# Nutrient Objectives for Small Streams in Agricultural Watersheds of Alberta
# AI2535

Public Final Report
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Prepared for
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Alberta Government

# CLEAN RESOURCES FINAL PUBLIC REPORT

## 1. PROJECT INFORMATION:

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| **Project Title:** | **Nutrient Objectives for Small Streams in Agricultural Watersheds of Alberta** |
| **Alberta Innovates Project Number:** | AI2535 |
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| **AI Project Advisor:** | Dallas Johnson |

## 2. APPLICANT INFORMATION:

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## 3. PROJECT PARTNERS

This work was conducted in partnership with Drs. Suzanne Tank and Rolf Vinebrooke in the Department of Biological Sciences at the University of Alberta. Assistance provided by Ms. Emily Barrie and Ms. Sydney Huculak, who completed their Master's theses on this project under the supervision of Dr. Tank and Dr. Vinebrooke, is gratefully acknowledged. Invaluable feedback was received throughout this project from Vanessa Swarbrick, Joanne Little and Richard Casey of Alberta Environment and Parks, Ron Axelson of the Intensive Livestock Working Group, Fiona Briody of the Crop Sector Working Group, Mary Ellen Shain and Michelle Gordy of the North Saskatchewan Watershed Alliance, and Janet Pomeroy of the Athabasca Watershed Council. Ongoing support and feedback from Dr. Dallas Johnson of Alberta Innovates throughout the project was well received.

## A. EXECUTIVE SUMMARY

This project addresses the lack of numeric nutrient guidelines that are applicable to small, wadeable streams in Alberta's agricultural region. The goal of this project is to derive numeric nutrient targets to facilitate the assessment and evaluation of nutrient issues in agricultural watersheds. The lack of numeric guidelines challenges the ability of water resource professionals to assess the impact of nutrients on aquatic ecosystems and subsequently design watershed management programs to mitigate nutrient pollution.

A stressor-response study design was applied to streams across the provincial agricultural area in order to assess how aquatic ecosystems respond to nutrient enrichment. These designs are able to establish threshold-levels of nutrients that are associated with ecological change within a target ecological region. The outcomes of this study will provide nutrient targets that are protective of aquatic ecosystem health and reflect the ecological and socioeconomic condition of Alberta's agricultural region.

This project represents the second-phase of a five-year investigation, with a goal of deriving nutrient targets for streams across Alberta's agricultural region. The first objective of the current study is to apply a stressor-response design to streams in the Boreal region. The second objective is to evaluate whether nutrient targets for streams should be based upon watershed types that reflect differences in the underlying topography, geology and climate of agricultural watersheds, rather than on pre-determined natural region boundaries. The final objective is to evaluate nutrient limitation relationships in agricultural streams to identify the predominant nutrient driving ecosystem changes and to inform nutrient management practices for the protection of aquatic ecosystems.

A total of 25 metrics were calculated that represent the structure and function of aquatic ecosystems in the target regions. Threshold statistics were applied to calculate the concentration of nitrogen and phosphorus at which measurable changes to the ecosystem metrics were evident. Numeric boundaries for four categories that represent the risk of impact to aquatic ecosystems owing to nutrient enrichment were derived from the distribution of ecosystem thresholds. The boundaries indicate the transition between low, moderate, high and very-high risk of aquatic ecosystem impacts owing to nutrient enrichment and form the basis of the recommended nutrient targets. Separate ranges of nutrient

targets were derived for each natural region and category of watersheds. The watershed categories determined in this study appeared to better reflect the inherent similarity among stream systems than those designated by natural regions.

Nutrient limitation studies were conducted to determine the nutrient most likely to drive changes to aquatic ecosystems in wadeable streams. Algal assemblages were found to respond predominantly to nitrogen inputs, although members of the green algae groups were found to respond to phosphorus more than other community members such as diatoms or blue-green algae. While phosphorus is important to manage for lakes, reservoirs and large rivers, the results of this study suggest that nitrogen should be managed in equal measure to ensure the health of small streams that are tributaries of larger lotic and lentic systems in order to ensure the health of the entire aquatic network.

The nutrient targets developed here are protective of aquatic ecosystem health and are applicable to the agricultural region of Alberta – an area with substantial human activity and agricultural development. The project deliverables will improve assessments of water resource quality, prioritization of watersheds in need of management to make more efficient use of scarce resources, and will provide more suitable and phase benchmarks to evaluate the success of watershed and agricultural management programs. Taken together, the nutrient targets developed here, as well as planned future efforts around watershed management prioritization, will improve the assessment and management of surface water resources within agricultural landscapes of the province.

## B. INTRODUCTION

Water quality objectives, including those for nutrients, are being set for mainstem rivers in Alberta as part of Water Management Frameworks (WMF) in regional land-use plans. All land users in a basin will be expected to help meet the WMF objectives, including the agricultural industry, by reducing non-point source pollution (NPSP) through the use of beneficial management practices (BMPs). In general, NPSP management programs are designed and monitored in catchments drained by smaller-order streams. However, no valid nutrient objectives are available for broad application that can assist in prioritizing, planning, and evaluating watershed management programs at this scale. This lack of information leaves watershed and agricultural management programmers with limited capacity for contextualizing water quality data with respect to aquatic ecosystem impairment, gauging water quality improvements realized through BMP implementation from an aquatic ecosystem perspective, or determining whether a successful endpoint has been reached in an NPSP management program.

This project represents the second of a two-phase project targeting provincial-scale development of nutrient targets for small streams in Alberta's agricultural areas. In the previous phase, Alberta Agriculture and Forestry (AF) developed a unique weight-of-evidence approach for setting risk-based nutrient targets in wadeable streams by examining threshold responses of aquatic ecosystem structural and functional components to concentrations of nitrogen and phosphorus. The outcome of this approach is four risk levels, bound by numeric ranges of nutrient concentrations, which represent low, moderate, high and very high risk of aquatic ecosystem impacts. The upper and lower bounds of the risk categories can be used as management triggers and targets, respectively, depending on the current nutrient status of the waterbody. In this context, management triggers are defined as a level at which, if exceeded, management actions are implemented to maintain the current state of water quality. By contrast, management targets are understood as numeric values that represent the desired endpoints resulting from management action where the objective is to improve water quality. The first phase of this study was applied only to the Grassland and Parkland Natural Regions in Alberta. While these natural regions contain a large proportion of agricultural activity, certain areas of the Boreal region (specifically, the Boreal Transition and Peace Lowland ecoregions) also support substantial agricultural activity. These areas in the Boreal were not included in the first phase of this research program. Using the results of the first project phase, a streamlined approach has been developed for deriving nutrient targets that can be applied to the Boreal region, thus allowing for relevant nutrient targets to be suggested for all areas across the province that contain agricultural activity.

One consideration in using a regional basis for setting nutrient targets is the large degree of variation among stream properties, such as flow and water quality parameters, which manifests in broad ranges of nutrient concentrations that define the boundaries of risk categories. In discussion with stakeholders, an alternative approach for setting nutrient targets would be to categorize watersheds according to topographic, climatic (e.g., precipitation, evapotranspiration), and physiographic (e.g., watershed size and shape, dominant geology and soil type, etc.) variables. Preliminary work on this concept yielded narrower concentration ranges of the risk categories, demonstrating a proof of concept. The categorization approach used, however, was relatively simple and did not include any watersheds in the Boreal region, representing a major knowledge gap for applying the concept across the province. In the second phase of the project, the nutrient target derivation approach was applied to alternate watershed classifications in an effort to reduce the uncertainty in the risk categories for surface water nutrients.

In our work to date, aquatic ecosystem responses have been evaluated based on their response to individual nutrient species. However, these responses can vary according to the relative ratios of total and dissolved nitrogen and phosphorus. Most efforts for nutrient management in Alberta tend to target phosphorus endpoints (e.g.., Alberta Phosphorus Watershed Management Tool; Bow River Phosphorus Management Tool), which is known to be important for the management of receiving environments, such as rivers, reservoirs and lakes. However, changes to aquatic ecosystem properties in smaller-order streams tend to correlate with concentrations of nitrogen, particularly dissolved fractions, suggesting phosphorus is not the limiting element driving ecosystem health in these environments. In addition to expanding the derivation of nutrient targets to the Boreal region, this phase of the project examined the nature of nutrient limitations on stream algal growth in all three natural regions (the Grassland, Parkland and Boreal) across the province. Considering that aquatic ecosystem structure and function in streams are altered with nutrient enrichment, understanding the mechanisms that underlie these changes is an important step in addressing nutrient management for the protection of aquatic ecosystem health throughout the entire watershed.

## C. PROJECT DESCRIPTION

**Objective 1. Apply a stressor-response study design to measure aquatic ecosystem structure and function response to nutrient concentrations at 30 streams in the Boreal Agricultural Area.**

This study applied a stressor-response study design, which involves collecting concurrent information on stressor variables (e.g., nutrients) of increasing concentrations and ecosystem response variables (e.g., dissolved oxygen). These designs are recommended for setting numeric standards for non-toxic chemical stressors, such as nutrients, and where conditions do not permit comparison to control (i.e., undisturbed or minimally-disturbed) conditions. In the agricultural area of Alberta, most watersheds have a large degree of land conversion to agricultural, municipal, or other land-uses, so a control-comparison was not possible. In the previous phase of the project, separate stressor-response designs were applied to both the Grassland and Parkland natural regions of Alberta. These regions contain a high degree of agricultural activity, yet have been found to have differing concentrations and forms of nutrients. For instance, the Parkland natural region has been found to have higher nutrient concentrations, as well as a greater proportion of dissolved nutrients than the Grassland natural region. This phase of the project was intended to apply the same stressor-response study design to the Boreal agricultural area. Watersheds in this area contain low-to-high degrees of agricultural activity, depending on the region, yet the type of agriculture tends to differ and focuses to a large degree of pasture, tame forage and hayland systems; however, annual field crops are still prevalent throughout the region. It is expected that the combined effect of differing agricultural systems and ecological conditions in the area will lead to differential response of aquatic ecosystems to nutrients. The Boreal region contains more forested lands and/or riparian areas, has different soil types, more wetlands and peatlands that emit organic carbon, and generally has a cooler and wetter climate than the other ecoregions. Including this area would allow for an assessment of regional differences, and also enable provincial-scale nutrient targets to be developed.

*Variance from planned activities:*

No variances from the planned activities occurred for this objective.

*Performance Metrics:*

The success of this objective will be demonstrated by the completion of a two-year field program to measure aquatic ecosystem structure and function in tandem with water quality analyses at 30 streams in the Boreal region.

**Objective 2. Derive nutrient objectives for streams within Alberta's agricultural region according to: (i) a natural region-based classification (Grassland, Parkland, Boreal); and (ii) a watershed-type classification that is based on watershed physiographic features.**

***Watershed classification and categorization***

The intent of this objective is to establish an alternative approach to categorize smaller-order streams in Alberta's agricultural regions rather than on the basis of the natural regions. The intent, then, is to derive nutrient targets for this alternate, watershed-based category. The rationale behind this work is:

(i) watersheds, and their streams, can straddle two or more natural regions, making it confusing to assign natural region-based nutrient targets in some circumstances; and (ii) streams identified within the three main natural regions exhibit differential hydraulic behavior and/or water quality properties. Conceptual investigations revealed that a watershed-based categorization tended to reduce uncertainty in the risk of aquatic ecosystem impacts associated with nutrients by reducing the variability among streams within the alternate classification.

The watershed classification procedure was based on topographic, climatic and physiographic properties of the monitored watersheds. Geospatial attributes of the watersheds were used for classifying the watersheds in order to extend the project results to the remaining unmonitored watersheds in the province. The classification procedure was based on the study streams to ensure that the categories would be applicable to the stressor-response data obtained at the study sites, which form the basis for the recommended nutrient targets. The same watershed attributes used to classify the watersheds were calculated for each watershed within the agricultural area of Alberta, and the class membership of the unmonitored watersheds was determined by statistical similarity of aggregated watershed attributes to the developed categories.

In the first phase of the project, a weight-of-evidence procedure for deriving risk-based nutrient targets for wadeable streams was developed. This procedure was applied to streams studied in the Grassland and Parkland natural regions at the end of the first project phase. In this phase of the project, the nutrient target derivation procedure will be applied to the Boreal natural region as well as to each alternate watershed category. In order to limit confusion and streamline the use of the project deliverables, only the natural region or watershed category nutrient targets will be publicly communicated. The project stakeholder committee will be consulted to decide on which set of nutrient targets to publish at a later date.

*Variance from planned activities:*

The initial concept of the project was to classify watersheds according to an approach being used by the Prairie Water group of the Global Water Futures research consortium. However, the Prairie Water group limited their scope to the Canadian Prairie Ecozone, which did not contain the complete coverage of Alberta's agricultural areas. Subsequently, it was proposed that an alternate classification procedure would be developed and applied either to the PFRA- or HUC10-based watershed delineations. Upon further research and discussion, it was determined that the generation of the clustering model would be best performed using HUC8 boundaries because the PFRA watershed delineations are no longer supported and do not integrate with broader provincial water management frameworks and the HUC10 delineations are only available in the Eastern Slopes region of Alberta and do not cover the provincial agricultural area.

*Performance Metrics:*

Successful completion of this objective will be measured by:

i. Determination of alternate watershed categories based on topographic, climatic and physiographic attributes of watersheds;

ii. Classification of provincial HUC8 watersheds intersecting Alberta's agricultural areas within the derived watershed categories; and,

iii. Derivation of numeric nutrient targets for small-order streams within each natural region and alternate watershed category.

**Objective 3. Assess nutrient limitations on algal growth in streams of the Grassland, Parkland and Boreal natural regions to inform regional nutrient management practices.**

Most efforts for managing nutrients in Alberta for the preservation of water resources tends to focus on phosphorus management. Phosphorus has been determined to be a key limiting nutrient in large lotic and lentic systems, such as major rivers, lakes and irrigation reservoirs. However, little is known about the limiting nutrient driving changes to smaller, wadeable streams. Aquatic habitats are a network of interconnected systems, and it is equally important to manage the health of small streams for the overall benefit at the basin scale. The intent of this objective is to empirically determine the limiting nutrient that drives changes to algal communities within streams of the Grassland, Parkland and Boreal natural regions. Ten streams in each region will be assessed along a gradient of increasing nutrients in each region to evaluate how ambient nutrients affect nutrient limitation status and whether there are regional differences in limiting nutrients.

*Variance from planned activities:*

No variances from the planned activities occurred for this objective.

*Performance Metrics:*

Successful completion of this objective will be measured by the calculation of nutrient limitation status of a subset of streams selected in the Grassland, Parkland and Boreal natural regions.

## D. METHODOLOGY

**Objective 1. Apply a stressor-response study design to measure aquatic ecosystem structure and function response to nutrient concentrations at 30 streams in the Boreal Agricultural Area.**

***Site selection***

A survey of 36 distinct stream sites in the Boreal region was conducted in Fall 2018, preceding the initiation of the project. Watershed-scale information on agricultural land cover (Annual Crop Inventory; AAFC 2017) and runoff potential (Runoff Potential Map for Alberta; Jedrych, 2014) were compiled for all watersheds in the Boreal agricultural area. Watershed boundaries used for site selection were the Hydrologic Unit Code 8 (HUC8) watersheds, which are available at the provincial scale. Land cover classes, available at a 10 $m^2$ resolution, were aggregated within each watershed, and principal component analysis (PCA) was used to reduce the land cover attributes to a single variable. The percentile values of each watershed along the first PCA axis was calculated. Nine watersheds were randomly selected within each quartile of the PCA variable representing land-cover classes, with three watersheds being selected in each of the low-, middle-, and upper-tertiles of runoff potential. This approach effectively stratified the selected watersheds into areas with low-to-high potential for nutrient transport from land to water systems.

Once the watersheds were selected, site visits were conducted to choose streams that were suitable for inclusion in the study. Suitable streams were logistically feasible with respect to travel and access constraints, had amenable landowners that would permit access to the sites, and had open water present at the stream reach to reduce shading effects on the aquatic ecosystem. Water samples were also collected during the site visits to verify the presence of a suitable gradient in concentrations of total nitrogen and phosphorus. From this information, 30 streams were selected for inclusion in the study.

***Field data collection for the Boreal natural region***

Algal bioassessments and water quality sampling were conducted in spring (April – May) and summer (June – July) of 2019 at each of the new sites in the Boreal region. Water quality sampling involved the collection of water samples for submission to an analytical services laboratory, as well as the in-situ measurement of field water quality parameters using a handheld multi-parameter sonde and measurement of flow using an acoustic Doppler velocimeter or an acoustic Doppler current profiler. The submitted water samples were analyzed for total, dissolved, and inorganic nitrogen and phosphorus, as well as for suspended solids and organic carbon contents. Algal bioassessments were conducted at all streams, and consisted of measurements of phytoplankton Chlorophyll a (water column) and periphyton (attached to substrates) taxonomy and pigment profiles. Periphyton were harvested using floating artificial samplers (periphytometers) containing glass slides, that were deployed at each site for approximately four weeks. The slides were then collected and submitted to the partnering laboratories at the University of Alberta for the analysis of algal taxonomy, via microscopy, and accessory pigment profiles using high-performance liquid chromatography (HPLC). Properties of the algal communities represent a structural assessment of the aquatic ecosystem, whereby changes in community composition of primary producers, the basis of aquatic food webs, can be related to nutrients.

Functional assessments of aquatic ecosystems were conducted in a subset (n = 15) of the Boreal streams in 2019 only. At these locations, litter decomposition rates were determined through litterbag studies, and whole-stream metabolism rates were analyzed through the deployment of multi-parameter water quality sondes. The litterbag studies included the deployment and incubation of both fine (0.2 mm) and coarse (2 mm) in order to examine the relative rate of microbial decomposition to total decomposition, respectively. Litterbags were incubated for approximately eight weeks in each stream. Diurnal cycling of oxygen was used to calculate the rates of daily gross primary productivity (GPP) and ecosystem respiration (ER) occurring in the stream. In the previous phase of the project, the focal point of functional processes in streams was alternately targeted to the Grassland (2017) and Parkland (2018) natural regions over a two-year period. Functional assessments were conducted in Boreal streams only in 2019 so that each target natural region had two years of biological assessments and one year of functional assessments as the dataset for statistical threshold analysis.

Restrictions put in place in response to the COVID-19 pandemic limited the project team’s ability to conduct full algal bioassessments in the spring period of 2020. During this assessment period, only water quality samples in situ water quality parameters were collected; concentrations of Chl a are the only biological response metric available for Spring 2020 in the Boreal. The summer 2020 bioassessment period was completed in full once a suitable mitigation plan was developed for conducting field work during the pandemic.

**Objective 2. Derive nutrient objectives for streams within Alberta's agricultural region according to: (i) a natural region-based classification (Grassland, Parkland, Boreal); and (ii) a watershed-type classification that is based on watershed physiographic features.**

**Watershed classification procedure**

As a first step to the watershed classification, landscape variables were calculated for each of the 80 study streams included in this and the previous phases of the project. The watershed areas for the study sites were first delineated using ArcHydro tools in ArcGIS. Then, several morphological, geologic, and climate variables were aggregated within the watershed boundaries for each study site. Morphological features were calculated using spatial analysis tools in ArcView. Soil and geologic information for the watersheds were aggregated from static geospatial data available from provincial or federal data portals. The climate variables were collected from the Alberta Climate Information Service. Here, the complete interpolated data record (1969 – 2019) was extracted for each township that is located within or adjoining the watershed boundaries. Consequently, the climate metrics represent 50-year averages for the watersheds. In total, 29 watershed attributes were calculated for each watershed and used as the basis for watershed classification. Once the watershed variables were calculated, watershed categories were determined using self-organizing maps (SOM), an unsupervised machine learning technique that generates a two-dimensional output visualization of multi-dimensional relationships. Cluster analysis on the trained SOM was preformed to create categories of watersheds that exhibited commonalities in watershed attributes – nutrient targets were derived for these watershed categories.

The same watershed attributes that were collected for the study watersheds were also collected for every HUC8 watershed that intersects the agricultural region of Alberta. Once compiled, the dataset containing watershed attributes for each HUC8 watershed was applied to the trained SOM to determine group membership. Each HUC8 watershed was positioned onto the map node with the best fit to the set of watershed attributes, and the category that encompasses that SOM node was applied to the HUC8 watersheds.

**Derive nutrient targets for wadeable streams.**

A stressor-response approach for developing numeric nutrient targets was used in this study as these methods are commonly used to define levels of non-toxic water quality parameters that are protective of a designated use (e.g. aquatic ecosystem health). In stressor-response relationships, estimates of threshold values in stressor variables are typically different depending on the response metric being examined and the statistical methods used to detect the threshold. Therefore, instead of relying on a single response metric and statistical method, 25 response metrics were used to establish a range of potential ecological thresholds applicable to aquatic ecosystems in each natural region or watershed category. Correlation analysis of the metrics used for threshold analysis confirmed that redundancy of metrics was not a concern given that strong correlations among the metrics was very rare (data not shown). Threshold analysis of response metrics derived from algae bioassessment data were performed separately for each natural region and watershed category. The periphyton community metrics at each site were related to the average of the two water samples collected at the time of deployment and retrieval of the periphytometers. For the analysis of functional metrics (litter decomposition, nutrient uptake, and whole-stream metabolism), data from all natural regions or watershed categories were combined to obtain a sufficient sample size for threshold analyses. This was because fewer streams were studied and many of these were only studied for one year with a specific focus on the Grassland, Parkland, and Boreal natural regions between the years.

In addition, three different statistical methods were applied to analyze for thresholds in each metric, in recognition that stressor-response relationships may not all be best-represented by the same model, and that the best model for a given relationship is unknown. Thresholds in the response of indicators of aquatic ecosystem health to concentrations of TN and to TP were detected using classification and regression trees (CART), piecewise linear regression (PLR), and quantile piecewise linear regression (QPLR) statistical methods. Of the methods selected, each assumes a different relationship between stressor and response metrics. CART analysis models a step-change in the mean of the response metric, with the threshold value representing a point along the stressor gradient where the mean abruptly changes. PLR methods differ in that they model situations where the linear slope of the mean of the response metric changes along the stressor variable, with the threshold representing the point at which the slope changes.  QPLR models a conditional quantile of a response metric distribution rather than the mean. QPLR can also portray a step relationship, as it has no requirement of continuity or linear connectivity at the threshold value. In our analysis, we used the 75$^{th}$ quantile to emulate "limiting factor" relationships in which nutrients control the *upper* limit of response metrics, but at any given site response metrics may be depressed owing to other limiting factors. The 75$^{th}$ quantile was chosen to approximate an upper limit given that we had small datasets prone to outliers, negating the use of higher quantiles that are more affected by outliers. In all analyses, models were constrained to a single threshold with a minimum of four data points on either side of the threshold.

The distribution of retained threshold values from each combination of nutrient, natural region or watershed category was used to develop the numeric boundaries of nutrient target zones. The range of ecological thresholds obtained from the above analysis was used to define numeric boundaries of aquatic ecosystem health impact (AEHI) risk categories (low, medium, high, and very high) that can be used as nutrient targets for adaptive management purposes. Boundaries between AEHI risk states were established using the 10$^{th}$, 50$^{th}$, and 90$^{th}$ percentiles of the fits of gamma-distributions to the empirical distribution functions (EDFs) of calculated thresholds. Concentrations below the 10$^{th}$ percentile were designated as representing low risk of AEHI owing to nutrient enrichment, those between the 10$^{th}$ and 50$^{th}$ percentile were deemed moderate risk. Concentrations between the 50$^{th}$ and 90$^{th}$ percentile were labelled as having high risk of AEHI, with those over the 90$^{th}$ percentile were considered to have very high risk.

**Objective 3. Assess nutrient limitations on algal growth in streams of the Grassland, Parkland and Boreal natural regions to inform regional nutrient management practices.**

Ten streams within each natural region were selected from those sites previously or concurrently monitored as part of Phases 1 and 2 of the project. Sites were chosen to represent a gradient in nutrient enrichment, from low to high, and also in contrasting ratios of nitrogen to phosphorus (N:P), given the understanding the N:P ratio can affect aquatic ecosystem responses to limiting nutrients. Previously and concurrently collected data on nutrient concentrations, nutrient ratios, and flow conditions were used in the selection process.

Nutrient limitation experiments were conducted in June – July of 2019. For each stream, five replicate sets of nutrient-diffusing substrates (NDS) were prepared with each set containing four NDS (n = 20 NDS per stream). Each set of NDS contained jars filled with agar (control) and agar plus nitrogen (potassium nitrate), phosphorus (potassium phosphate) or both nitrogen and phosphorus. Water chemistry and ecosystem covariates, such as flow, light, and temperature, were measured concurrently. After the incubation period, the NDS substrates were collected and the biomass on the NDS surface was harvested and analyzed for ash-free dry mass, as well as chlorophyll and accessory pigments through high performance liquid chromatography (HPLC) methods. Chlorophyll *a* (Chl *a*) was used as a surrogate metric for algal biomass on NDS discs. Composition of algal communities were inferred from concentrations of taxonomically-diagnostic pigments identified through HPLC. The major algal groups identified were: Bacillariophytes (diatoms), Chlorophytes (green algae), Cryptophytes, and Cyanophytes (blue-green algae). Relative abundance of each algal group was calculated as the sum of the concentration of individual pigments characteristic for each algal group for each replicate, averaged across replicates for all treatment combinations at each stream.

Nutrient limitation was assessed at each site using a linear mixed model (LMM). At each site, the presence or absence of N and P in the NDS and their interaction were included as fixed effects, and the NDS rack number of each replicate was included as the random effect to account for blocking. Post hoc tests were conducted to contrast between the control and treatment NDS within each stream. The significance of the contrasts formed the basis of the type of nutrient limitation evident in that stream (Table 1).

Response ratios (RR) were calculated to quantify the magnitude of nutrient limitation by normalizing algal response to nutrient treatments relative to the control. At each site, the RR was calculated as the logarithmic ratio of the mean Chl *a* concentration on treatment $_x$ discs (e.g., averaged concentration on N discs) divided by the mean Chl *a* concentration on control discs. A RR greater than zero indicates a positive effect of enrichment on algal biomass, while a RR less than zero indicates an inhibitory effect. Two-tailed t-tests were performed on each RR ($RR_N$, $RR_P$, and $RR_{NP}$), pooled across all sites, to detect if RRs were significantly less than or greater than zero. One-way ANOVAs were then used to assess whether RR varied significantly across ecoregions and watershed categories. A Kruskal-Wallis (KW) test was used to assess differences among all RR ($RR_N$, $RR_P$, and $RR_{NP}$) across the study region as a whole. Tukey HSD and pairwise Wilcoxon rank sum post hoc tests followed ANOVAs and KW tests, respectively.

**Table 1.** Interpretation of nutrient limitation using main LMM effects and post hoc contrasts ($p < 0.1$). Black triangles indicate significant terms. Grey triangles indicate cases where the term may or may not be significant (see notes). The greater and less than symbols (> and <) indicate which treatment term resulted in a higher mean biomass response (e.g., if N-C = > ▲, the mean for N treatments was significantly higher than for controls).

| Main effects | *N-limited* | *P-limited* | *Co-limited** | | |
|---|---|---|---|---|---|
| | | | **Interpretation** | | |
| N | ▲ | | ▲ | | ▲ |
| P | | ▲ | ▲ | | ▲ |
| Interaction (N*P) | | | | ▲ | ▲ |

| Contrasts | *N-limited* | *P-limited* | *Independent Colimitation* | *Simultaneous Colimitation* | *Serial N-driven Colimitation* | *Serial-P driven Colimitation* |
|---|---|---|---|---|---|---|
| N-C | > ▲ | | > ▲ | | > ▲ | |
| P-C | | > ▲ | > ▲ | < ▲[3] | | > ▲ |
| NP-C | > ▲[1] | > ▲[1] | > ▲ | > ▲ | > ▲ | > ▲ |
| N-P | > ▲ | < ▲ | | > ▲[3] | > ▲ | < ▲ |
| NP-N | | | > ▲[2] | > ▲ | > ▲ | > ▲ |
| NP-P | | | > ▲[2] | > ▲ | > ▲ | > ▲ |

*Colimitation was detected when either (1) significant interaction term only, (2) main effects for both N and P were significant but not the interaction, or (3) all three terms were significant.

[1]NP-C may not be significant for single nutrient-limited (either N or P) sites if P-inhibition occurs.

[2]NP-N and NP-P will only be significant if the co-limited response is additive or synergistic.

[3]P-C and/or N-P may be significant if P inhibition occurs. Only when N-C or P-C was significant was the site classified as Serial Colimitation.

## E. PROJECT RESULTS

**Objective 1. Apply a stressor-response study design to measure aquatic ecosystem structure and function response to nutrient concentrations at 30 streams in the Boreal Agricultural Area.**

The study design is based on stressor-response relationships, where the intent is to establish at what point along a gradient of nutrient concentrations an aquatic ecosystem is likely to shift. To be successful, the stressor gradient must be well-defined and capture the likely threshold point at which an ecosystem property will be sufficiently impacted for a shift in ecosystem properties to be measurable. Including a suitable number of sites that represents the geographic area of concern is critical for the curation of a strong and representative nutrient gradient. The selected study sites exhibited suitable geographic distribution within the Boreal area (Figure 1).

The sites selection process was successful with respect to the enrolled sites exhibiting a strong gradient in both total nitrogen and total phosphorus (Figure 2). In comparison to the Grassland and Parkland natural regions, overall gradient in total nitrogen in the Boreal region is higher than the Grassland but lower than the Parkland natural regions. The gradient in total phosphorus appears to be relatively comparable with the Grassland natural region, but well below the concentrations observed in the Parkland natural region. That said, while the gradient in nutrient stressors may be similar between the Boreal and Grassland sites, it is very likely that the aquatic ecosystem would exhibit different response levels, owing to differences in temperature and light that are due to climatic and vegetative differences between the regions.

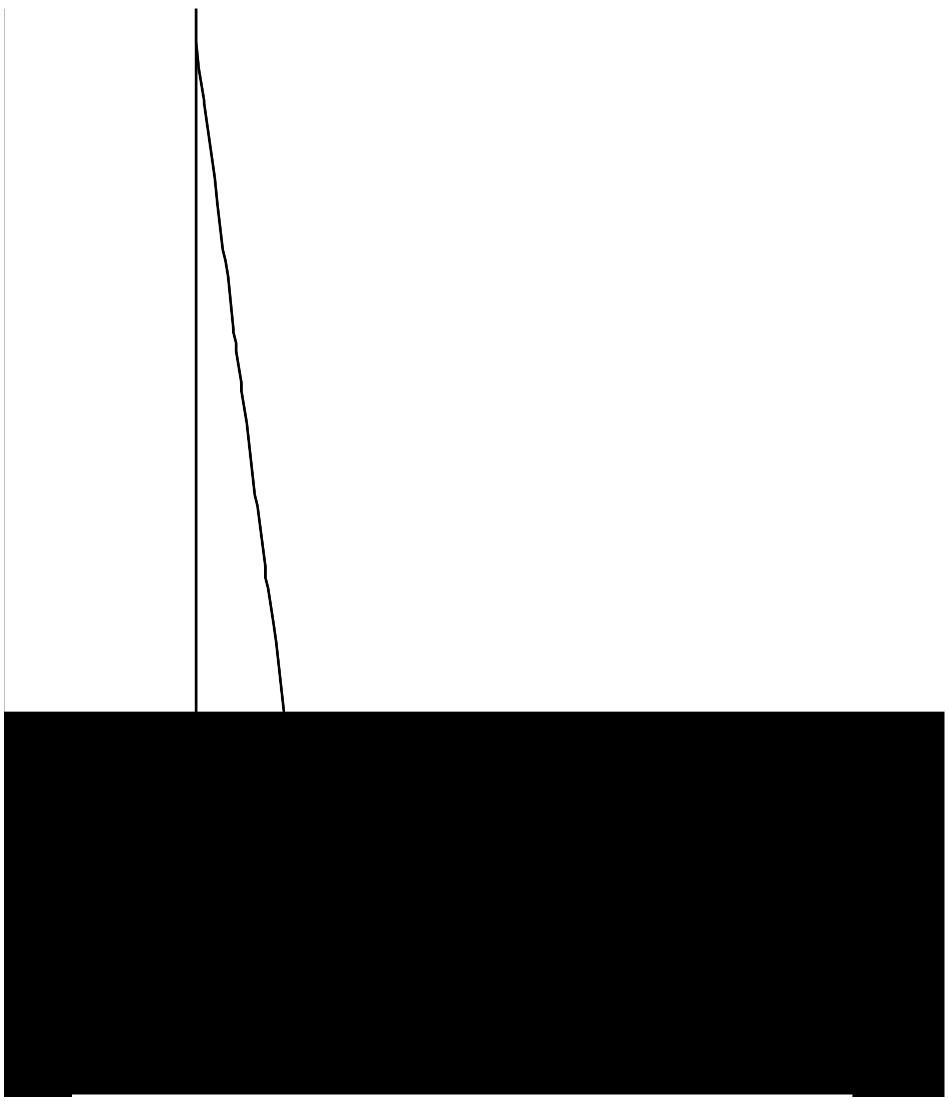

Figure 1. Map of monitoring locations and boundaries of the Boreal, Grassland, and Parkland natural regions in Alberta's agricultural area. Phase 2 target area (Boreal) is highlighted in magenta.

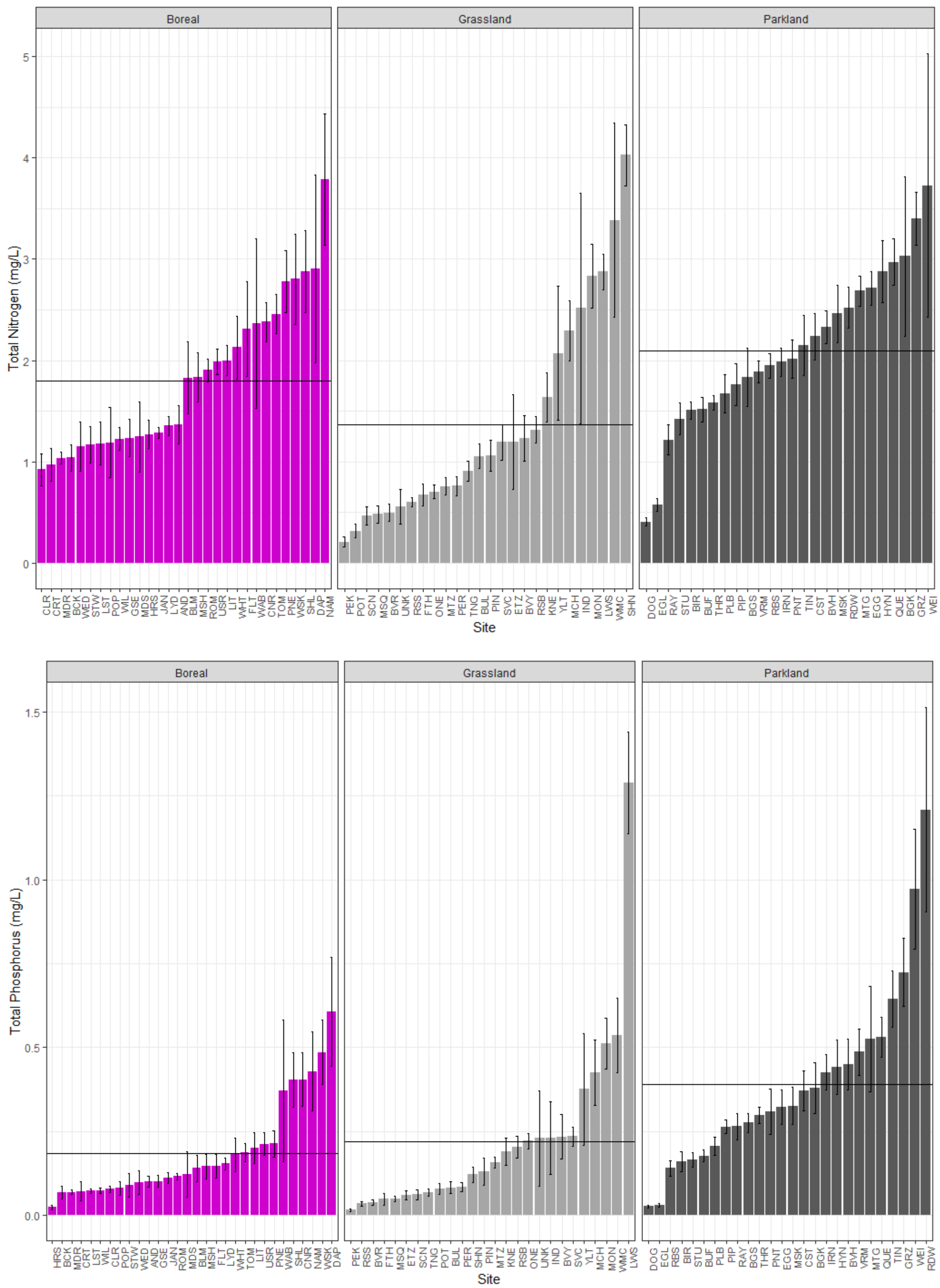


Figure 2. Gradients of nutrient stressors as represented by mean concentrations of total nitrogen (a) and total phosphorus (b) observed within the study streams within the Boreal, Grassland and Parkland natural regions. Error bars reflect the standard error of the mean. Horizontal bars indicate the mean value within the category.

**Objective 2. Derive nutrient objectives for streams within Alberta's agricultural region according to: (i) a natural region-based classification (Grassland, Parkland, Boreal); and (ii) a watershed-type classification that is based on watershed physiographic features.**

***Watershed Classification Procedure***

A number of methods were tested for classifying watersheds, but the self-organizing map (SOM) approach proved to the most robust as it was less influenced by user selection parameters and was less sensitive to the inclusion and/or removal of specific variables with respect to the stability of the generated clusters. Furthermore, the ability to classify new sites into the watershed categories is simple to perform once the SOM is generated. Conversely, by using other clustering techniques a second statistical method would have to be used to assign class membership, which may present some inherent bias to the overall process.

The output of the SOM process is a 2-dimensional map that places sample sites within the map nodes, which are in turn influenced by the relative weight of the input variables at that node. The optimal configuration of the SOM map was a 5 x 6 topology, which resulted in a good distribution of sites within maps and a stable classification of sites when forcing successive iterations of random starting points. A k-means clustering algorithm was applied to the weight matrix of the resulting SOM map to partition the sites into three categories (Figure 3). The location of the study sites on the map nodes and associated categories are presented, in addition to heatmaps of a few of the influential variables; only 9 of the 29 watershed attributes are presented here. Full details of the watershed attributes and statistical results will be provided in a planned Government of Alberta technical report that will be made publicly available on the GoA webpage in future.

By relating the weighting of variables that associate with map nodes contained within the three categories, the resulting watershed categories can be described as follows:

**Category I watersheds (green)**: higher slope and runoff potential, with higher mean annual temperature and evapo-transpiraton rates and well drained, calcareous, predominantly Chernozemic soils.

**Category II watersheds (blue)**: moderately-sloped watersheds with moderate runoff potential, higher snowpack, leaching, and are found in areas with low temperature and contain poorly-drained forested or organic soils that are acidic or neutral.

**Category III watersheds (yellow)**: low-sloped watersheds with average temperature and precipitation conditions, low runoff or leaching potential, and have a higher proportion of saline seeps and contain predominantly Chernozemic soils with high proportions of Solonetzic soils.

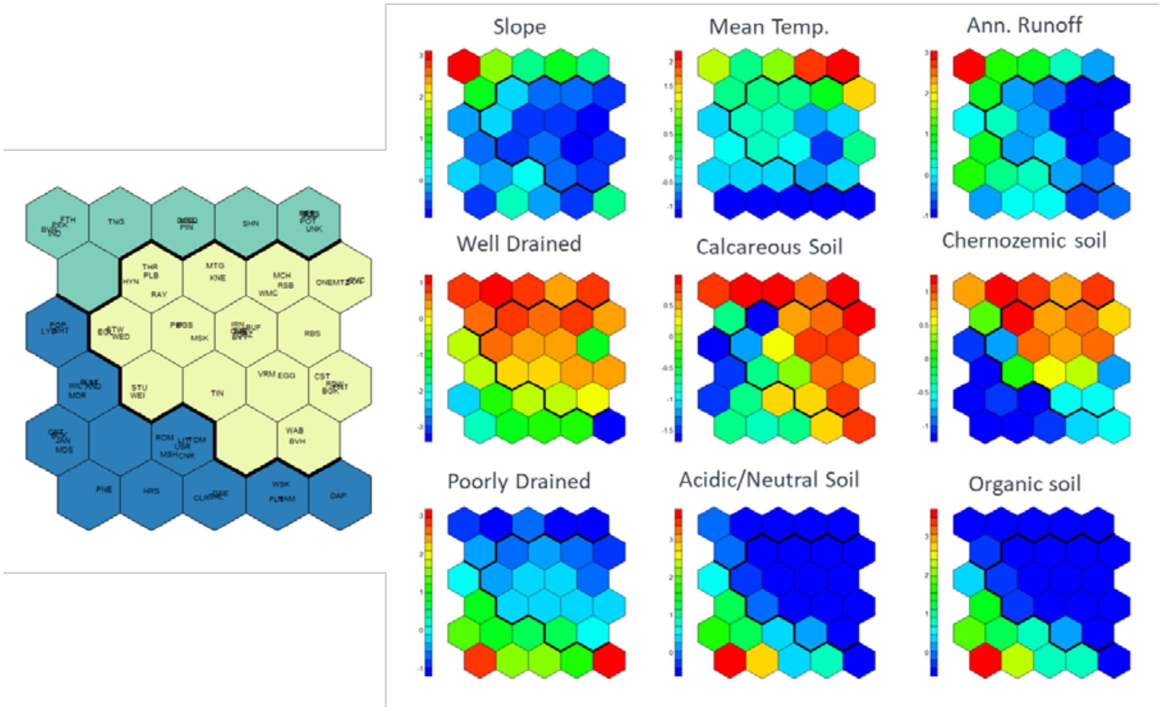


Figure 3. Self-organizing map (SOM) of monitoring sites, clustered into three categories (separate colours) through k-means clustering analysis on the final map positions. Heatmap of select important variables (9 of 29) are included to conceptually illustrate the alignment of watershed variables with nodes on the SOM, and are presented on standardized axes (mean = 0, standard deviation = 1).

In applying a matrix of geospatial variables collected for each HUC8 watershed intersecting the agricultural region of Alberta to the SOM map, the class membership of each watershed was determined and plotted in Figure 4. In looking at their geographic distribution of the study watersheds (Figure 4a) and the HUC8 watersheds (Figure 4b), it appears that the clustering approach recognized a strong latitudinal gradient in sites and overlapped to some degree with the natural region boundaries. The Category I watersheds are predominantly located in higher-slope regions of the foothills, Milk River basin, and the Cypress Hills region, whereas the Category II watersheds largely reflect the Boreal transition area. The Category III watersheds are located predominantly in the Parkland region, but contain a large component of the Northern Fescue Grasslands and extend into the Boreal transition area to the north of the Parkland boundary and into the Peace River agricultural region.

In comparing the mean concentrations of nutrients for sites located within each category, it appears that a reasonable gradient in nutrient stressors is present within each of the new watershed categories (Figure 5). In general, Category I watersheds have lower overall total nitrogen and total phosphorus concentrations than the other two categories, although a few of the sites have comparable levels of nitrogen. Category II watersheds have comparable nitrogen concentrations, but lower concentrations of total phosphorus than Category III watersheds. Category III watersheds have the highest average values, but a strong gradient in nutrient concentrations is observed in this category.

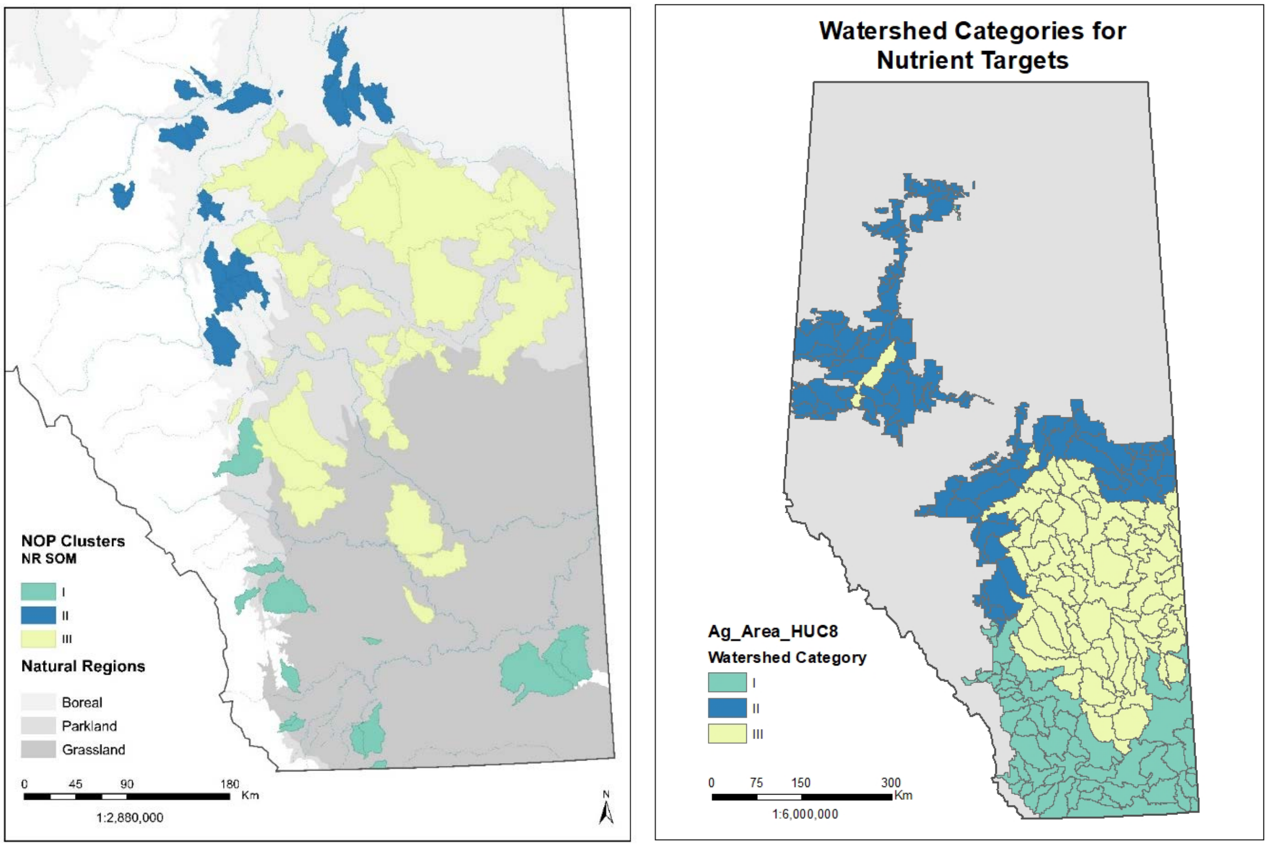


Figure 4. (a) Map of study watersheds included in the alternate watershed classification in comparison to the natural region classification; (b) membership of all HUC8 watersheds in the agricultural area within the derived watershed categories.

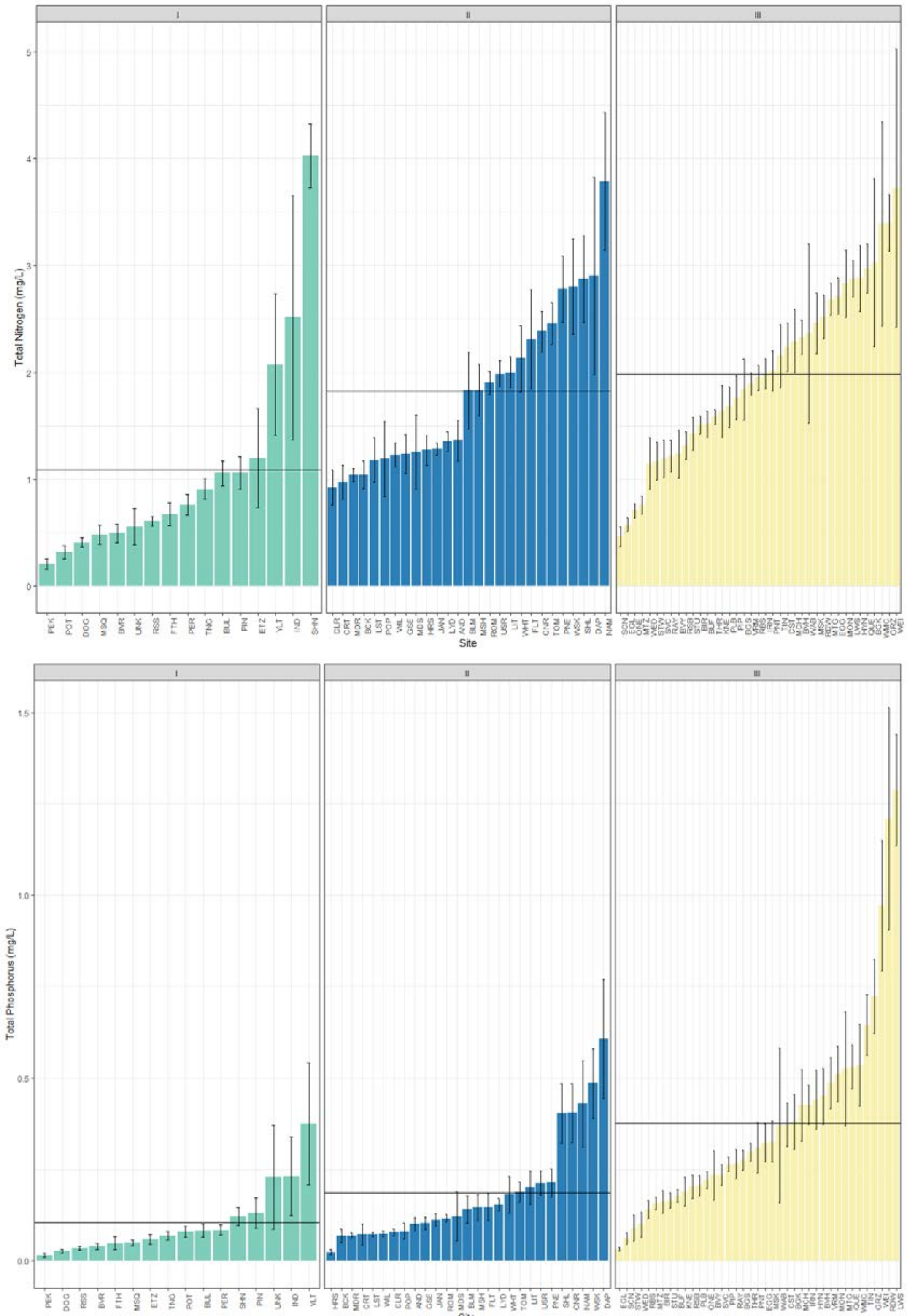


Figure 5. Gradient of nutrient stressors for the alternate watershed categories defined as mean concentrations of total nitrogen (a) and total phosphorus (b) observed within the study streams. The error bars reflect the standard error of the mean. Horizontal bars indicate the mean value within the category.

***Calculated Nutrient Targets for the Geographic Areas***

In total, 25 distinct metrics of aquatic ecosystem health were used in the study. Combined with the three separate statistical methods, a total of 75 possible combinations of statistics and metrics were available for each region. Each combination was assessed for its strength and validity. For all regions, only 13 to 32 metrics were included to calculate cumulative distribution function for each geographic region from which the nutrient targets were determined. One of the primary mechanisms to assess the validity of the calculated thresholds was to apply a bootstrap function to the statistical analysis and assess the bootstrap distribution for the threshold parameter. Only those metrics that had well-defined, unimodal threshold distributions (as illustrated in Figure 6a) were kept for analysis as they were less likely to be indicating spurious threshold detection. Each threshold was also validated through projections onto the relationship of the metric to the nutrient being analyzed (Figure 6b). The median value from the bootstrap threshold distribution was then back-transformed and used as the threshold value for that metric (Figure 6c).

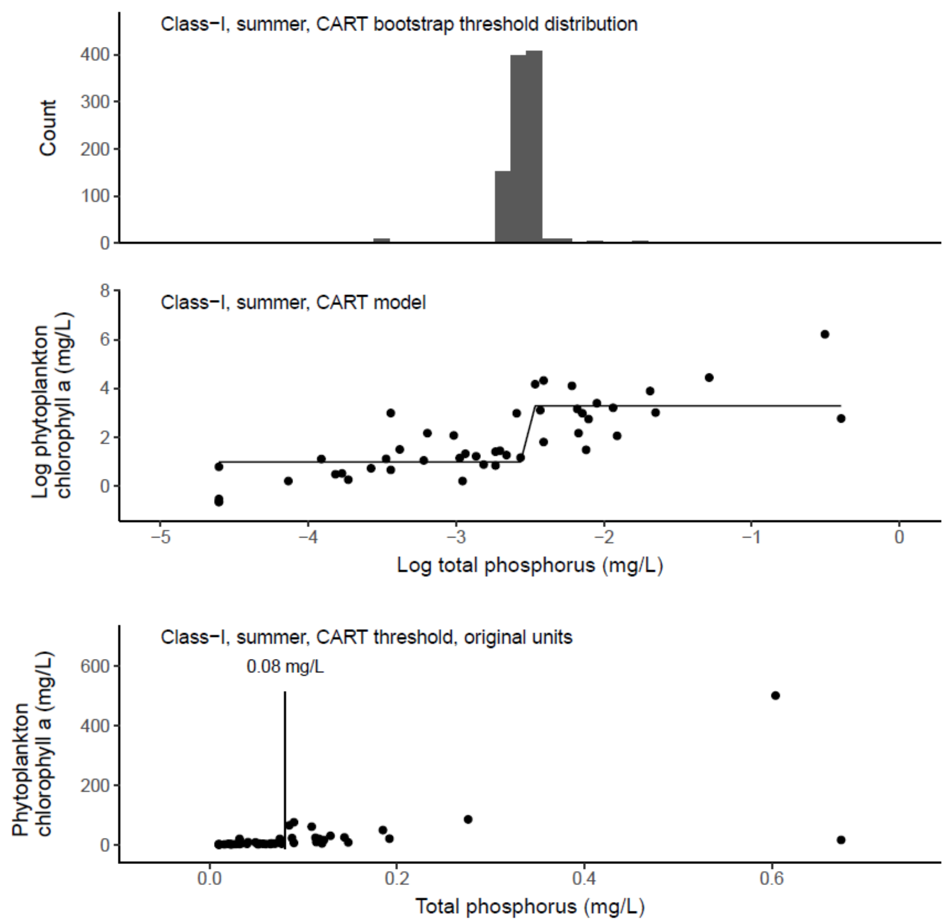


Figure 6. Example of threshold analysis using classification and regression tree (CART) to calculate thresholds in the relationship of phytoplankton chlorophyll a to concentrations of total phosphorus. Illustrated are: (a) bootstrap distribution of the CART-derived thresholds; (b)plot of log-transformed concentration data illustrating the median threshold that transitions between mean concentrations of chlorophyll a concentrations; and, (c) back-transformed concentration data with median threshold value identified.

Once the threshold values were calculated and the valid thresholds were retained, a gamma distribution was fit to the threshold values for a particular region and a cumulative distribution function was prepared. The numeric bounds of the recommended nutrient targets were derived from the 10th, 50th, and 90th percentiles of the CDFs for the gamma distribution fit to the measured thresholds. Separate distributions were created for each natural region or watershed category. Illustrated in Figure 7 is the CDF of ecosystem thresholds for total nitrogen and total phosphorus in Category I watersheds.

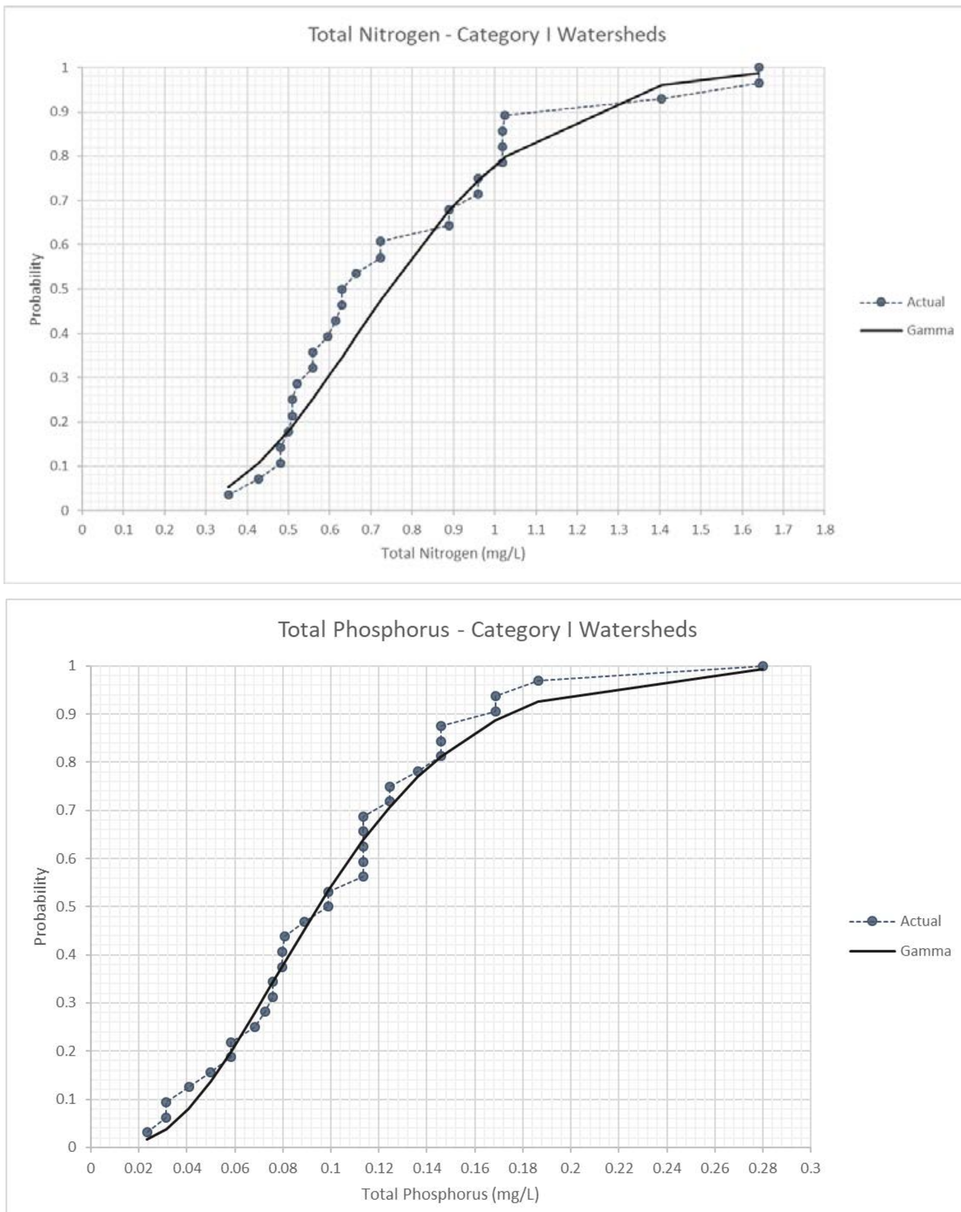


Figure 7. Example of cumulative distribution functions of the probability of threshold values in ecosystem metrics against concentrations of (a) total nitrogen and (b) total phosphorus for Category I watersheds. Plotted are the actual probabilities of threshold values calculated for measured ecosystem properties and modeled probabilities using gamma-distributions. Nutrient target ranges were established from 10th, 50th, and 90th percentiles of the gamma-distribution.

Matrices that designate the numeric boundaries of the categories of risks to aquatic ecosystem health impacts for the natural region and watershed categories are presented in Figure 8. Apparent from the nutrient targets derived for the two regional-designations is that the targets for the natural regions tend to have a considerable degree of overlap between the regions, perhaps reflecting the overlap of stream-type within the regions. Conversely, more distinct boundaries are observed in the watershed-categories, particularly for Category I streams which appear to be more sensitive to nutrients than the other categories. The clustering of watersheds based on topography, geology, soil and climate likely reflects differential exposure to flow conditions, stream morphology, precipitation, temperature, and dissolved organic carbon, which act in concert to affect the nature of the stressor-response relationship for the target region.

| Summer | | | | | |
|---|---|---|---|---|---|
| Parameter | Natural Region | Low | Moderate | High | Very High |
| Total Nitrogen (mg/L) | Grassland | <0.49 | 0.49 – 0.89 | 0.89 – 2.50 | >2.50 |
| | Parkland | <0.62 | 0.62 – 1.00 | 1.00 – 2.46 | >2.46 |
| | Boreal | <0.97 | 0.97 – 1.22 | 1.22 – 2.41 | >2.41 |
| Total Phosphorus (mg/L) | Grassland | <0.05 | 0.05 – 0.17 | 0.17 – 0.36 | >0.36 |
| | Parkland | <0.04 | 0.04 – 0.19 | 0.19 – 0.61 | >0.61 |
| | Boreal | <0.07 | 0.07 – 0.16 | 0.16 – 0.40 | >0.40 |
| Percentage of aquatic ecosystem properties altered | | <10% | 10% - 50% | 50% - 90% | >90% |

| Summer | | | | | |
|---|---|---|---|---|---|
| Parameter | Category | Low | Moderate | High | Very High |
| Total Nitrogen (mg/L) | I | <0.42 | 0.42 – 0.74 | 0.74 – 1.26 | >1.26 |
| | II | <0.91 | 0.91 – 1.31 | 1.31 – 2.39 | >2.39 |
| | III | <0.67 | 0.67 – 1.49 | 1.49 – 2.72 | >2.72 |
| Total Phosphorus (mg/L) | I | <0.04 | 0.04 – 0.09 | 0.09 – 0.17 | >0.17 |
| | II | <0.07 | 0.07 – 0.18 | 0.18 – 0.34 | >0.34 |
| | III | <0.06 | 0.06 – 0.27 | 0.27 – 0.63 | >0.63 |
| Percentage of aquatic ecosystem properties altered | | <10% | 10% - 50% | 50% - 90% | >90% |

Figure 8. Matrices of nutrient targets for wadeable streams in Alberta's agricultural region determined for: (a) natural regions, and (b) watershed categories. Matrices indicate numeric concentrations of total nitrogen and total phosphorus for each category that are associated with low, moderate, high or very high risk of aquatic ecosystem impacts owing to nutrient enrichment. Risk boundaries are defined by the 10$^{th}$, 50$^{th}$ and 90$^{th}$ percentiles of the distribution of thresholds in the response of aquatic ecosystem metrics to increasing concentrations of nutrients.

While separate nutrient target ranges were prepared based upon the natural region or watershed category designations. However, only one set of nutrient objectives will be targeted for public release in order to limit confusion. It is in the view of the project team that the nutrient targets derived on a watershed category basis are stronger, but more consultations with stakeholder groups are required to confirm which set will be communicated to broader audiences.

Several challenges were confronted in the spring assessment periods, ranging from high flow events affecting assessment devices to administrative restrictions put in place in response to a global pandemic. As such, the quality of data obtained for the spring assessments requires further consideration by the stakeholder panel for the project and the derivation of distinct nutrient targets may not be justifiable at this time. Consequently, only the nutrient targets derived for the summer season are presented here.

**Objective 3. Assess nutrient limitations on algal growth in streams of the Grassland, Parkland and Boreal natural regions to inform regional nutrient management practices.**

The growth of algal biomass on nutrient-diffusing substrates containing nitrogen, phosphorus or both were compared against control substrates to understand the nature of nutrient limitation in the study streams. The effect of nutrient supplements on algal biomass was measured for the whole algal assemblage by assessing concentrations of chlorophyll a, as well as for major groups of algae by assessing changes in taxonomically-diagnostic pigments. While many accessory pigments were found, only those for diatoms (bacillariophytes) and green algae (chlorophytes) were consistently determined across all streams. Consequently, the nutrient limitation status of algal groups were limited to diatoms and green algae.

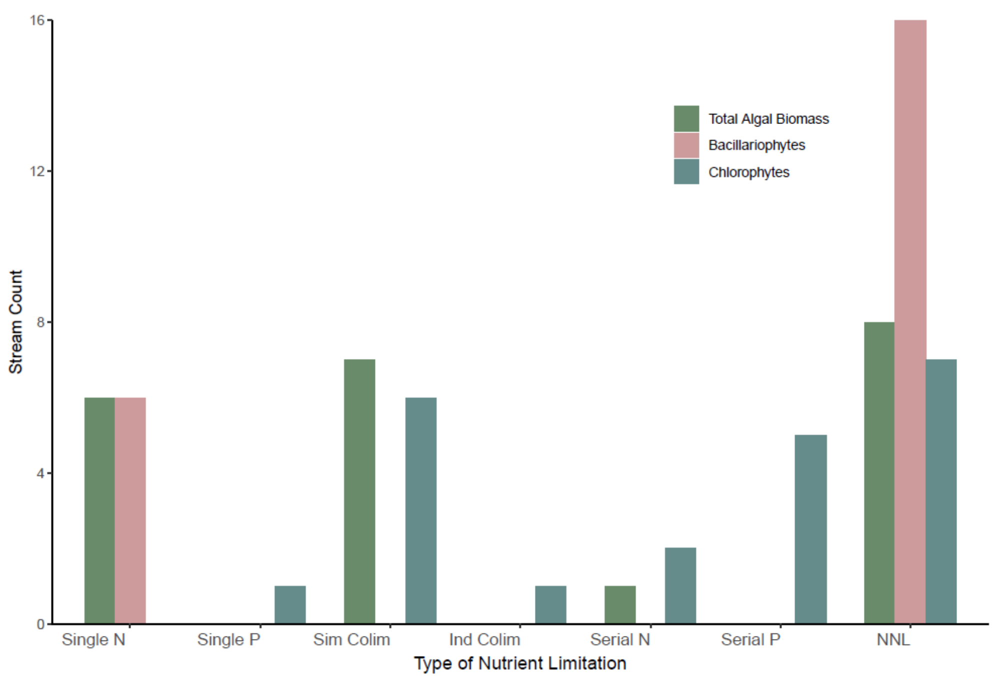


Figure 9. Bar plot summarizing the frequency of the types of nutrient limitation (Single N, Single P, Simultaneous co-limitation (Sim Colim), Independent co-limitation (Ind Colim), N-driven serial co-limitation (Serial N), P-driven serial co-limitation (Serial P), and Not Nutrient Limited (NNL) detected for both total algal biomass (i.e., Chlorophyll a) and each detected algal group (Bacillariophytes and Chlorophytes) limitation across all streams (n = 22)..

There were seven main nutrient limitation states identified in the study streams (Figure 9). Total algal biomass was observed to be either not nutrient limited (36% of streams), nitrogen-limited (27%), simultaneously co-limited (32%) or under N-driven serial co-limitation (5%). All nutrient-limitation states, then, for the whole algal community were in part dependent on nitrogen limitation. When comparing the response of algal groups, however, there were divergences in their relative response to nutrients. Diatom (bacillariophytes) were found to be either not nutrient limited (73% of streams) or nitrogen-limited (27%). By contrast, green algae (chlorophytes) were observed to be either not nutrient limited (32%), phosphorus-limited (5%), P-driven serial co-limited (68%), N-driven serial co-limited (10%), independently co-limited (5%) or simultaneously co-limited (27%).

Response ratios, or the magnitude of biomass growth relative to the control substrate, were calculated for the nitrogen, phosphorus and nitrogen+phosphorus treatments and contrasted among the natural regions and watershed categories (Figure 10). The magnitude of algal growth was observed to be significant for both N- and N-P treatments, and P-treatments were observed to have a slight inhibitory effect to the magnitude of algal biomass. No differences in the magnitude of growth were observed between natural regions. Category II watersheds were observed to have a lower magnitude of biomass growth in the presence of nutrients than the other categories; however, the only significant difference was the contrast between N-P treatments in Category II and III watersheds, with Category III watersheds exhibiting greater biomass.

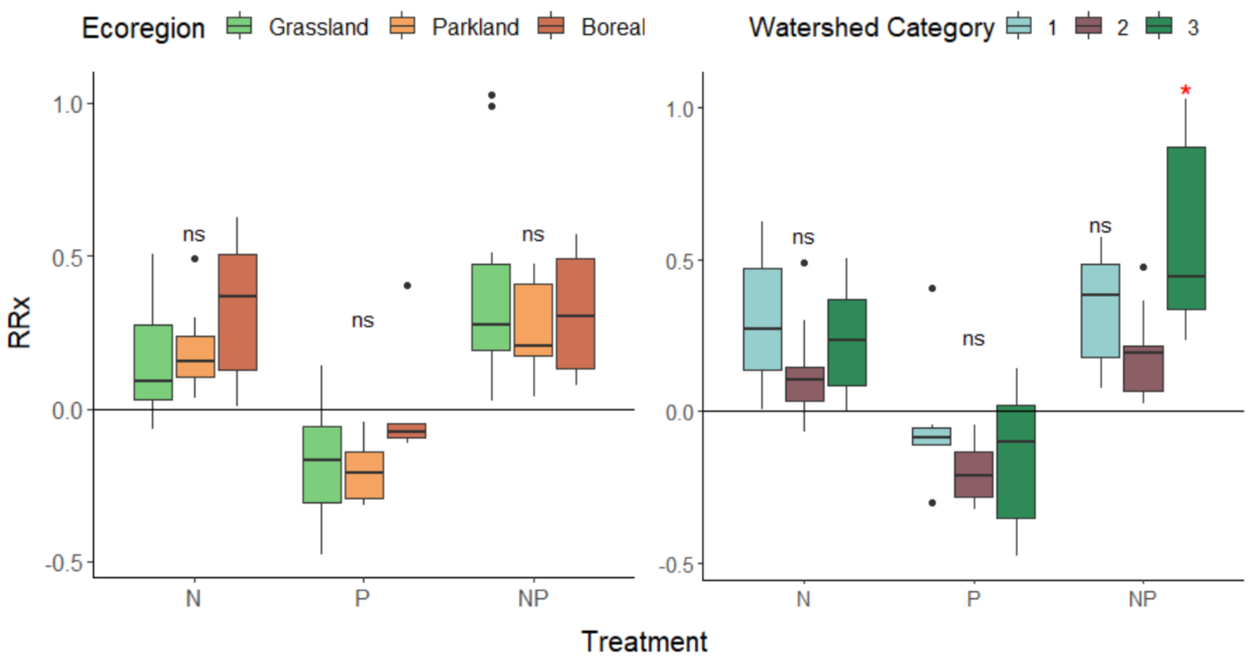


Figure 10. Boxplots of RR for each nutrient amendment (N, P, and NP) across both ecoregions: Boreal (n=5), Grassland (n=10), Parkland (n=7) and watershed categories: 1 (n=6), 2 (n=10), 3 (n=6). Significance ($p < 0.05$) is indicated by letters (ns = not significant). The boxes represent the interquartile range, including the median value (centre line). Outliers are plotted as points.

When comparing the response ratios for N, P and NP treatments among the algal groupings, a distinct increase in green-algae (chlorophytes) in the presence of phosphorus over nitrogen or both nitrogen and phosphorus was observed (Figure 10). In contrast, the diatoms (bacillariophytes) were observed to have a significant increase in biomass in the presence of nitrogen over phosphorus or both nitrogen and phosphorus.

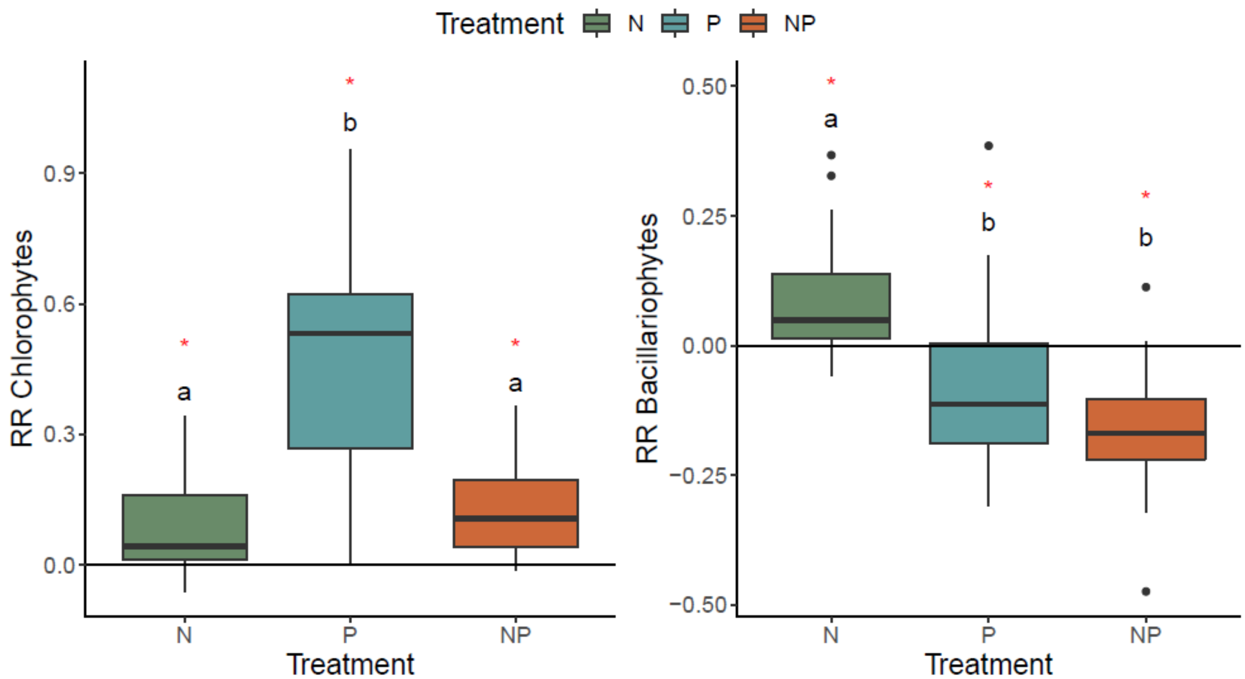


Figure 10. Boxplot comparing RR for chlorophytes (RRCHLORO) and bacillariophytes (RRBACILL) across all treatments (N, P, and NP). Asterisks (*) indicate RR is significantly different ($p < 0.05$) from zero. Significant differences ($p < 0.05$) are indicated by letters. The boxes represent the interquartile range, including the median value (centre line). Outliers are plotted as points.

Taken together, the results indicate that the whole community assemblage of periphyton biofilms respond to increases in nitrogen or both nitrogen and phosphorus together, although the magnitude of response does not appear to have significant regional variation. The response of the major algal groups, appear to exhibit differential responses to nutrients. Diatom assemblages display a greater response to nitrogen additions in some streams, but diatoms are not nutrient limited in most streams. By contrast, green algae appear to respond more strongly to phosphorus additions, although the nature of their limitation status between nitrogen and phosphorus were complex and appear to be influenced by co-varying factors in the stream ecosystem. Nonetheless, the results indicate that controlling nitrogen additions to streams would reduce excess growth over whole algal communities, and controlling phosphorus would help mitigate shifts from diatom-dominated communities to green-algae communities. Green-algae contains many of the filamentous algal forms that cause nuisance growth in stream ecosystems that affect the aesthetic and habitat quality of aquatic ecosystems, so their control is equally important.

## F. KEY LEARNINGS

The key learnings for this project include:

1. Numeric nutrient targets have been established for streams and tributaries to major rivers across agricultural regions in Alberta. These targets can be used to improve assessments of aquatic ecosystem health and to establish management triggers and targets for smaller-order streams.
   a. The targets have been set both on a natural region-basis as well for an alternative watershed categorization based on physiographic attributes of the watersheds.
   b. The alternate watershed categories align with the natural region boundaries, but with some overlap. Category I watersheds occur in more southerly, drier, and higher-slope watersheds that tend to have higher flow and lower ambient concentrations of nutrients. Category I watersheds align with the Grassland region, although includes watersheds in the Foothills Parkland sub-region. Category II are associated with more treed watersheds that are cooler, have higher precipitation, aligning with the Boreal natural region. Category III watersheds encompass the Central Parkland natural region and also include watersheds from the northern Grassland region and south-central Boreal region.
   c. It is likely that the alternate watershed categories are better suited than the natural region designation for setting nutrient targets for streams, as the hydrological and water quality conditions respond to the nature of the topography, soil, geology and climate conditions of an area. The calculated targets tend to be narrower
2. Streams within the agricultural region have been found to be either limited by nitrogen, co-limited by both nitrogen and phosphorus, or are not nutrient limited. Much of the focus of nutrient management for the protection of aquatic life in Alberta has focused to a large degree on phosphorus management. While phosphorus is important to control for the benefit of downstream receiving environments, such as lakes, reservoirs and rivers, nitrogen appears to be more important for preserving the health of aquatic ecosystems in smaller streams. No distinct regional variation in the limiting nutrient was observed in this study. In order to protect the health of the lotic system in watersheds, both nitrogen and phosphorus need to be managed in concordance through landscape management planning.

## G. OUTCOMES AND IMPACTS

**Project Outcome and Impacts:**

The lack of nutrient guidelines for wadeable streams in Alberta was the major knowledge gap being addressed in this study. The lack of suitable guidelines challenged water resource professionals and watershed managers to evaluate the status of aquatic ecosystem health impacts owing to nutrient enrichment in Alberta's agricultural area. Consequently, the prioritization of watershed management projects was challenged as it was unknown which areas were truly impaired based upon historic water quality sampling data.

The stressor-response study conducted over the two phases of this project provided sufficient data to confidently determine how aquatic ecosystems respond to increasing concentrations of nutrients. By simultaneously assessing a number of metrics of aquatic ecosystem health, we were able to identify multiple thresholds of ecosystem response to nutrients, allowing for the development of risk-levels that permit a phased approach to watershed assessment and management. End users will now be able to estimate the degree to which aquatic ecosystems have been altered by assessing single or low-numbers of samples from water quality monitoring programs by comparing the observed concentrations of nutrients against the matrices of nutrient targets developed here. It has also been experimentally determined that nitrogen is an important nutrient to manage for the benefit of aquatic ecosystem health along the stream network and should be emphasized more broadly than is currently done in watershed management programs.

**Clean Energy Metrics:**

The Clean Resource Metrics for this study relate to communications and HQP training. Two M.Sc. students and three undergraduate students were trained and gained experienced in working on water quality monitoring and aquatic ecosystem assessments in Alberta. It is expected that four manuscripts, two M.Sc. theses, and one government technical report will be prepared from this study, and from the previous phase of the project. The final technical report will provide the background information for advancing one provincial policy related to establishing nutrient targets for wadable streams in the agricultural region (White Area) of Alberta. Future communications will see the development of an online mapping tool that will enable users to determine nutrient targets for specific watersheds. This website has started to be developed and was proposed based upon stakeholder consultations held during the study, but was not originally a planned deliverable for this project.

**Program Specific Metrics:**

The sole program-specific metric is the number of collaboration partners, which amounted to six. The project was led by the department of Agriculture and Forestry in partnership with the University of Alberta. Key stakeholders in this project included two Watershed Planning and Advisory Councils (WPACs; North Saskatchewan Watershed Alliance and Athabasca Watershed Council), water policy specialists at Alberta Environment and Parks, and two agriculture industry groups (Crop Sector Working Group and Intensive Livestock Working Group). The collaborative partnership between these organizations on this project was a success, and all stakeholder groups are supportive of the methods and results of the research, and the communication strategy for the project outcomes.

**Project Outputs:**

A new government was sworn in on April 30, 2019, which resulted in a restricted communication activity as the government became abreast of current files and activities within the department. Permission to proceed with communications was not granted until Fall of 2019. Below are details of the communication activities completed during the reporting period.

Presentations at Conferences, Workshops and Forums:

| | |
|---|---|
| November 26, 2019 | Science Seminar Series, Alberta Environment and Parks – Office of the Chief Scientist OCS, Edmonton, AB |
| November 12-27, 2019 | Pulse, Barley, and Wheat Commission Regional Meetings – various locations (component of broader agricultural water quality initiatives) |
| March 3 – 5, 2020: | R.E. Peter Biology Conference, University of Alberta<br>- 2x presentations by M.Sc. students |
| June 7 – 12, 2020: | Society for Freshwater Science, Virtual Conference<br>- 2x poster presentations by M.Sc. students |

Stakeholder Committee Meetings:

| | |
|---|---|
| October 2, 2019: | Discussed summer 2019 field season, plan for Phase 2 of the project, and results from the Phase 1 report |
| March 4, 2020: | Update on approach to classify watersheds, 2020 field season plan, and presented draft communications plan |
| June 22, 2020: | Discussed results of survey on project terminology for communications plan |

Theses:

TBD: Nutrient limitation of periphyton in agricultural streams: Implications for watershed management. M.Sc. Thesis by Sydney Huculak – defended March 15, 2021; yet to be published.

TBD: Assessing stream function across an agricultural gradient in three ecoregions of Alberta. M.Sc. Thesis by Emily Barrie – defending March 29, 2021; yet to be published.

Upcoming Communications:

- Five manuscripts submitted to academic journals
  - Three from M.Sc. theses, publishing material from the overarching theses
  - One on the statistical process to derive nutrient targets
  - One on the watershed classification procedure
- One final technical report published on the Government of Alberta webpage
- One online mapping product that can be used by end users to query nutrient targets for watersheds across Alberta's agricultural area

## H. BENEFITS

There are currently no numeric guidelines established for concentrations of nitrogen and phosphorus in surface waters in Alberta that are protective of aquatic ecosystem health. The narrative statement that is intended to inform nutrient management requires sufficient data to establish a case for natural variation in nutrient concentrations at that site. However, many smaller streams and tributaries in Alberta do not have sufficient data available to understand the natural range of variation nor to assess the potential impact of nutrient concentrations at that site.

**Economic**

The economic implications of the project's benefits surround adaptive management of agricultural landscapes for the preservation of water supplies. Previously, the only available reference guidelines for nutrient concentrations in streams were based upon ecological conditions in lakes and major rivers in areas outside of the Canadian Prairies. Comparison to inappropriate guidelines may lead to erroneous assessments on the status of aquatic ecosystem health and potential overcompensation in managing human activities to achieve conditions that are lower than what is naturally occurring. By establishing regionally appropriate nutrient targets, and in providing a phased approach for nutrient management by having tiered benchmarks, the implementation of land management activities can be done judiciously and without over-expenditure on practices that may not be necessary.

**Environmental**

The project results hold substantial benefits for improving the assessment and management of aquatic ecosystem health in Alberta. The established nutrient targets fill a key knowledge gap in understanding the degree of impact to aquatic ecosystems associated with nutrients. These targets will enable water resource professionals to improve recommendations on management practices to mitigate nutrient impacts to aquatic ecosystems.

**Social**

Agricultural producers in Alberta pride themselves on being good stewards of their lands and key contributors to preservation efforts in the Canadian Prairies. Water quality and aquatic ecosystems are important to landowners and producers, and they are willing to adopt practices that help reduce their impacts on water. However, producers expect that the practices that they adopt will have tangible benefits on the landscape. The historic lack of nutrient guidelines has challenged our collective efforts to educate and inform agricultural producers on beneficial management practices (BMPs) for water quality, as it was difficult to explain to producers the need for and benefit of BMPs in the absence of measurable guidelines for nutrients in surface water. By having nutrient targets that are founded on aquatic ecosystem health, and having a phased approach to impact management, it enables a conversation between land-managers and producers to be based on scientifically-supported evidence.

**Innovation Capacity**

Through this project, two Master's level students and two undergraduate students received training on aquatic ecosystem health and water quality assessments in the Canadian Prairie and Boreal regions.

## I. RECOMMENDATIONS AND NEXT STEPS

The outcomes of this project provide critical background material for prioritizing watershed management in Alberta's agricultural region. It is now known what concentrations of nutrients are protective of aquatic ecosystem health, and phased risk-zones for aquatic ecosystem health have been determined. Next steps in this initiative are to use pre-existing water quality information from this study and from other long-term monitoring sites to build a predictive model for concentrations of nutrients in streams across Alberta's agricultural region. Once a predictive model is built and nutrient concentrations have been estimated for every small watershed (defined by current HUC8 boundaries), the outputs can be compared against the nutrient target risk matrix to define a risk category for every watershed in the agricultural zone. The assigned risk rating is critical information that can be used to prioritize watershed management projects and programs.

Over the next two years, the project team will compile existing monitoring data and develop a statistical model that can be used to predict nutrient concentrations in every basin in Alberta's agricultural area. The model currently being considered is the SPARROW (SPAtially Referenced Regressions on Watershed attributes) model, which has been developed by the USGS. As part of the geospatial data acquisition for this project, sufficient geophysical, land cover, and land-use data have been compiled for every HUC8 watershed in Alberta's agricultural area. A predictive model for flow-weighted concentrations of nitrogen and phosphorus can be built using the watershed attributes already collated, and predictions for unmonitored basins can be made based on the collected watershed data.

Consultations with Alberta WPACs will be held over the next several months to discuss the outcomes of this project, the proposed modelling framework, and how the outputs can be used by these organizations to help plan and prioritize watershed management programs.

## J. KNOWLEDGE DISSEMINATION

A technical publication detailing the scientific methods, results, and outputs of both phases of the project will be prepared and published on the Government of Alberta website. The publication will be open to the public. A project webpage will also be developed that will provide an online, navigable map that users can browse to search for relevant nutrient targets assigned for watersheds and streams across Alberta. The webpage will be expanded in the future to include the SPARROW model predictions of average annual concentrations of nutrients in streams within the identified watersheds. The ability of users to view estimated concentrations, comparison to calculated nutrient targets, and assist with prioritization of sub-watersheds within the integrated watershed management plans of the major river basins. The target audience for these publications are watershed managers, water resource professionals (engineers, biologists in private industry), and other water managers, such as the Alberta Irrigation Districts. A communications strategy to raise awareness of the project outputs will be conducted, which will include online webinars, in-person presentations at WPAC forums, and technical conferences for water resource professionals.

## K. CONCLUSIONS

The goal of this project was to define numerical targets for concentrations of nitrogen and phosphorus in wadeable streams of Alberta's agricultural region differentiated according to natural region zones and watershed boundaries. The project also sought to understand which of nitrogen or phosphorus was responsible for driving algal growth and ultimately leading to aquatic ecosystem impairment. Nutrient targets were calculated for the three ecoregions that support agricultural activity in Alberta (Grassland, Parkland and Boreal) as well as for three categories of watersheds that were classified based on topographic, climatic, and physiographic attributes. These targets, which represent ranges of nutrients that relate to changes in ecosystem properties were developed for all watersheds in Alberta, both on a natural region and watershed category basis. The targets are presented as numeric bounds to risk categories for aquatic ecosystem health impacts, and can be used by end users to assign ratings of low, moderate, high or very high risks to aquatic ecosystem impacts based upon measured concentrations of nutrients in a stream. It was also determined that wadeable streams in the region are either nitrogen-limited, co-limited or not nutrient limited, such that phosphorus is not the predominant nutrient driving ecosystem change in these systems. The outcomes of this study can be used by water and watershed managers to inform assessments of aquatic ecosystem health status in wadeable streams, make decisions on where to prioritize watershed management efforts and how to monitor program success toward maintaining or improving aquatic ecosystem health. The outcomes are expected to improve the planning, prioritization and measurement of success for watershed management programs. Next steps following the completion of this project are to apply a statistical modelling approach to estimate nutrient concentrations in unmonitored basins across provincial agricultural areas. The modelled concentrations will be compared to the developed nutrient targets to identify the risk rating for each basin. These results will be communicated to water and watershed managers to aid in the prioritization of watershed management programs. An online platform will be developed where end users can select a basin of concern in Alberta and extract the estimated concentration of nutrients, the risk-based nutrient targets, and geospatial data for the watershed that was used for estimating nutrient concentrations.