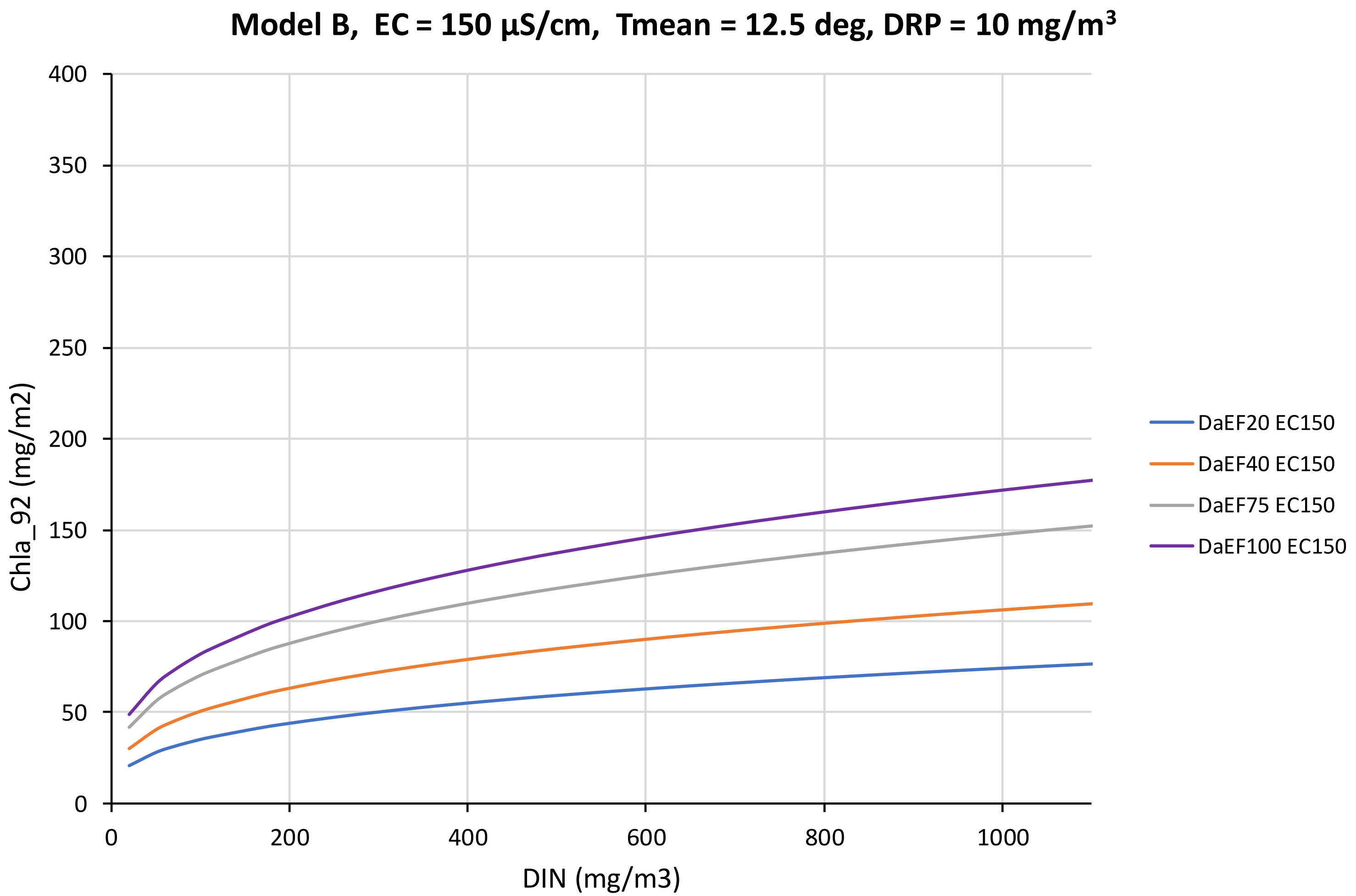

Model G, pccoarse = 30%
Chla_92 (mg/m2)
DIN (mg/m3)
0
50
100
150
200
250
300
350
400
0
200
400
600
800
1000
EC50
EC100
EC150
EC200
EC250
EC300

Model H. Predictions for EC = 300 not shown because it was outside the range in the dataset.

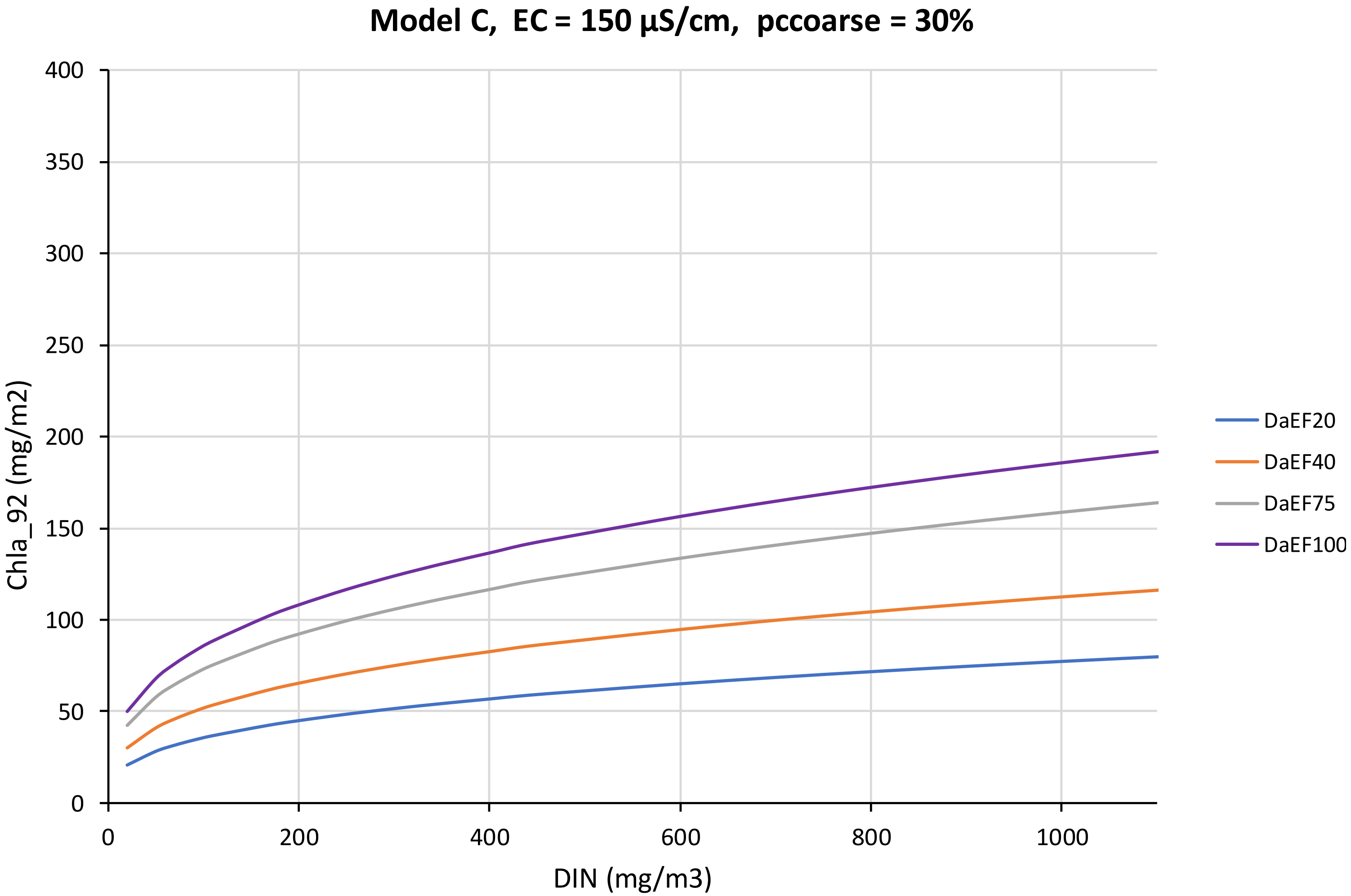


Effect of accrual period (DaEF)

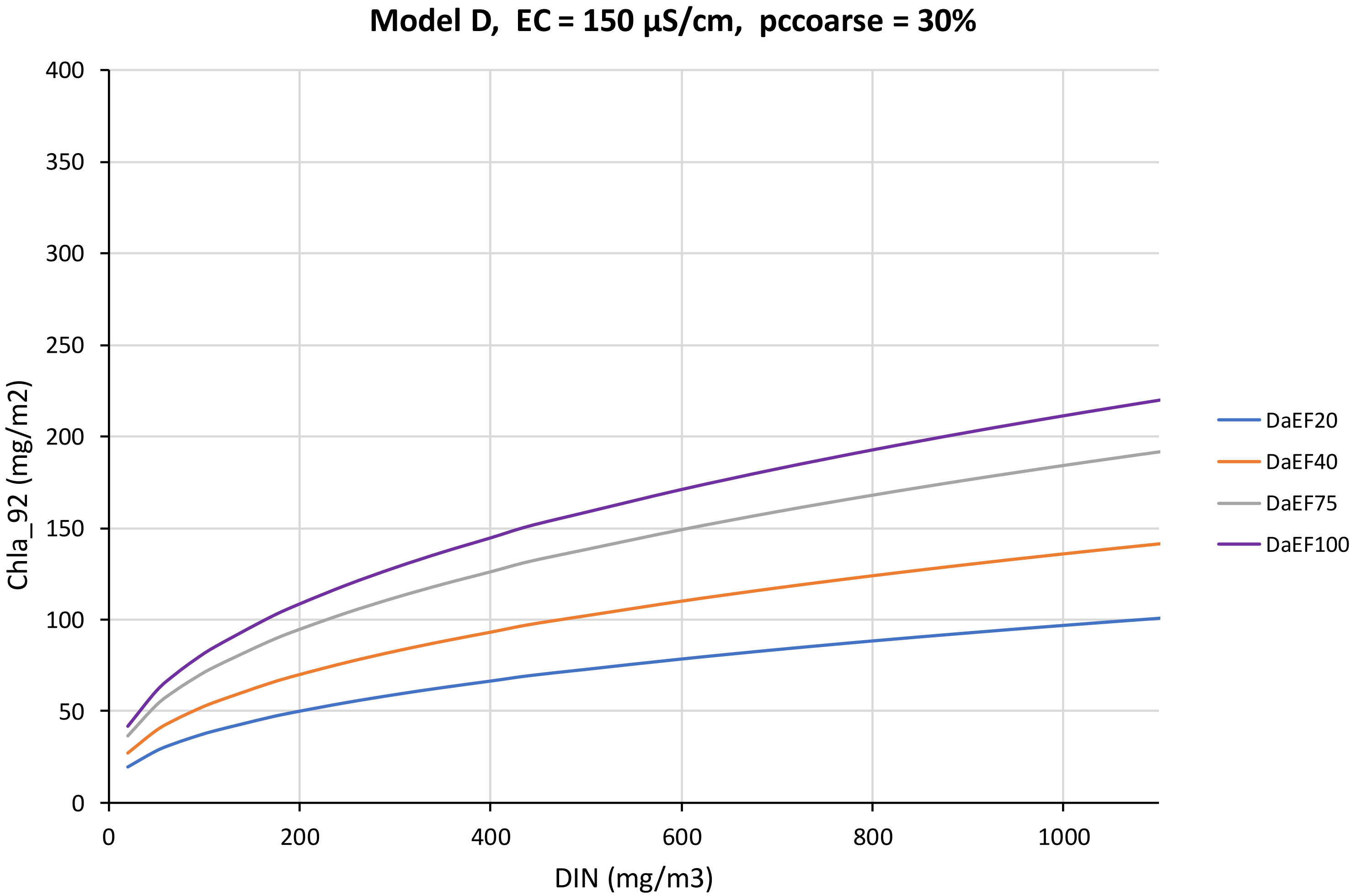




Model B, EC = 150 µS/cm, Tmean = 12.5 deg, DRP = 10 mg/m3
400
350
300
250
200
150
100
50
0
Chla_92 (mg/m2)
0
200
400
600
800
1000
DIN (mg/m3)
DaEF20 EC150
DaEF40 EC150
DaEF75 EC150
DaEF100 EC150



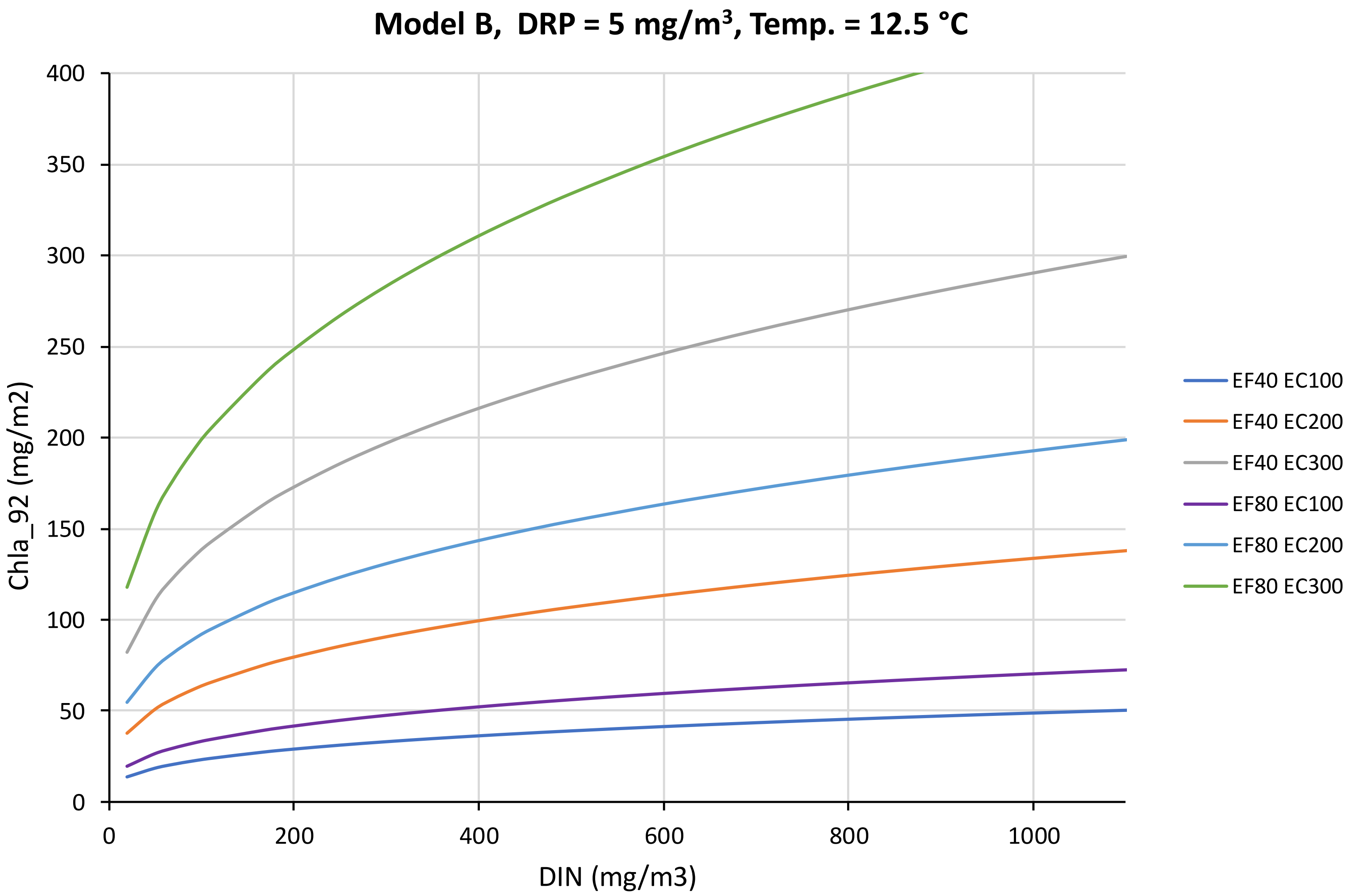
Model C, EC = 150 µS/cm, pccoarse = 30%
Chla_92 (mg/m2)
400
350
300
250
200
150
100
50
0
0
200
400
600
800
1000
DIN (mg/m3)
DaEF20
DaEF40
DaEF75
DaEF100

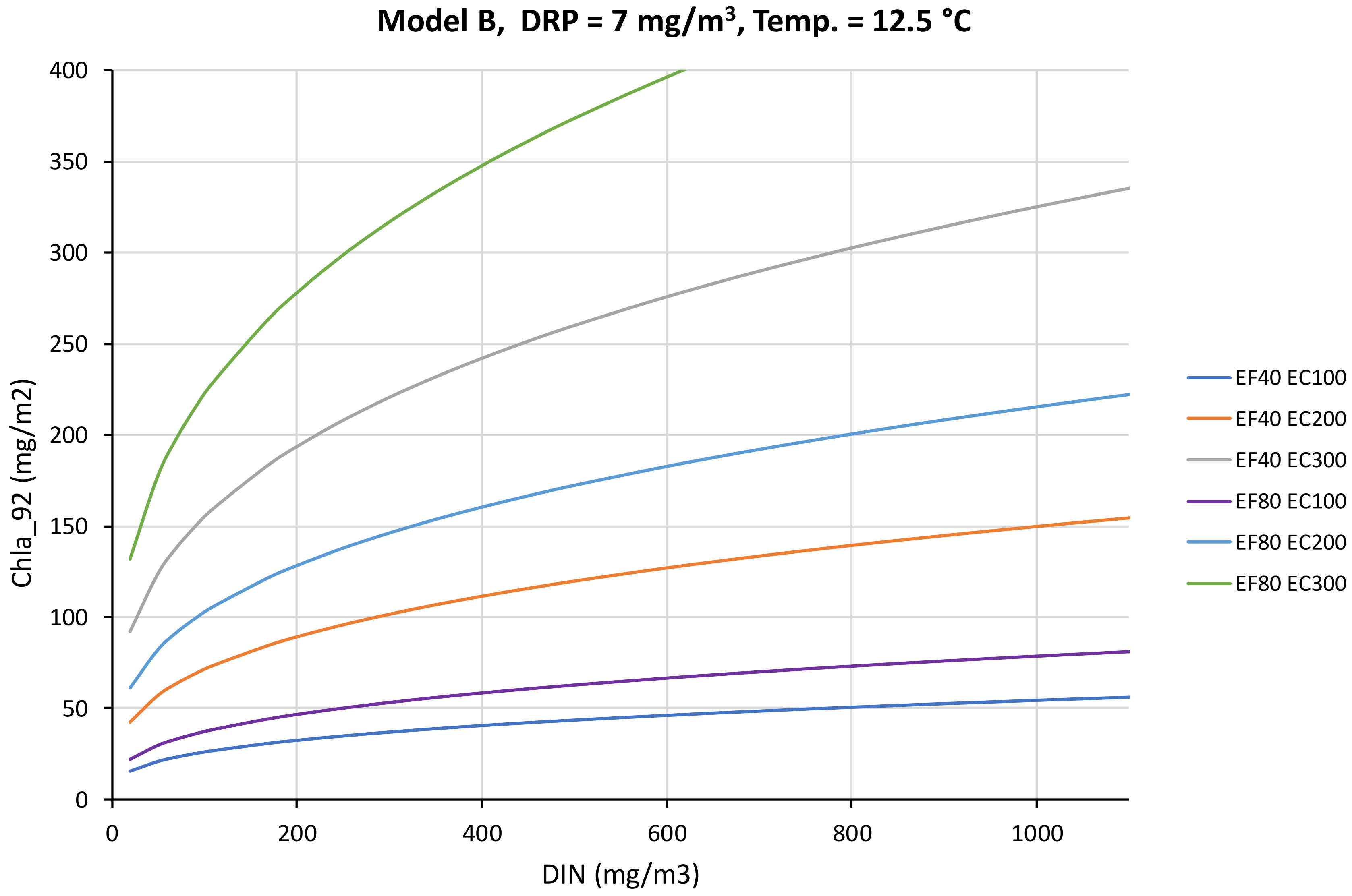


Model D, EC = 150 µS/cm, pccoarse = 30%
400
350
300
250
200
150
100
50
0
Chla_92 (mg/m2)
0
200
400
600
800
1000
DIN (mg/m3)
DaEF20
DaEF40
DaEF75
DaEF100

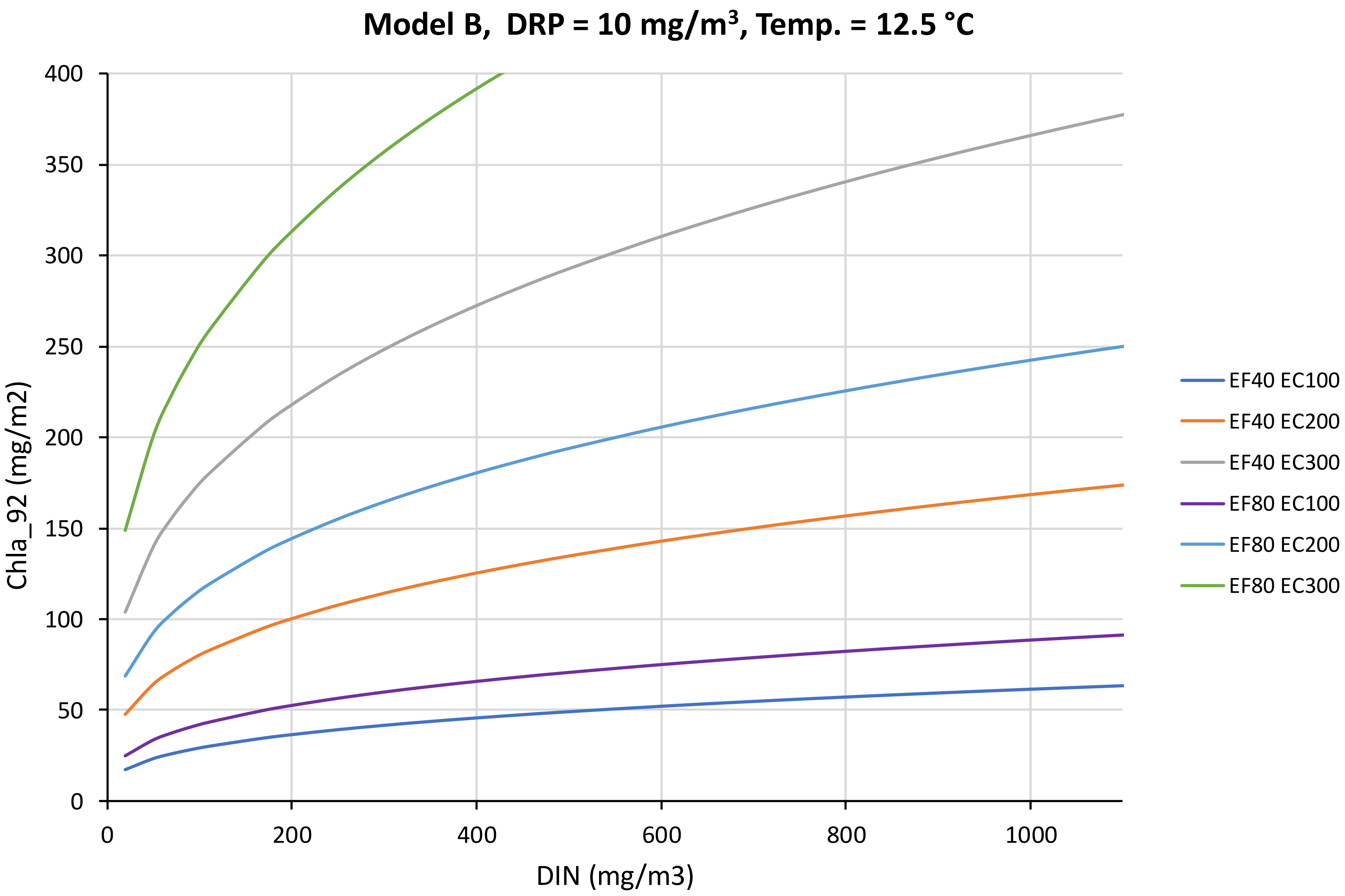
Effect of DRP at average water temperature

Predictions along the gradient of DIN on each plot (four concentrations of DRP) are shown for two lengths of DaEF (40 and 80 days) and three values of EC (100, 200 and 300 µS/cm). Temp. refers to Tmean.

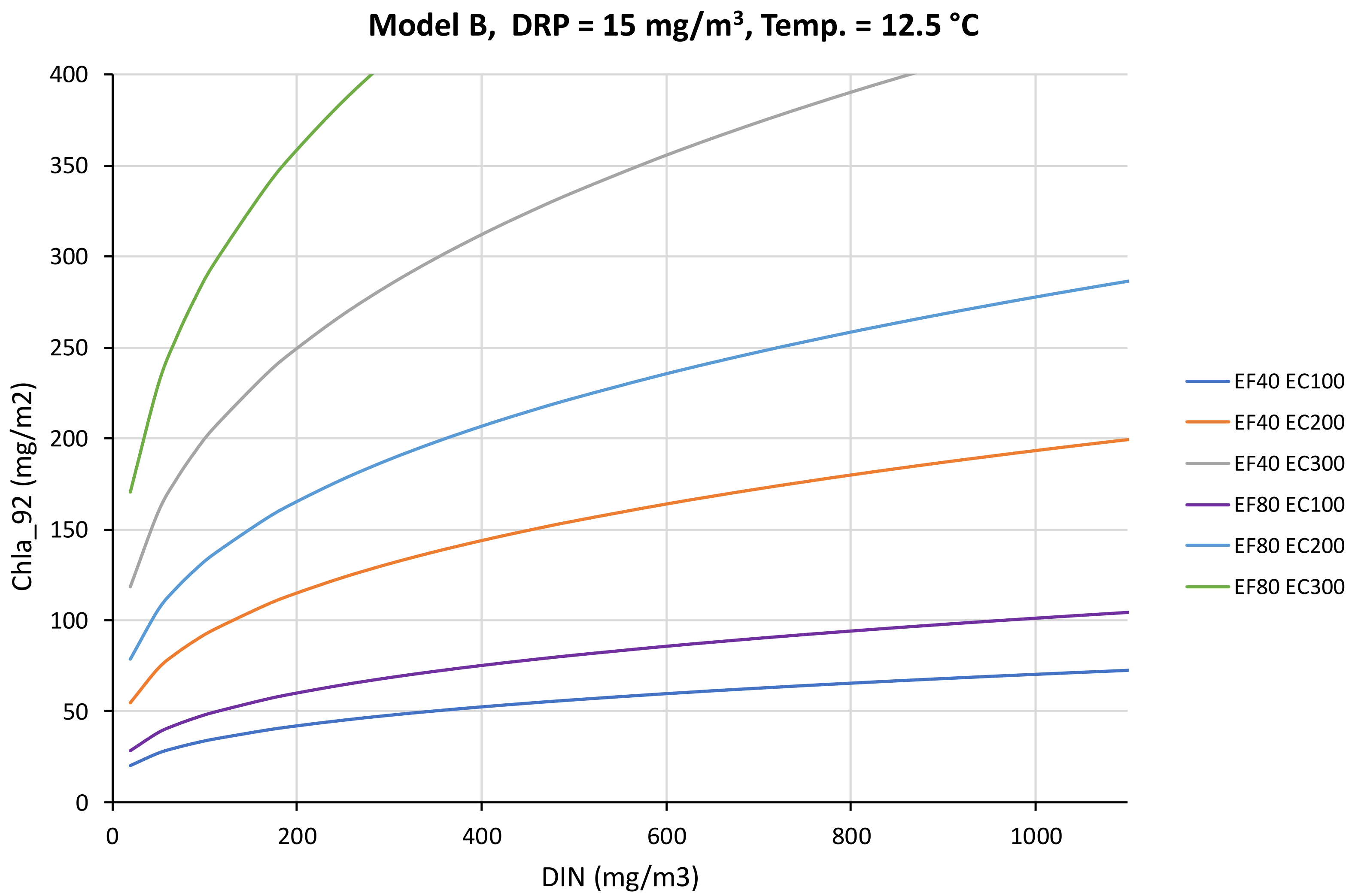




Model B, DRP = 7 mg/m³, Temp. = 12.5 °C
400
350
300
250
200
150
100
50
0
Chla_92 (mg/m2)
0
200
400
600
800
1000
DIN (mg/m3)
EF40 EC100
EF40 EC200
EF40 EC300
EF80 EC100
EF80 EC200
EF80 EC300



Model B, DRP = 10 mg/m3, Temp. = 12.5 °C
Chla_92 (mg/m2)
0
50
100
150
200
250
300
350
400
0
200
400
600
800
1000
DIN (mg/m3)
EF40 EC100
EF40 EC200
EF40 EC300
EF80 EC100
EF80 EC200
EF80 EC300



Model B, DRP = 15 mg/m3, Temp. = 12.5 °C
Chla_92 (mg/m2)
400
350
300
250
200
150
100
50
0
0
200
400
600
800
1000
DIN (mg/m3)
EF40 EC100
EF40 EC200
EF40 EC300
EF80 EC100
EF80 EC200
EF80 EC300

Appendix D Mean values of predictor variables at each site

Abbreviated site names are shown. Refer to Appendix E for full sites names. Means were calculated from the average of three-year means in five three-year periods. DIN and DRP may differ slightly from the values in Appendix E.

Site abbreviation	DaEF	EC	pccoarse	temp	DRP	DIN
kumeti_tr	27	83	16	13.1	9.0	545
makakahi_doc	81	56	51	10.1	6.7	26
makakahi_ham	128	107	36	13.1	5.8	287
makotuku_ds_rae		93	30			
makotuku_rae		94	52	11.3	7.2	285
makotuku_sh49	36	78	38	10.1	9.7	189
makotuku_us_rae		99	35	11.2	8.5	329
makuri_tuscan	27	323	49	11.7	7.7	838
manawatu_ds_pncc	32	184	24	14.5	16.3	572
manawatu_hop	16	214	17	14.4	20.2	298
manawatu_opik	14	175	2	14.2	13.6	518
manawatu_tc	14	180	24	14.5	9.6	247
manawatu_ug	19	187	16	13.5	9.3	440
manawatu_us_pncc	22	173	17	14.3	12.0	302
manawatu_weber	37	267	26	13.0	15.7	216
mangapapa_troup	66	123	15	14.7	12.0	213
mangatainoka_ds_db	93	119	34	14.0	7.5	818
mangatainoka_ds_pah	93	122	42	14.4	10.7	865
mangatainoka_huk	36	76	38	14.5	6.4	580
mangatainoka_lars	61	57	47	12.4	5.7	34
mangatainoka_pahiatua		106	35	15.0	7.0	876
mangatainoka_putara	39	50	52	9.6	4.4	15
mangatainoka_scarb	70	91	37	15.2	6.1	936
mangatainoka_sh2	79	113	38	13.7	6.1	792
mangatainoka_us_pah	79	113	40	14.6	8.8	806
mangatainoka_us_tir	93	122	39	14.8	7.0	738
mangatepopo_gi	122	212	58	10.2		
mangatera_ds_dan		188	16	11.7	177.7	1134
mangatera_us_dan		155	7	12.9	43.0	286
mangawhero_doc		62	61	8.8	14.1	10
mangawhero_ds_oha		92	49	10.1	19.7	175
mangawhero_pakihi	173	98	53	10.4	12.4	191
mangawhero_us_oha		85	43	10.0	14.4	145
moawhango_waiouru	878	140	36	10.2	8.5	10

Site abbreviation	DaEF	EC	pccoarse	temp	DRP	DIN
ohau_gladstone	45	69	35	12.0	8.0	40
ohau_haines	31	85	28	14.0	6.9	268
ohau_sh1	16	78	32	12.8	9.9	197
oroua_almadale	25	113	31	13.2	8.5	55
oroua_apiti	25	73	31	9.6	6.0	50
oroua_awahuri		162	20	15.6	19.2	707
oroua_ds_fei		166	17	13.9	15.5	1209
oroua_us_fei		139	16	13.8	15.2	158
oruakeretaki_sh2	18	101	28	13.6	13.1	719
pohangina_mais	32	127	34	12.4	11.8	38
pohangina_pir		69	45	10.2	5.3	34
porewa_ds_hun		281	23	14.8	17.7	75
porewa_us_hun		277	27	14.3	15.0	34
rangitikei_man	59	123	51	12.1	6.5	37
rangitikei_mk	42	170	22	14.3	11.7	44
rangitikei_one	45	155	25	13.2	8.1	42
rangitikei_puk	48	78	48	10.6	6.1	21
tamaki_res		70	43	11.2	8.9	49
tamaki_ste	26	79	31	13.2	8.0	271
tiraumea_ds_mangat		198	17	13.9		
tiraumea_nga	23	299	32	12.5	8.6	581
tokiahuru_kar		125	24	9.1	50.4	7
tokomaru_hb		79	43	12.2	6.0	52
waikawa_nmr	12	83	37	12.8	9.5	46
waitangi_ds_wai		177	22	10.9	53.0	460
waitangi_us_wai		167	22	10.7	29.3	266
whakapapa_ds_gen	92	129	60	8.6	22.6	26
whanganui_ds_gen		90	48	8.5	25.0	12

Appendix E List of One Plan Water Management Zones and current chlorophyll *a*, DRP and DIN targets

The list below includes all Water Management Zones listed in Table E.2 of the One Plan but does not list all Sub-zones unless represented by a current periphyton monitoring site. Where a Zone or Sub-Zone has more than one monitoring site, each site is listed on a separate line. LSC is the life-supporting classification assigned by Horizons. The classification is based on catchment position (L = lowland, H = hill, U = upland) and geology.

The columns under Observed values show the 92nd percentile of chlorophyll *a* (Chla_92), and the geometric means of DIN and DRP, calculated for all data between July 2009 and about April 2016. Note that DRP and DIN units are mg/L for consistency with Table E.2 of the One Plan. Throughout most of this report, DRP and DIN are shown in mg/m^3 (i.e., mg/L x 1000) to avoid the use of multiple decimal places.

Cells are shaded to show exceedances of the One Plan targets: Chla_92, orange; DRP, red; DIN, blue. Note that metrics are not specified for the targets in the One Plan (i.e., annual median, etc.). We are therefore assuming that the selected metrics are appropriate.

Models for potential use in setting nutrient criteria (Models A to G, as specified in Table 3-1) applicable to each site are shown in the right-hand column. Colour coding: green, flow-insensitive sites, models E to H only; lilac, flow sensitive sites, models A to G; grey, no flow data, models E to G.

Water Management Zones							One Plan targets			Observed values			
Zones	Sub-zones	Zone Code	Sub-Zone Code	LSC	Periphyton monitoring site name in full (as supplied by HRC)	Site_abbreviation (from Kilroy et al. 2018)	Chla mg/m^3	DRP mg/L	DIN mg/L	Chla_92 mg/m^3	DRP mg/L	DIN mg/L	Models
Upper Manawatu	Upper Manawatu	Mana_1	Mana_1a	HM	Manawatu at Weber Road	manawatu_weber	120	0.010	0.167	162	0.017	0.203	E-H
Weber-Tamaki	Mangatera	Mana_2	Mana_2b	HM	Mangatera d/s Dannevirke STP	mangatera_ds_dan	120	0.010	0.444	75	0.188	1.232	E-G
Weber-Tamaki	Mangatera	Mana_2	Mana_2b	HM	Mangatera u/s Dannevirke STP	mangatera_us_dan	120	0.010	0.444	36	0.044	0.285	E-G
Upper Tamaki	Upper Tamaki	Mana_3	Mana_3	UHS	Tamaki at Reserve	tamaki_res	50	0.006	0.070	11	0.010	0.046	E-G
Upper Kumeti	Upper Kumeti	Mana_4	Mana_4	UHS	Kumeti at Te Rehunga	kumeti_tr	50	0.006	0.070	18	0.010	0.536	A-G
Tamaki - Hopelands	Tamaki - Hopelands	Mana_5	Mana_5a	HM	Manawatu at Hopelands	manawatu_hop	120	0.010	0.444	168	0.022	0.300	A-G
Tamaki - Hopelands	Lower Tamaki	Mana_5	Mana_5b	HM	Tamaki at Stephensons	tamaki_ste	120	0.010	0.444	14	0.009	0.275	A-G
Tamaki - Hopelands	Oruakeretaki	Mana_5	Mana_5d	HM	Oruakeretaki at SH2	oruakeretaki_sh2	120	0.010	0.444	38	0.014	0.732	A-G
Hopelands - Tiraumea		Mana_6			NO SITES		120	0.010	0.444				

Water Management Zones							One Plan targets			Observed values			
Zones	Sub-zones	Zone Code	Sub-Zone Code	LSC	Periphyton monitoring site name in full (as supplied by HRC)	Site_abbreviation (from Kilroy et al. 2018)	Chla mg/m³	DRP mg/L	DIN mg/L	Chla_92 mg/m³	DRP mg/L	DIN mg/L	Models
Tiraumea	Lower Tiraumea	Mana_7	Mana_7b	HSS	Tiraumea d/s Mangatainoka confl	tiraumea_ds_mangat	120	0.010	0.444				
Tiraumea	Lower Tiraumea	Mana_7	Mana_7b	HSS	Tiraumea at Ngaturi	tiraumea_nga	120	0.010	0.444	208	0.010	0.571	A-G
Tiraumea	Makuri	Mana_7	Mana_7d	ULi	Makuri at Tuscan Hills	makuri_tuscan	120	0.010	0.110	245	0.009	0.822	A-G
Mangatainoka	Upper Mangatainoka	Mana_8	Mana_8a	UHS	Mangatainoka at Larsons Road	mangatainoka_lars	50	0.006	0.070	16	0.006	0.038	A-G
Mangatainoka	Upper Mangatainoka	Mana_8	Mana_8a	UHS	Mangatainoka at Putara	mangatainoka_putara	50	0.006	0.070	2	0.005	0.014	E-H
Mangatainoka	Middle Mangatainoka	Mana_8	Mana_8b	HM	Mangatainoka at Hukanui	mangatainoka_huk	120	0.010	0.444	21	0.007	0.572	A-G
Mangatainoka	Middle Mangatainoka	Mana_8	Mana_8b	HM	Mangatainoka at Scarborough Konini Rd	mangatainoka_scarb	120	0.010	0.444	51	0.006	0.951	A-G
Mangatainoka	Lower Mangatainoka	Mana_8	Mana_8c	HM	Mangatainoka d/s DB Breweries	mangatainoka_ds_db	120	0.010	0.444	105	0.008	0.826	A-G
Mangatainoka	Lower Mangatainoka	Mana_8	Mana_8c	HM	Mangatainoka d/s Pahiatua STP	mangatainoka_ds_pah	120	0.010	0.444	103	0.011	0.872	A-G
Mangatainoka	Lower Mangatainoka	Mana_8	Mana_8c	HM	Mangatainoka at Pahiatua Town Bridge	mangatainoka_pahiatua	120	0.010	0.444	135	0.007	0.890	E-H
Mangatainoka	Lower Mangatainoka	Mana_8	Mana_8c	HM	Mangatainoka at SH2	mangatainoka_sh2	120	0.010	0.444	113	0.007	0.804	A-G
Mangatainoka	Lower Mangatainoka	Mana_8	Mana_8c	HM	Mangatainoka u/s Pahiatua STP	mangatainoka_us_pah	120	0.010	0.444	70	0.010	0.823	A-G
Mangatainoka	Lower Mangatainoka	Mana_8	Mana_8c	HM	Mangatainoka u/s Tiraumea confl	mangatainoka_us_tir	120	0.010	0.444	85	0.008	0.746	A-G
Mangatainoka	Makakahi	Mana_8	Mana_8d	HM	Makakahi at DOC Reserve	makakahi_doc	120	0.010	0.444	5	0.007	0.028	E-H
Mangatainoka	Makakahi	Mana_8	Mana_8d	HM	Makakahi at Hamua	makakahi_ham	120	0.010	0.444	117	0.007	0.292	E-H
Upper Gorge	Upper Gorge	Mana_9	Mana_9a	HM	Manawatu at Upper Gorge	manawatu_ug	120	0.010	0.444	42	0.010	0.444	A-G
Upper Gorge	Mangapapa	Mana_9	Mana_9b	HM	Mangapapa at Troup Road	mangapapa_troup	120	0.010	0.444	30	0.013	0.214	E-H
Upper Gorge	Mangaatua	Mana_9	Mana_9c	HM	Mangaatua d/s Woodville STP		120	0.010	0.444				E-G
Upper Gorge	Mangaatua	Mana_9	Mana_9c	HM	Mangaatua u/s Woodville STP		120	0.010	0.444				E-G
Middle Manawatu	Middle Manawatu	Mana_10	Mana_10a	HM	Manawatu at Teachers College	manawatu_tc	120	0.010	0.444	31	0.010	0.246	A-G

Water Management Zones							One Plan targets			Observed values			
Zones	Sub-zones	Zone Code	Sub-Zone Code	LSC	Periphyton monitoring site name in full (as supplied by HRC)	Site_abbreviation (from Kilroy et al. 2018)	Chla mg/m³	DRP mg/L	DIN mg/L	Chla_92 mg/m³	DRP mg/L	DIN mg/L	Models
Middle Manawatu	Upper Pohangina	Mana_10	Mana_10b	UHS	Pohangina at Piripiri	pohangina_pir	50	0.006	0.070	10	0.006	0.033	E-G
Middle Manawatu	Middle Pohangina	Mana_10	Mana_10c	HM	Pohangina at Mais Reach	pohangina_mais	120	0.010	0.110	15	0.013	0.038	A-G
Lower Manawatu	Lower Manawatu	Mana_11	Mana_11a	HM	Manawatu d/s PNCC STP	manawatu_ds_pncc	120	0.010	0.444	253	0.017	0.587	A-G
Lower Manawatu	Lower Manawatu	Mana_11	Mana_11a	HM	Manawatu at Opiki	manawatu_opik	120	0.010	0.444	121	0.014	0.521	A-G
Lower Manawatu	Lower Manawatu	Mana_11	Mana_11a	HM	Manawatu u/s PNCC STP	manawatu_us_pncc	120	0.010	0.444	70	0.013	0.300	A-G
Oroua	Upper Oroua	Mana_12	Mana_12a	HM	Oroua at Almadale	oroua_almadale	120	0.010	0.167	16	0.010	0.057	A-G
Oroua	Upper Oroua	Mana_12	Mana_12a	HM	Oroua at Apiti Gorge	oroua_apiti	120	0.010	0.167	8	0.007	0.049	A-G
Oroua	Middle Oroua	Mana_12	Mana_12b	HM	Oroua d/s Feilding STP	oroua_ds_fei	120	0.010	0.444	95	0.017	1.324	E-G
Oroua	Middle Oroua	Mana_12	Mana_12b	HM	Oroua u/s Feilding STP	oroua_us_fei	120	0.010	0.444	40	0.017	0.142	E-G
Oroua	Lower Oroua	Mana_12	Mana_12c	LM	Oroua at Awahuri Bridge	oroua_awahuri	120	0.010	0.444	55	0.020	0.740	E-G
Coastal Manawatu	Lower Tokomaru	Mana_13	Mana_13c	LM	Tokomaru at Horseshoe Bend	tokomaru_hb	50	0.006	0.070	32	0.007	0.050	E-H
Upper Rangitikei	Upper Rangitikei	Rang_1			NO SITES		50	0.006	0.070				
Middle Rangitikei	Middle Rangitikei	Rang_2	Rang_2a	UHS	Rangitikei at Pukeokahu	rangitikei_puk	50	0.006	0.070	14	0.007	0.021	A-G
Middle Rangitikei	Middle Moawhango	Rang_2	Rang_2d	UVM	Moawhango at Waiouru	moawhango_waiouru	120	0.010	0.110	178	0.009	0.009	E-G
Lower Rangitikei	Lower Rangitikei	Rang_3	Rang_3a	HM	Rangitikei at Mangaweka	rangitikei_man	120	0.010	0.110	33	0.008	0.037	A-G
Lower Rangitikei	Lower Rangitikei	Rang_3	Rang_3a	HM	Rangitikei at Onepuhi	rangitikei_one	120	0.010	0.110	40	0.009	0.043	A-G
Coastal Rangitikei	Coastal Rangitikei	Rang_4	Rang_4a	HM	Rangitikei at McKelvies	rangitikei_mk	120	0.010	0.110	58	0.013	0.044	A-G
Coastal Rangitikei	Porewa	Rang_4	Rang_4c	HSS	Porewa d/s Hunterville STP	porewa_ds_hun	120	0.010	0.110	145	0.016	0.086	E-G
Coastal Rangitikei	Porewa	Rang_4	Rang_4c	HSS	Porewa u/s Hunterville STP	porewa_us_hun	120	0.010	0.110	124	0.015	0.043	E-G
Upper Whanganui	Upper Whanganui	Whai_1	Whai_1	UVA	Mangatepopo d/s Genesis Intake	mangatepopo_gi	50	0.006	0.070	13	0.008	0.018	A-G
Upper Whanganui	Upper Whanganui	Whai_1	Whai_1	UVA	Whanganui d/s Genesis Intake	whanganui_ds_gen	50	0.006	0.070	15	0.028	0.012	E-G

Water Management Zones							One Plan targets			Observed values			
Zones	Sub-zones	Zone Code	Sub-Zone Code	LSC	Periphyton monitoring site name in full (as supplied by HRC)	Site_abbreviation (from Kilroy et al. 2018)	Chla mg/m³	DRP mg/L	DIN mg/L	Chla_92 mg/m³	DRP mg/L	DIN mg/L	Models
Cherry Grove	Upper Whakapapa	Whai_2	Whai_2b	UVA	Whakapapa d/s Genesis Intake	whakapapa_ds_gen	50	0.006	0.070	20	0.024	0.025	E-G
Te Maire		Whai_3			NO SITES								
Middle Whanganui		Whai_4			NO SITES								
Pipikiri		Whai_5			NO SITES								
Paetawa		Whai_6			NO SITES								
Lower Whanganui		Whai_7			NO SITES								
Upper Whangaehu	Waitangi	Whau_1	Whau_1b	UVM	Waitangi d/s Waiouru STP	waitangi_ds_wai	120	0.010	0.110	172	0.052	0.438	E-G
Upper Whangaehu	Waitangi	Whau_1	Whau_1b	UVM	Waitangi u/s Waiouru STP	waitangi_us_wai	120	0.010	0.110	94	0.031	0.270	E-G
Upper Whangaehu	Tokiahuru	Whau_1	Whau_1c	UVA	Tokiahuru at Karioi	tokiahuru_kar	50	0.006	0.070	49	0.051	0.007	E-G
Middle Whangaehu		Whau_2			NO SITES		200	0.015	0.167				
Lower Whangaehu	Upper Makotuku	Whau_3	Whau_3b	UVA	Makotuku at SH49	makotuku_sh49	50	0.006	0.070	34	0.010	0.191	E-H
Lower Whangaehu	Lower Makotuku	Whau_3	Whau_3c	UVA	Makotuku d/s Raetihi STP	makotuku_ds_rae	50	0.006	0.070	218			E-H
Lower Whangaehu	Lower Makotuku	Whau_3	Whau_3c	UVA	Makotuku at Raetihi	makotuku_rae	50	0.006	0.070	96	0.008	0.285	E-H
Lower Whangaehu	Lower Makotuku	Whau_3	Whau_3c	UVA	Makotuku u/s Raetihi STP	makotuku_us_rae	50	0.006	0.070	132	0.010	0.305	E-H
Lower Whangaehu	Upper Mangawhero	Whau_3	Whau_3d	UVA	Mangawhero at DoC	mangawhero_doc	50	0.006	0.070	11	0.015	0.011	E-H
Lower Whangaehu	Upper Mangawhero	Whau_3	Whau_3d	UVA	Mangawhero d/s Ohakune STP	mangawhero_ds_oha	50	0.006	0.070	70	0.021	0.175	E-H
Lower Whangaehu	Upper Mangawhero	Whau_3	Whau_3d	UVA	Mangawhero at Pakihi Road Bridge	mangawhero_pakihi	50	0.006	0.070	69	0.013	0.192	A-G
Lower Whangaehu	Upper Mangawhero	Whau_3	Whau_3d	UVA	Mangawhero u/s Ohakune STP	mangawhero_us_oha	50	0.006	0.070	49	0.016	0.147	E-H
Coastal Whangaehu		Whau_4			NO SITES		200	0.015	0.167				
Turakina		Tura_1			NO SITES		200	0.015	0.167				
Ohau	Upper Ohau	Ohau_1	Ohau_1a	UHS	Ohau at Gladstone Reserve	ohau_gladstone	50	0.006	0.070	7	0.009	0.040	E-H

Water Management Zones							One Plan targets			Observed values			
Zones	Sub-zones	Zone Code	Sub-Zone Code	LSC	Periphyton monitoring site name in full (as supplied by HRC)	Site_abbreviation (from Kilroy et al. 2018)	Chla mg/m³	DRP mg/L	DIN mg/L	Chla_92 mg/m³	DRP mg/L	DIN mg/L	Models
Ohau	Lower Ohau	Ohau_1	Ohau_1b	HM	Ohau at Haines Farm	ohau_haines	120	0.010	0.110	72	0.008	0.288	A-G
Ohau	Lower Ohau	Ohau_1	Ohau_1b	HM	Ohau at SH1	ohau_sh1	120	0.010	0.110	21	0.010	0.192	A-G
Owahanga		Owha_1			NO SITES		200	0.015	0.167				
East Coast		East_1			NO SITES		200	0.015	0.167				
Akitio		Akit_1			NO SITES		200	0.015	0.167				
Northern Coastal		West _1			NO SITES		200	0.015	0.167				
Kai Iwi		West _2			NO SITES		200	0.015	0.167				
Mowhanau		West _3			NO SITES		200	0.015	0.167				
Kaitoke Lakes		West _4			NO SITES		200	0.015	0.167				
S. Whanganui Lakes		West _5			NO SITES		200	0.015	0.167				
N. Whanganui Lakes		West _6			NO SITES		200	0.015	0.167				
Waitarere		West _7			NO SITES		200	0.015	0.167				
Lake Papaitonga		West _8			NO SITES		200	0.015	0.167				
Waikawa	Waikawa	West_9	West_9a	HM	Waikawa at North Manakau Road	waikawa_nmr	120	0.01	0.167	13	0.011	0.046	A-G
Lake Horowhenua		Hoki_1			NO SITES		200	0.015	0.167				