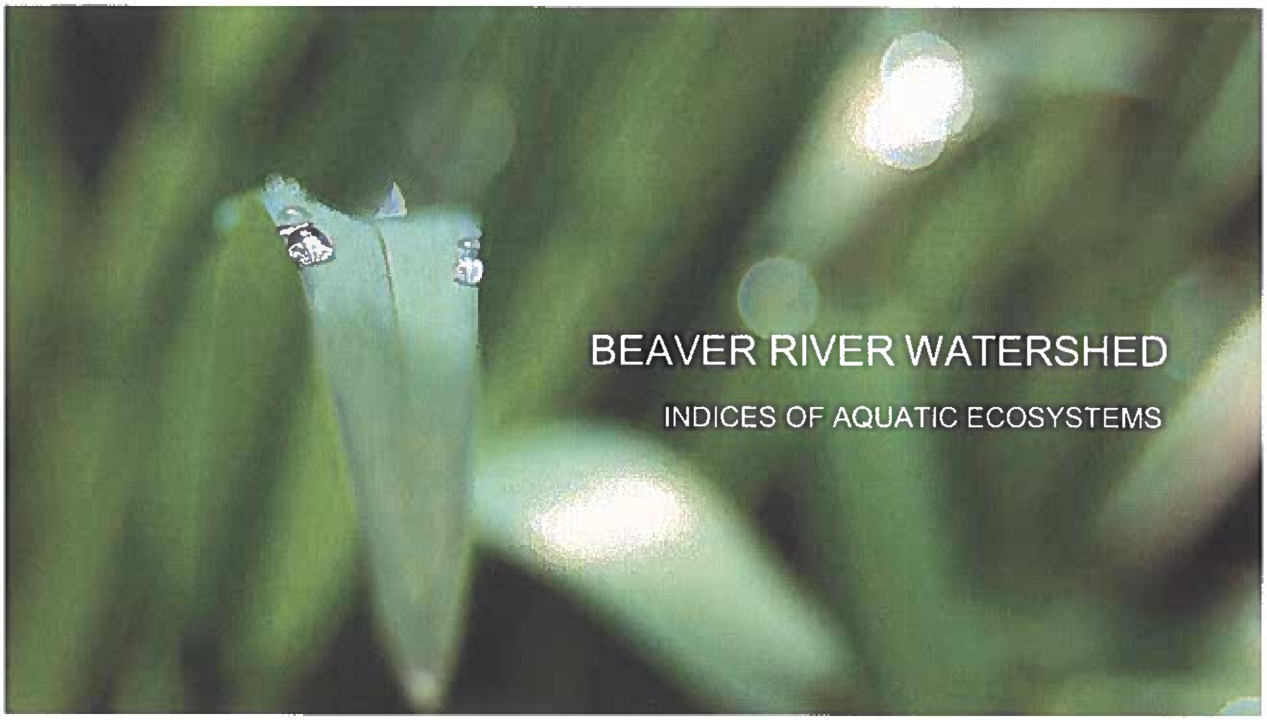

Prepared for: Beaver River Watershed Alliance

Completed on: March 23, 2015

CPP ENVIRONMENTAL

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Pell
Poscente

#154 – 150 Chippewa Road
Sherwood Park, AB, T8A 6A2
P 780.570.5818

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Contents

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Introduction

The Alberta portion of the Beaver River Watershed (BRW) covers approximately 22,000 km^2 (Figure 1). Nestled between the Athabasca watershed to the west/northwest and the North Saskatchewan watershed to the south, it is the second smallest of Alberta's seven major watersheds. It originates as the outflow from Beaver Lake near the Town of Lac La Biche and extends eastward towards Saskatchewan. The Beaver River ecosystem is controlled by a tapestry of natural in-stream processes. It is not fed by relatively pristine sources of water, such as glaciers. Instead, it is fed by a watershed that has many wetlands and rich deep soils, which produce water that is high in organics and nutrients. Thus, many surface waters contain tea-coloured and nutrient-rich water. In addition, stream channels in Alberta tend to be erodible, which can cause high suspended sediment, nutrient, and metal concentrations, particularly during peak flows. As a result of all of these influences, nutrient, organic, sediment, and metal concentration tend to be naturally high in the Beaver River mainstem. Furthermore, high nutrient and organic concentrations result in low oxygen concentrations, particularly under ice. These observations hold true even in streams from watersheds that have relatively little land disturbance. Lastly, but perhaps most importantly, being in a semi-arid region means that water quality and fish populations in a small system such as the Beaver River are highly controlled by climate-related processes. During dry periods, tributary and mainstem discharge decrease, water quality decreases due to longer flushing times, and fish condition degrades due to reduced habitat conditions and restricted passage causing limited access to the broader fish pool and reduced refugia options from stressful environments.

In addition to natural processes, land use pressures are responsible for some of the patterns in water quality, waterbirds, and the fish community. Fish populations along the entire Beaver River mainstem, from the headwaters (Amisk and Sand River) to the Saskatchewan border, were recently studied and synthesized through an Index of Biotic Integrity (IBI). This study revealed a highly stressed fish community fraught with disease and parasites. Fish communities were especially unhealthy in the upper Beaver and Amisk Rivers, where flows are particularly low and nutrients very high. Interviews with long-time anglers in the watershed indicate that sportfish have decreased in size and abundance over the past 30 years. In the IBI study, fish community metrics (% invertivorous cyprinids, % benthic invertivores, % omnivores, and % lithophils) were significantly related to human disturbance (e.g., human disturbance on bank, % cropland, road density; Cantin & Johns, 2011). Water quality of lakes (CPP Environmental, 2013) and wetlands (Bayley et al., 2011) is also strongly related to human disturbance; the greater the disturbance in a watershed (particularly agricultural), the more fertile and the less clear its lakes and wetlands generally become. Human disturbance in buffers around lakes is also very important in the occurrence of sensitive waterbirds (e.g., Common Loon, Great Blue Heron, Common Merganser, and Horned Grebe) that occupy the BRW (Found et al., 2008).

The Beaver River Watershed Alliance (BRWA), as the Watershed Planning and Advisory Council for the BRW, has a mission to maintain or improve the ecology of the BRW while respecting the diverse values of the watershed community. This will be achieved through broad community engagement, partnerships, sound scientific study, education, and the implementation of sustainable water management and land use practices. The BRWA has been charged with assessing aquatic ecosystem health and developing a series of strategies that will improve or maintain aquatic ecosystem health in the Beaver River Watershed.

The BRWA released a report entitled "A Plan for Healthy Aquatic Ecosystems in the Beaver River Watershed" (CPP Environmental, 2010), with the goal of protecting and managing the aquatic ecosystems within the Beaver River Watershed while recognizing stakeholder values. This report outlines an approach that marries Aquatic Ecosystem Health (AEH) assessment to conservation and restoration, with the purpose of supporting environmental management decisions. Objectives include:

1. Describing and tracking aquatic ecosystem health over time;
2. Identify indicators of water quality that will support decision-making;
3. Identifying strategies for managing the impact of stressors (identify conservation, mitigation and restoration opportunities).

This document directly addresses the second objective and supports the other two. The overall goal of this project is to develop Indices of Aquatic Ecosystem Health that can be used on an on-going basis to support watershed management planning in the Beaver River Watershed and the Boreal Transition Ecoregion. The ultimate outcome is to create a standardized index that can be used over time to monitor, report, and run scenarios on the state of aquatic ecosystem health in the BRW.

Methodology

General Approach

The backbone of this project is statistical equations that were derived specifically in the same ecoregion as the Beaver River watershed (Table 1). These equations describe relationships between land use and aquatic ecosystem metrics. We define land use metrics that result in environmental changes in the watersheds of aquatic ecosystems as "driver variables" (drivers) of ecosystem change. "Response variables" are potential biological indicators of aquatic ecosystem conditions. For this project, we only use response variables that are validated, thus we use the term "indicators" in place of "response variables". From a scientific perspective, these driver-indicator relationships were developed using the Human Disturbance Gradient or Reference-Degraded Continuum approaches (Wang et al., 2008; Ciborowski et al., 2010). The source of drivers and indicators are a paper published in a peer-reviewed journal (Found et al., 2008), three reports (CPP Environmental, 2013a, b; Cantin and Johns, 2011), and a thesis (Norris, 2012). Statistical relationships from CPP Environmental (2013) were modified for the purposes of efficiency and simplification, with little effect on relationship significance and relevance. Specifically, we re-ran the TN multiple regression by substituting agricultural intensity for % of watershed as human disturbance and removing the Watershed Area metric. For Conductivity, we substituted % of watershed as agricultural land with % watershed as human disturbance. A summary of each study is included in Appendix B. Study sites were all located in the Boreal Transition Ecoregion.

Data & Analyses

Geoprocessing, that is, clipping land use layers with watershed or buffer polygons, was used to extract values for model coefficients. Land cover and lake surface area data were obtained from the Alberta Biodiversity Monitoring Institute (ABMI land cover and human footprint datasets, 2011). These data were chosen over others since they are updated regularly (every 5 years or so), and thus can be used for continuous modelling purposes. Since ABMI data does not cover Saskatchewan, we merged together ABMI (Circa 2010) and Circa (2000) datasets to form a complete land cover dataset for the entire Beaver River Watershed. Watershed areas (Base Features Fully Filled Watersheds), lake maximum depth (internal data), and lake type (DEEP, SHALLOW, MARSH) data were obtained from ESRD. Lake buffers (500 m) were created with GIS (ESRI ArcGIS 10.1). Anthropogenic disturbance was calculated as a percentage within each watershed and lake buffer polygon.

The stream index was developed as a multi-proxy approach that includes information from multiple sources, which support each other. It is meant as a comprehensive index of water quality and fish community suitability. The stream phosphorus export index component was completed according to the methods in Norris (2012). Briefly, phosphorus export by stream sub-watershed was estimated for pre-development (conversion of current developed areas to forest) conditions and current land uses (as determined by the ABMI Human Footprint dataset) using phosphorus export coefficients per land use category listed in Norris (2012). The ratio of phosphorus export for these two scenarios was used as an index of change in phosphorus export per sub-watershed as a consequence of development. This ratio was mapped by sub-watershed as an index of stream productivity. As an index of fish habitat suitability, stream segments of order > 6 that have a watershed with a phosphorus ratio (developed/reference) greater than 3.5, as per Norris (2012), were labeled as having poor habitat suitability. We focused on stream segments greater than order 6 since, by observation, these segments flow most of the time and thus have the potential for diverse fish communities. Norris (2012) found that streams in the Little Smoky River area with watersheds above a threshold of 3.5 experienced winter anoxia and had no arctic grayling. Because this threshold was developed in an entirely different part of the province and for a species of fish that does not exist in the Beaver River watershed, we mapped on-site winter oxygen data and a multi-metric fish index of biotic integrity (Cantin and Johns, 2011) on top of the phosphorus threshold results as a method of validation.

Table 1: Indicators used in this study. Only statistically-significant and meaningful ($P \leq 0.05$; $R^2 > 0.7$) relationships between aquatic ecosystem indicators and driver variables were included to ensure a high accuracy of modelling results.

Indicator category	Models that best describe change in indicator values
Overall occurrence[1] of sensitive waterbirds in lakes	**Common Loon** = 2.53 + 0.01(Buff_Forest) – 3.59(Type(MARSH))
	Great Blue Heron = -1.01 + 0.05(Buff_Forest) – 2.13(Type(MARSH))
	Common Merganser = -4.69 + 0.0001(SA) + 2.44(Type(SHALLOW)) + 0.04(Buff_Forest)
	Western Grebe = 0.001(SA) – 0.03(Buff_Forest) – 1.9(Type(MARSH)) + 1.51(Type(SHALLOW)) – 0.42
Lake water quality	$\text{Log}_{10}(\textbf{TN}) = 3.34 - 0.378(\text{Log}_{10}(Z_{max})) + 0.216(\text{Log}_{10}(\text{DIST}))$
	$\text{Log}_{10}(\textbf{Conductivity}) = 3.01 - 0.16(\text{Log}_{10}(\text{WA})) - 0.11(\text{Log}_{10}(\text{SA})) + 0.107(\text{Log}_{10}(\text{DIST}))$
Stream water quality and fish community suitability	Comparison of pre- and post- development watershed phosphorus export, as per Norris (2012). Incorporate on-site winter dissolved oxygen and fish IBI data.

Notes:

A positive or negative sign before the coefficient for each variable represents the direction of the relationship; no sign before a coefficient means that a positive relationship exists.

[1] estimated as probability of use, based on a resource selection probability function (RSPF)

Variables:
Buff_Forest = percentage of a 500 m buffer surrounding the lake as forest cover.
MARSH = a categorical variable <3 m deep at full supply level and having marsh-like characteristics throughout
SHALLOW = a categorical variable <3 m deep at full supply level without marsh-like characteristics
TN = total nitrogen concentration in water in µg/L.
Conductivity = electrical conductivity of water in µS/cm.
WA = watershed area in km^2.
Z_{max} = maximum depth of the lake in m.
DIST = percentage of watershed area as anthropogenic disturbance in %.
SA = surface area of the lake in km^2.

Results and Discussion

Lake Waterbirds

Common Loons and Great Blue Herons are common in the Beaver River watershed, with occurrences typically greater than 80% (Figure 2; Table 1). The few lakes in our dataset with relatively low occurrences for these species are small lakes with large marsh vegetation zones. The Common Merganser and Western Grebe are not very common in the sites included in this study. These two species prefer large shallow lakes (<3 meters maximum depth) with little marsh vegetation. The majority of the lakes with data in the Beaver River watershed do not fit under these criteria. Occurrence of Western Grebe is very low in the entire Beaver River watershed, which is consistent with its recent re-classification as a Threatened Species (July 2014). Occurrence of this species in the northern portion of the Beaver River watershed is particularly low, which is consistent with the northern limit of their habitat range in Alberta. Common Merganser occurrence is generally higher in the northern portion of the Beaver River watershed, which is consistent with less anthropogenic disturbance in the back-shore. Indeed, lakes in the Lakeland Provincial Park natural area have the highest Merganser occurrences.

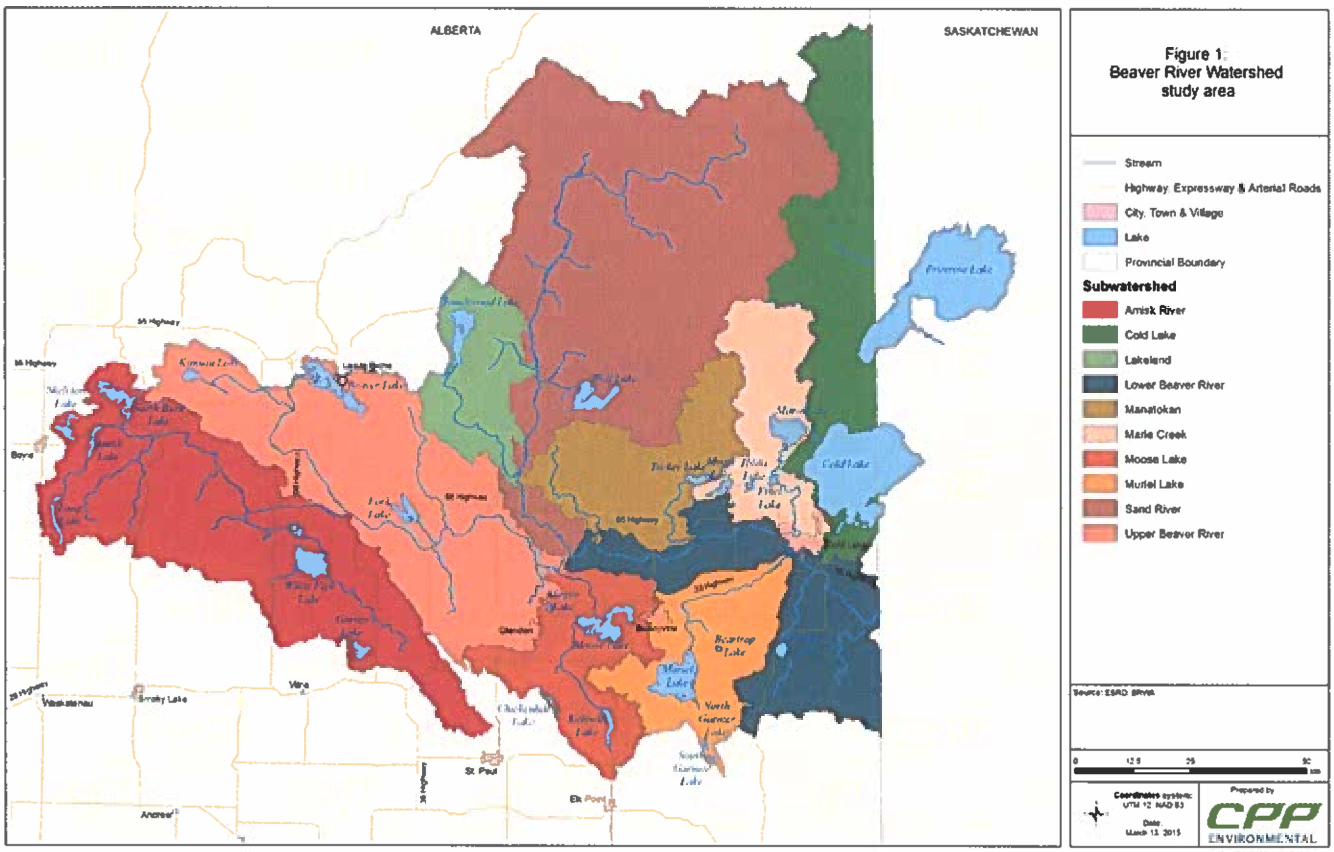


Figure 1: Beaver River Watershed study area

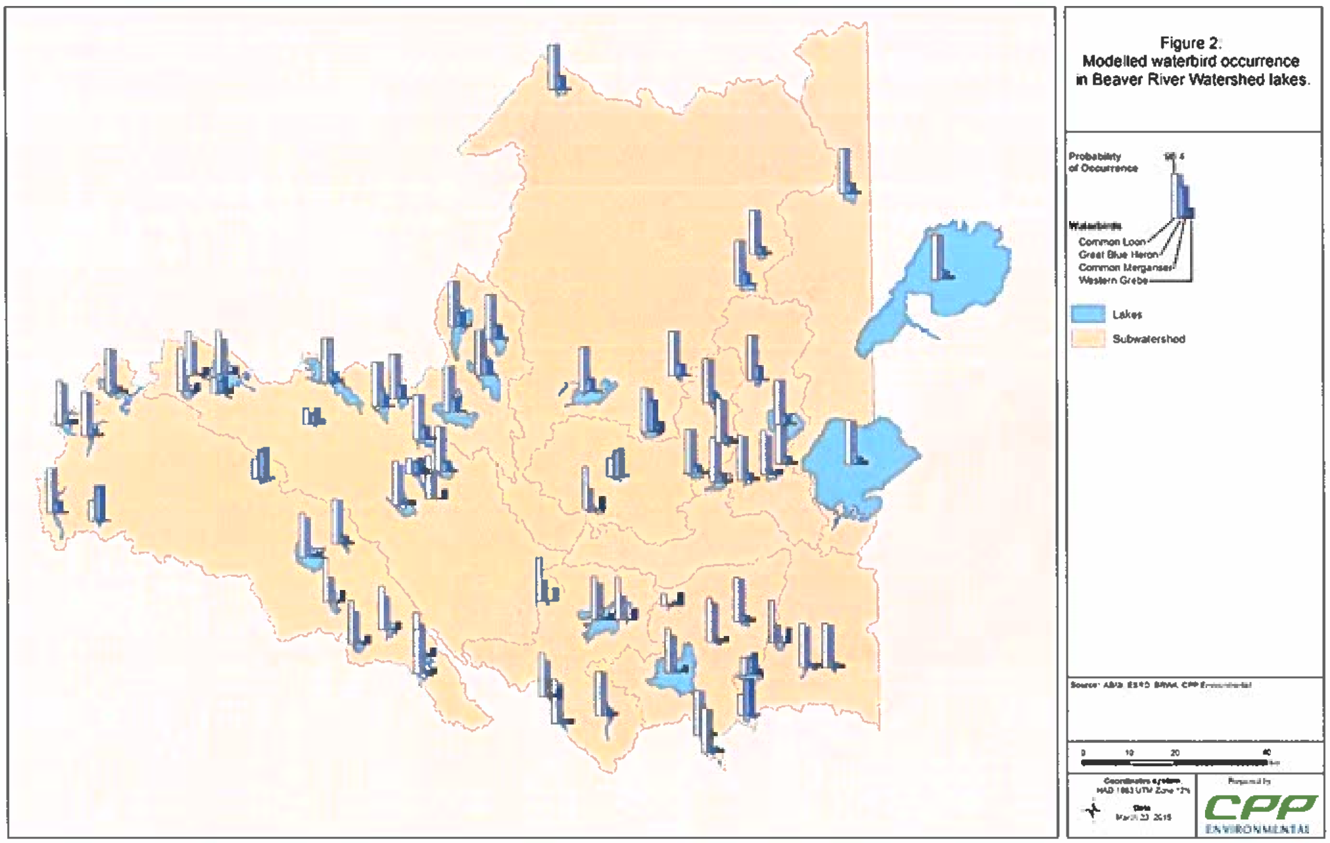


Figure 2.
Modelled waterbird occurrence in Beaver River Watershed lakes.

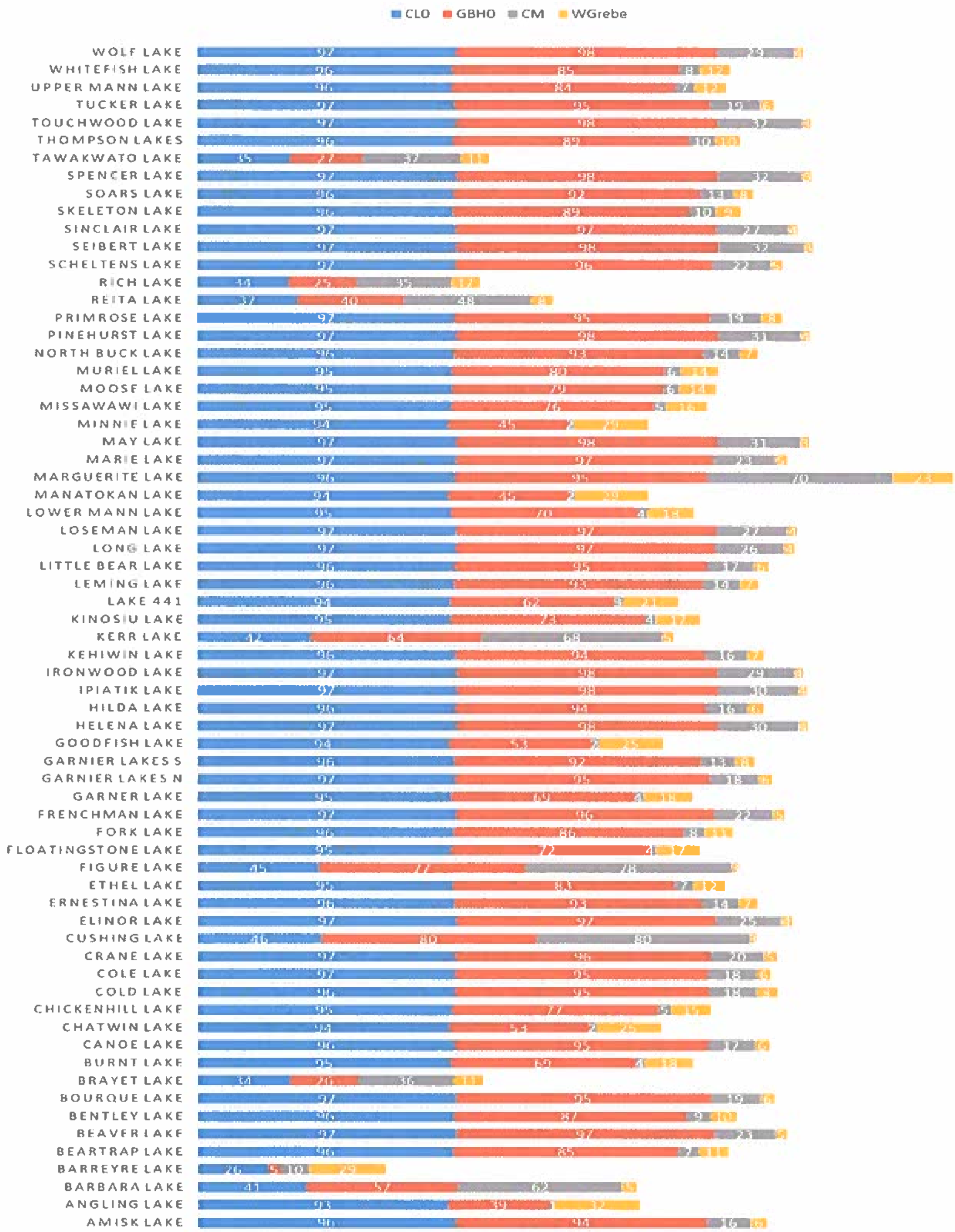


Table 1: Modelled Common Loon (CLO), Great Blue Heron (GBHO), Common Merganser (CM), and Western Grebe (WG) occurrence in Beaver River watershed lakes.

Lake Water Chemistry

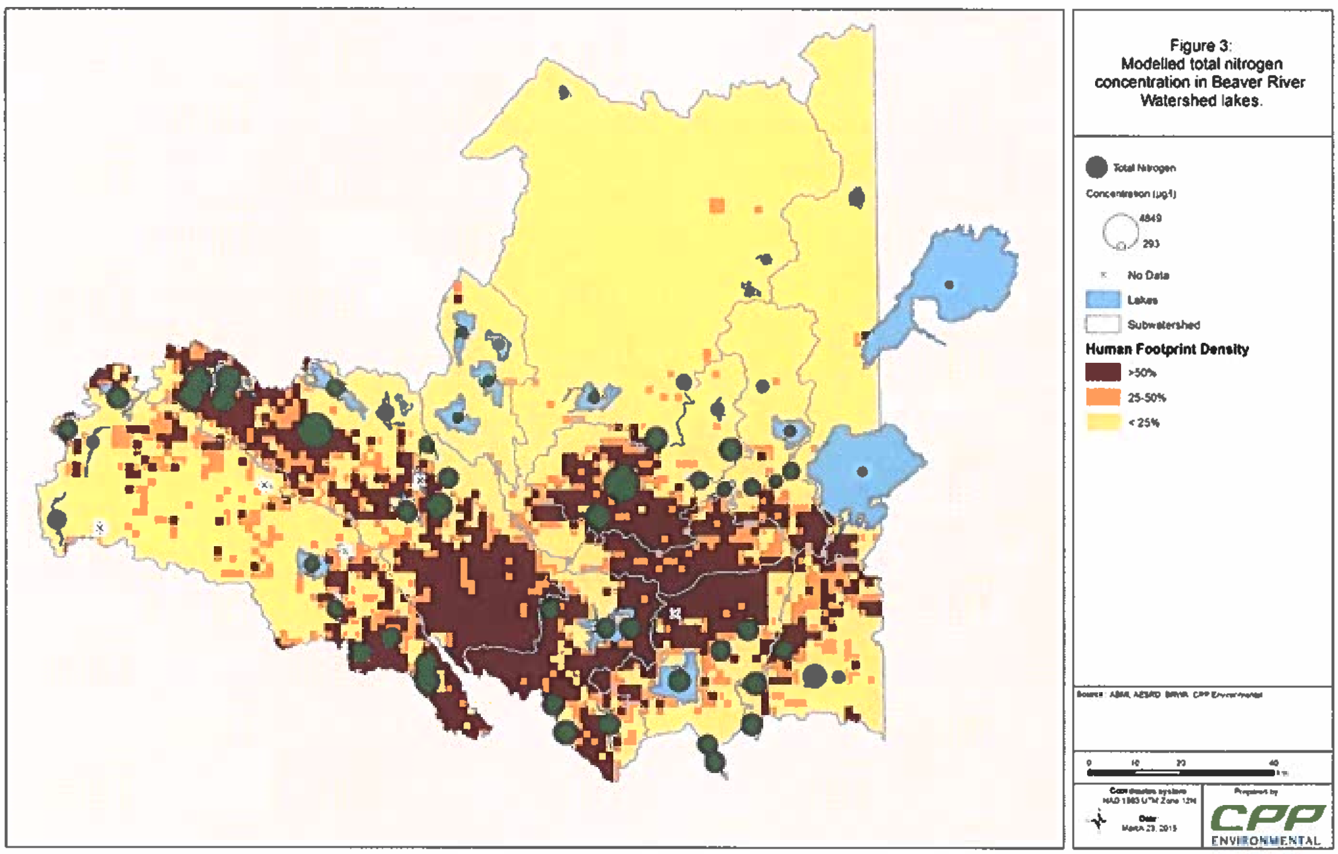
Modelled lake TN generally reflected human footprint density (Figure 3). TN was higher in the central and southern areas of the Beaver River watershed, where the human footprint is concentrated, and low in the relatively untouched lakes in more northern latitudes. This is consistent with the equation used for the model, which is not surprising since the total nitrogen regression model, which was modified from the original report, had a very good fit to the data ($R^2 = 0.86$). Conductivity is predicted by watershed area, lake surface area, and human footprint, thus it is difficult to discern spatial patterns on a map. However, conductivity is generally higher in areas where the human footprint is concentrated (Figure 4).

Modelled TN concentrations and conductivity derived through the modified models developed in this project were representative of measured concentrations, other than one outlier (Figures 5 and 6). The TN model has a relatively high degree of accuracy ($R^2 > 0.86$). However, it predicts a lower concentration for Muriel Lake than what was recently measured in the field. The conductivity model, although lower than nitrogen, has good accuracy ($R^2 \approx 0.7$). That said, it does not predict the conductivity of Muriel Lake very well. For our analysis, we excluded Muriel Lake from the model since the measured conductivity value was an extreme outlier. The model also predicts lower than measured conductivity concentrations for Moose Lake.

What makes Muriel Lake stand apart is the very high (> 4 times that of any other lake) lake surface area to maximum depth ratio. This high value means that the total amount of water in Muriel Lake is much more exposed to evaporation and wind effects than other lakes. A high evaporation effect will cause greater conductivity, particularly during an extended period of regional water deficit, as experienced in the Beaver River watershed (AENV, 2006). A high surface area to maximum depth ratio also causes a deeper lake mixing on average. TN concentration is highly related to maximum depth because shallow lakes in Alberta have more frequent polymixis (water column mixing to the lake bottom), which causes nutrient loading from the sediments during the summer when water quality samples are typically taken (Taranu et al. 2010). Due to this exceptionally high lake area to maximum depth ratio, Muriel Lake is likely polymictic most of the time and receives large sediment loads. Thus, our model is likely to under-predict nitrogen and conductivity for lakes that have high surface area to maximum depth ratios. We recommend that outliers in surface area to maximum depth ratio be excluded from modelling using our water quality equations. Accordingly, Figure 4 displays measured, rather than modelled, values for Muriel Lake.

After averaging results by sub-watershed, the Upper Beaver River, Mooselake River, and Manatokan and Jackfish sub-watersheds have the highest average lake TN concentrations (Figure 7). However, the variability (standard deviation) in two of these three watersheds is high, indicating much variability from one lake to the next (some lakes are high and some lakes are low). Such presentation of this type of data isn't particularly useful in cases where the goal is to manage lakes with the highest nutrient concentrations. Thus, information is lost when data is lumped in this way. Our results demonstrate that, although this has become a standard in state of the watershed reporting, this method is not appropriate in all circumstances, particularly when indicator health is controlled by localized factors. To report on or manage lake water quality and waterbirds, we recommend site-level rather than watershed-level assessments. With respect to regional management plans, appropriate management strategies can be developed for relatively good (e.g., green – continue to monitor), fair (e.g., yellow – conservation measures may be required; more intensive monitoring), and poor (e.g., red – conservation and restoration focus) sites within a region or sub-region.

Figure 3:
Modelled total nitrogen concentration in Beaver River Watershed lakes.



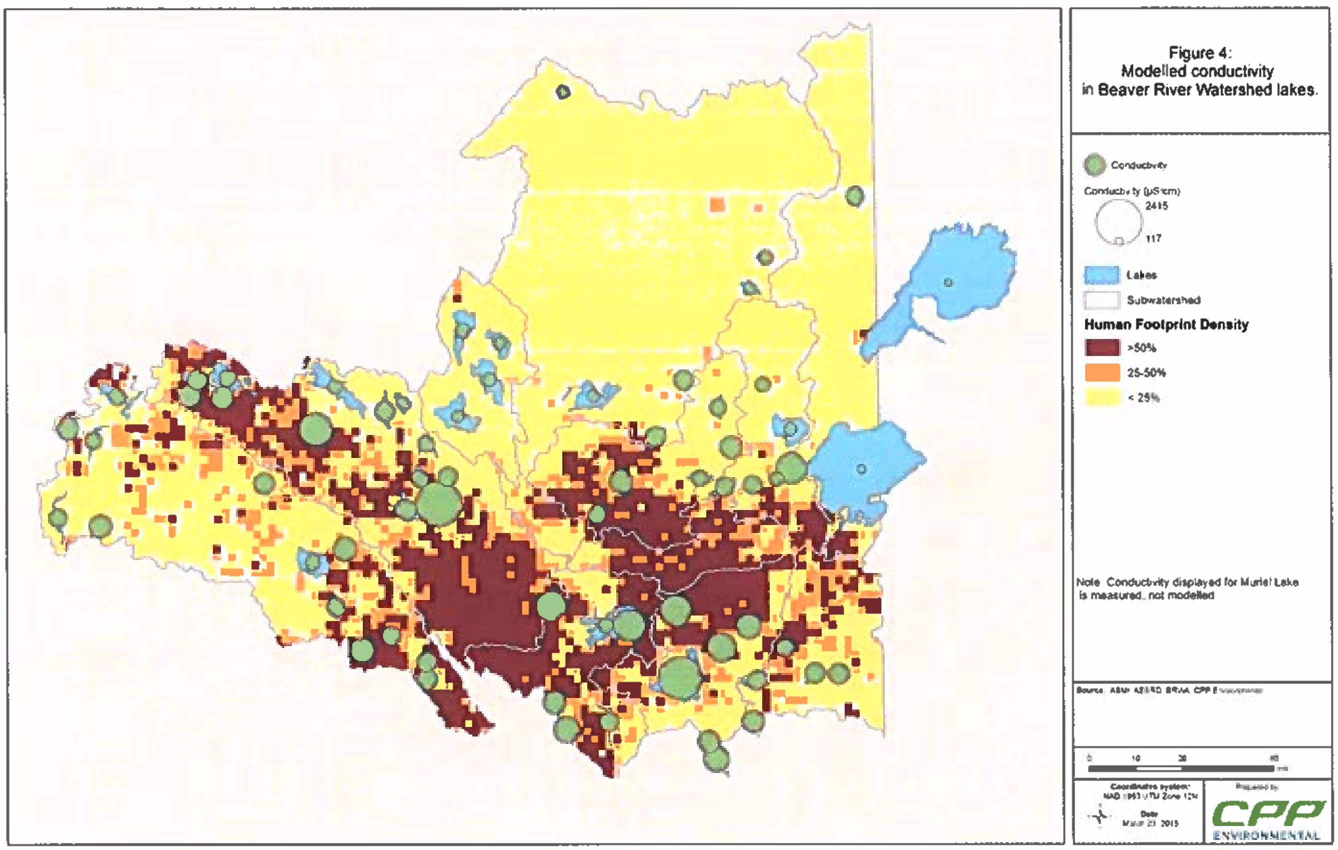


Figure 4:
Modelled conductivity
in Beaver River Watershed lakes.

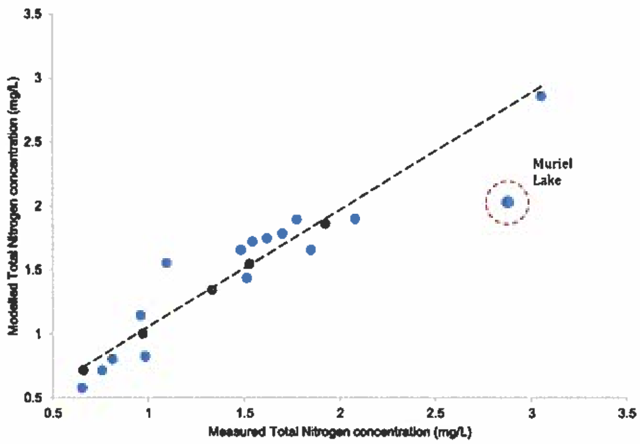


Figure 5: Relationship between measured and modelled total nitrogen concentrations in Beaver River watershed lakes.

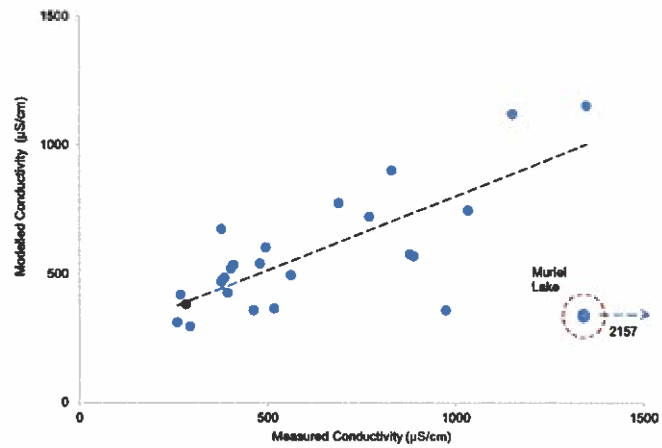


Figure 6: Relationship between measured and modelled conductivity in Beaver River watershed lakes.

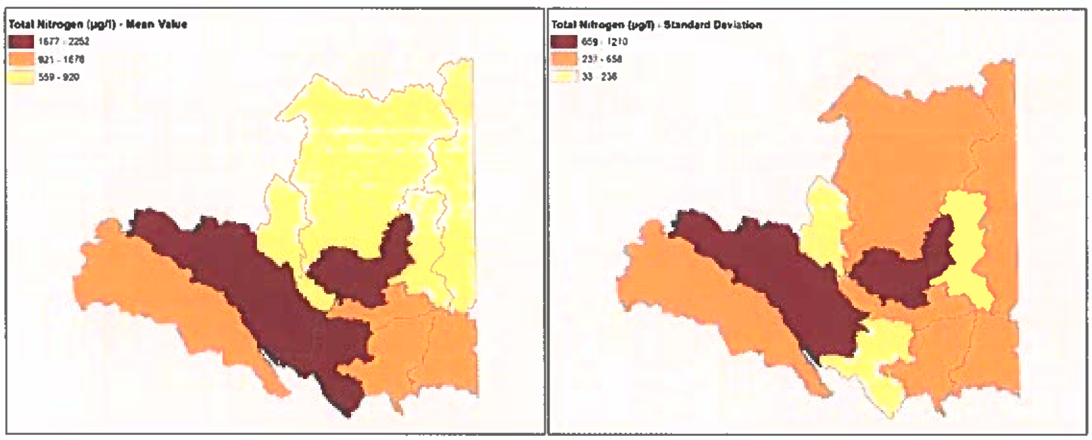


Figure 7:
Mean and standard deviation of modelled total nitrogen concentration in Beaver River Watershed lakes, by sub-watershed.

Source: ABMI AESRD BRWA, CPP Environmental

0 20 40 80 km

Coordinates system:
NAD 1983 UTM Zone 12N

Date:
March 13 2016

Prepared by
CPP ENVIRONMENTAL

Stream Water Quality and Fish Community Suitability

Phosphorus production (as indicated by the ratio between pre- and post-disturbance phosphorus export; see Norris, 2012), is highest in the Upper Beaver River, Mooselake River, Muriel Creek, and Manatokan and Jackfish sub-watersheds, coinciding with high-disturbance areas. Measured winter dissolved oxygen concentration along the Beaver River is low where watershed phosphorus production is high (Figure 8). Our results are consistent with those developed in the Grande Prairie area by Norris (2012), for a similar ecoregion as that of our study (Boreal Transition). Reaches of the Beaver River that experience winter anoxia generally also have a watershed that has a pre- to post-disturbance phosphorus export ratio above 3.5. These class 6 reaches, and those upstream (i.e., Amisk River) have very poor fish communities, as measured by a fish index of biotic integrity. The fish community in the Beaver River upstream of the Sand River is dominated by White Sucker and Brook Stickleback, which is indicative of highly stressed conditions.

Recommendations

The models collated and created for this project can be used to generate scenarios to inform decision-making, but true to all models; they should not be used for predicting specific future outcomes (Box and Draper, 1987). With information such as lake surface area, lake maximum depth, lake type (marshy vs open water), land cover, maximum depth, and watershed area, we modelled lake waterbird (Common Loon, Great Blue Heron, Common Merganser, Western Grebe) occurrence, lake water quality (nitrogen and conductivity), and river fish community suitability.

To increase the number of sites that can be modelled, we recommend collection of the following additional information:

- Lake maximum depths, which are used to estimate total nitrogen concentrations (and total phosphorus concentrations, if these are to be modelled in the future). Since the total nitrogen model is very sensitive to maximum depth, it is important to obtain an accurate measurement through bathymetric mapping of lake basins.

- MARSH/SHALLOW lake characterization data, which are used to model waterbird occurrence, are not readily available. Typing lakes in this way can be completed through remote sensing technologies but before that can happen; criteria for these designations must be published though consultation with wildlife biologists from ESRD, who created these metrics.

The models developed through this study can be immediately applied to other areas within the Boreal Transition Ecoregion, and cautiously applied to other ecoregions. When applied to other ecoregions, model validation, using ecoregional data, must be applied.

Acknowledgements

The indices used in this report are a culmination of work completed over the past decade by numerous individuals and organizations. We thank the following people and organizations for supporting this project:

- The Alberta Lake Management Society (ALMS) and ESRD who collected the lake water quality data that was used to refine model equations. Without the support to ALMS and its volunteer monitors, this study would not be possible;

- ESRD, who funded the project, collected waterbird data, supported the publication of Christine Found's paper, and generously supplied the geospatial data for the project;

- Grant Chapman (Senior Wildlife Biologist, Lac LaBiche, ESRD), and Mara Erickson (Alberta Fish and Game Association) who kindly offered their time to help re-construct methods used in Found (2008);

- The Alberta Conservation Association, who spearheaded intensive field surveys in the Beaver River, which allowed us to know the status of the fish community;

- The Alberta Biomonitoring Institute for creating such valuable products as the land use geo-spatial layer;

- Jordan Walker (ESRD), Mark Boyce (U. Alberta), and Michael Sullivan (ESRD), who reviewed the scope of work for the project; and finally

- The Beaver River Watershed Alliance guided the project to successful completion.

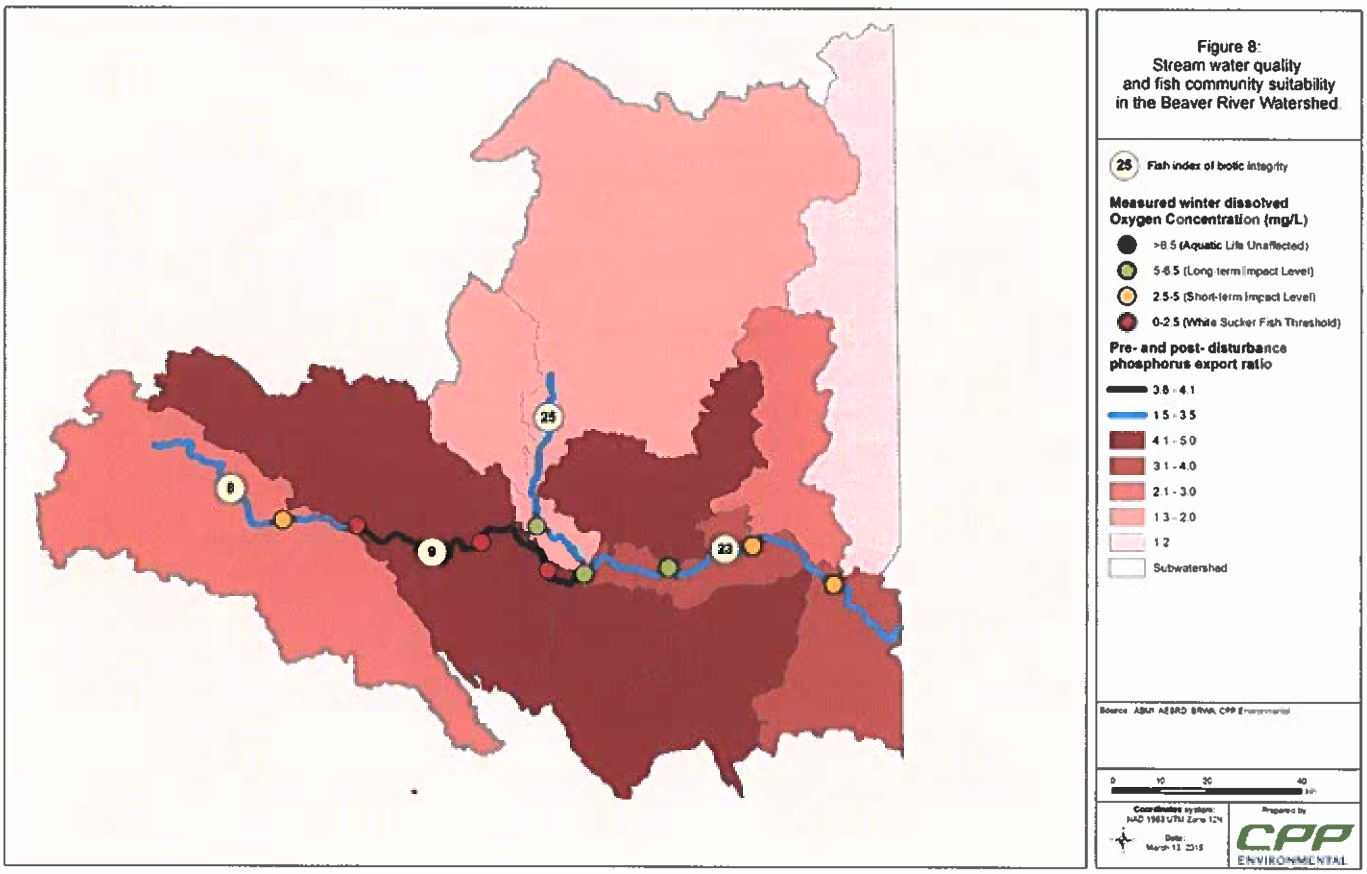


Figure 8:
Stream water quality and fish community suitability in the Beaver River Watershed

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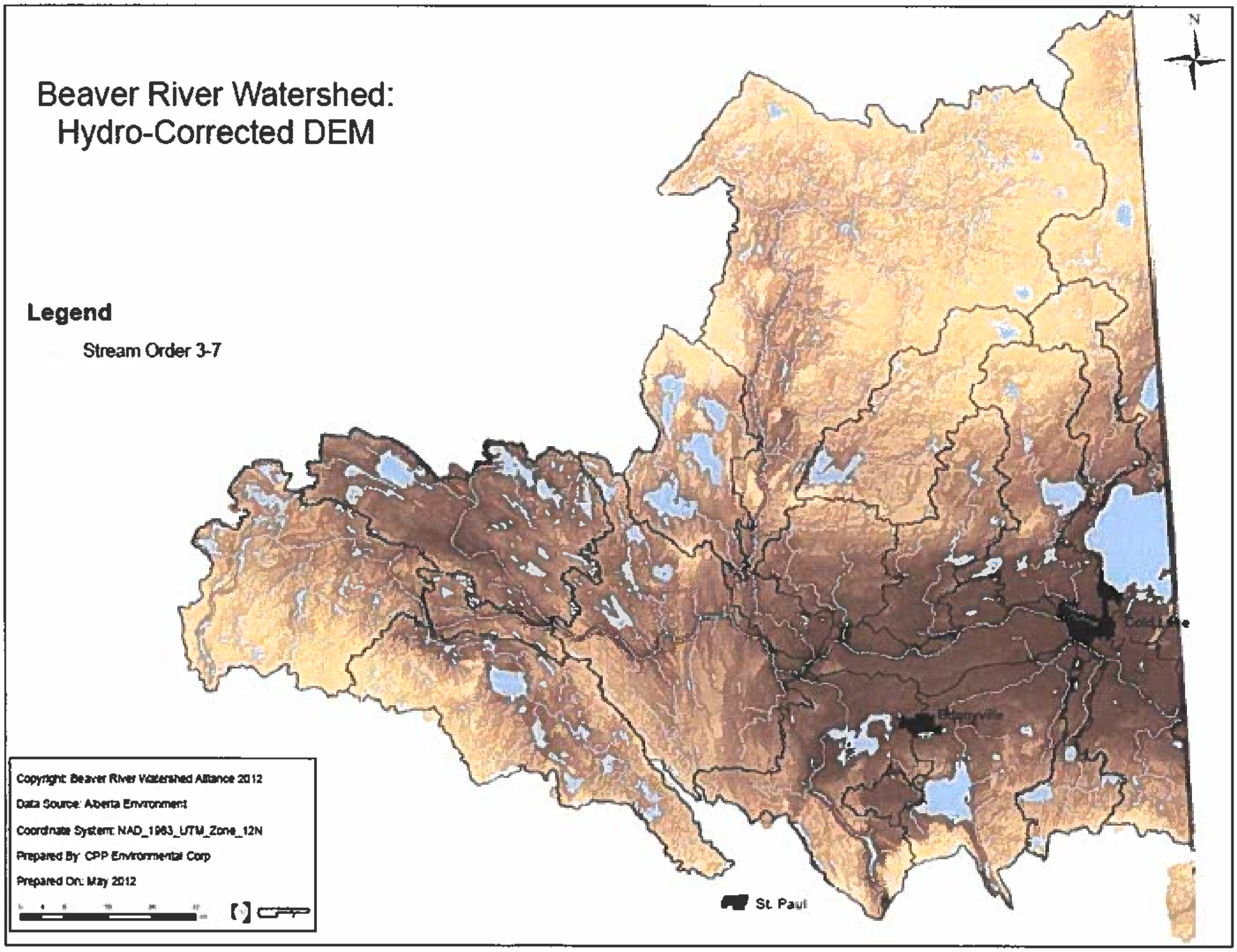
Appendix A – Beaver River Watershed Maps


Beaver River Watershed:
Hydro-Corrected DEM
Legend
Stream Order 3-7
N
St. Paul
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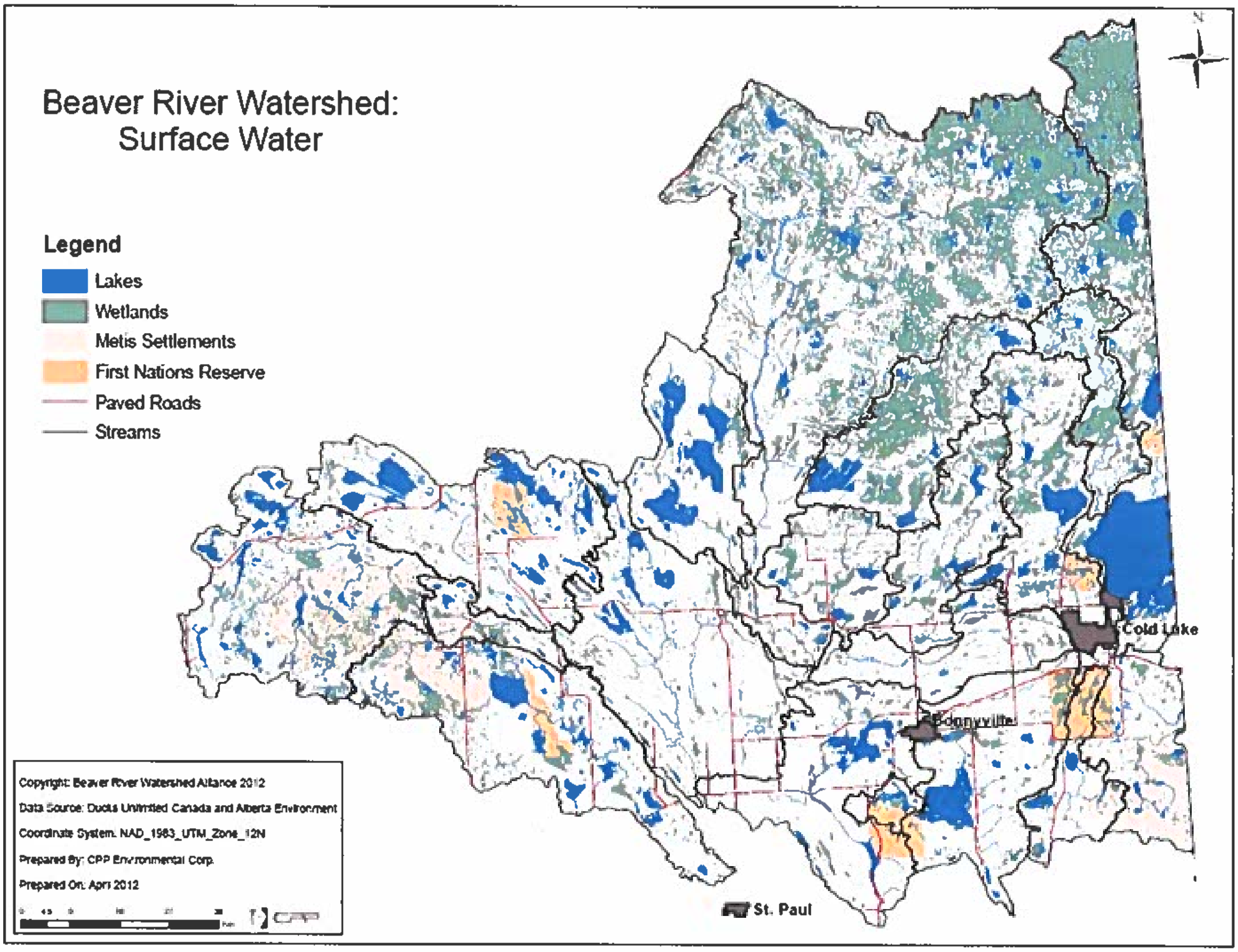
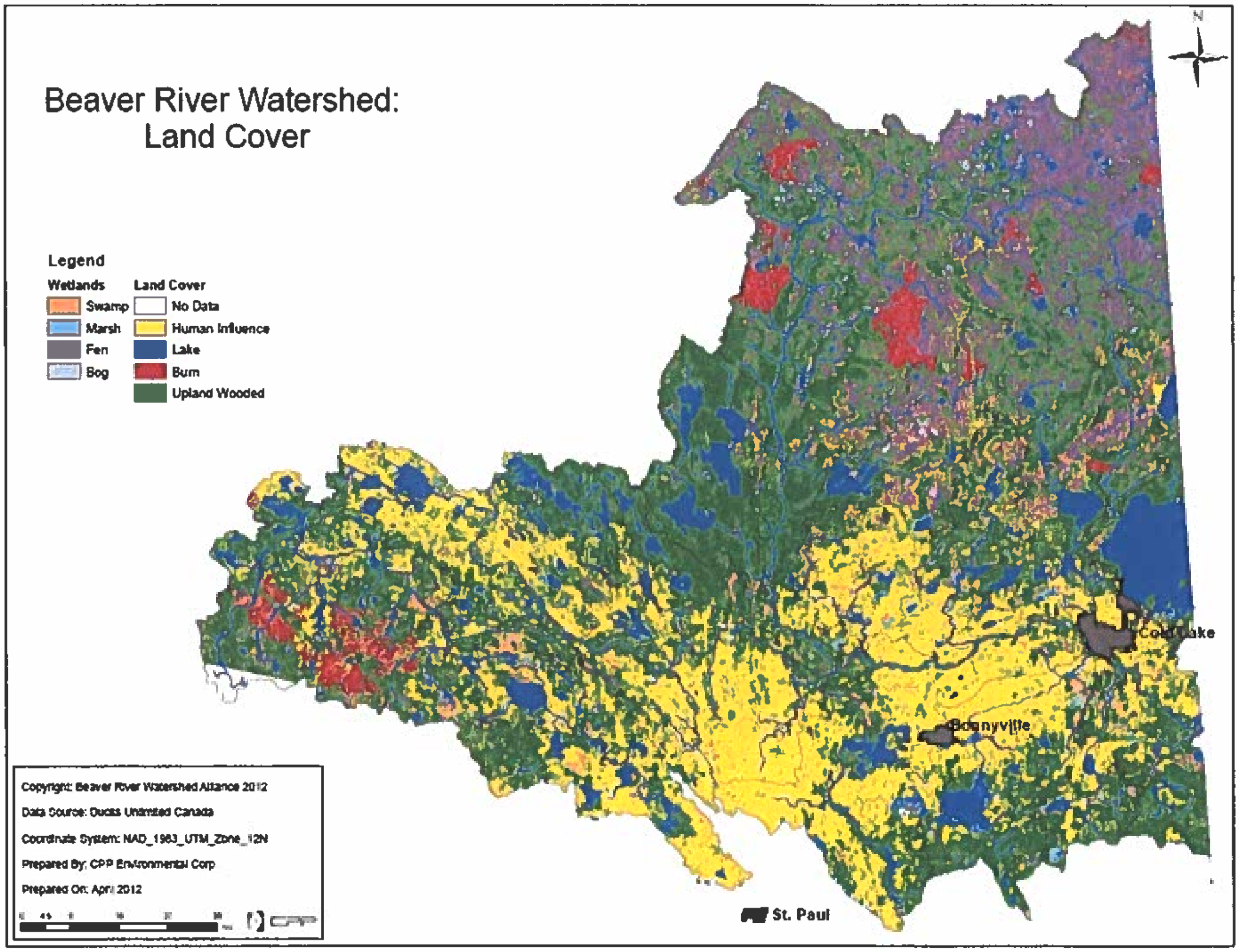
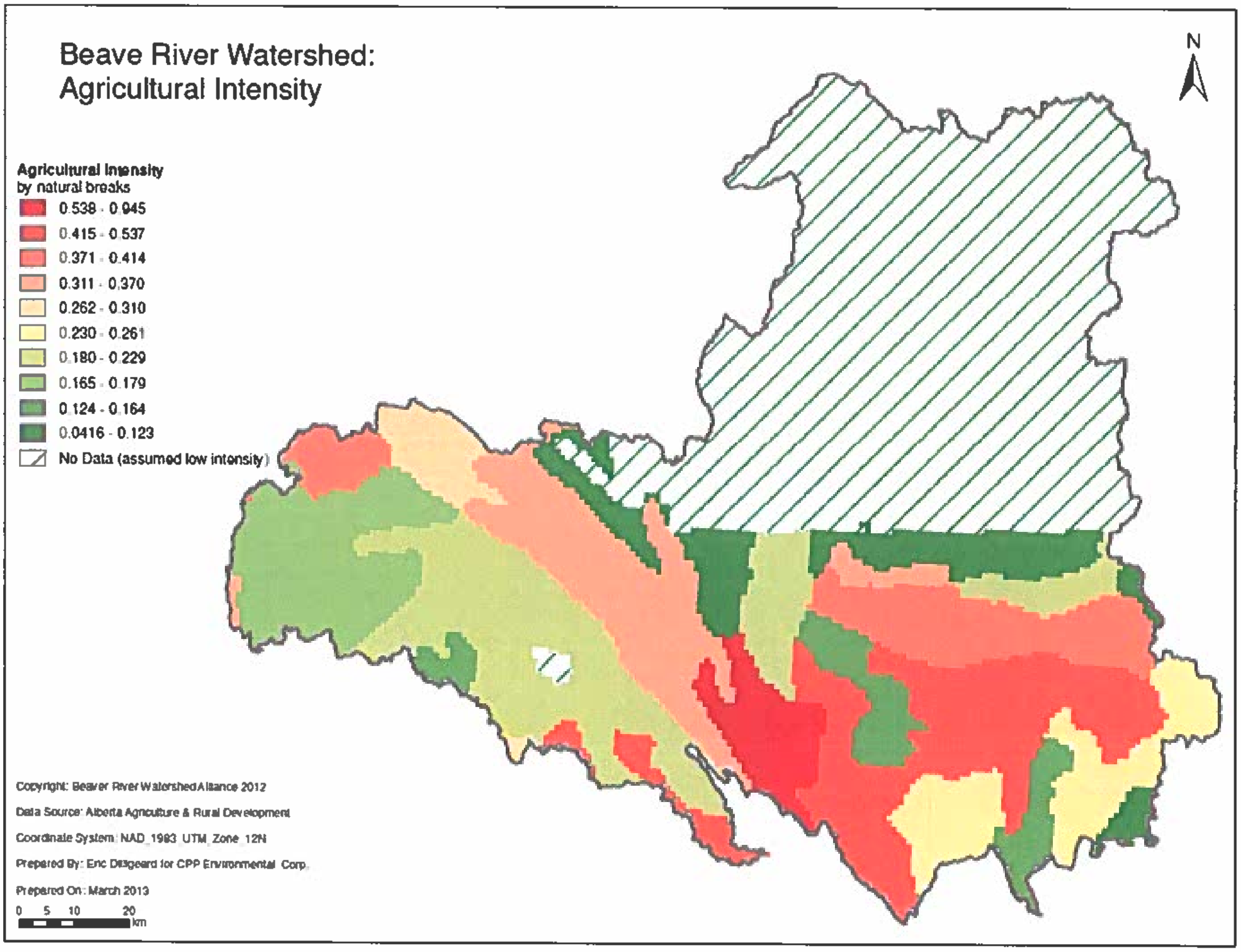
Data Source: Alberta Environment
Coordinate System: NAD_1983_UTM_Zone_12N
Prepared By: CPP Environmental Corp
Prepared On: May 2012

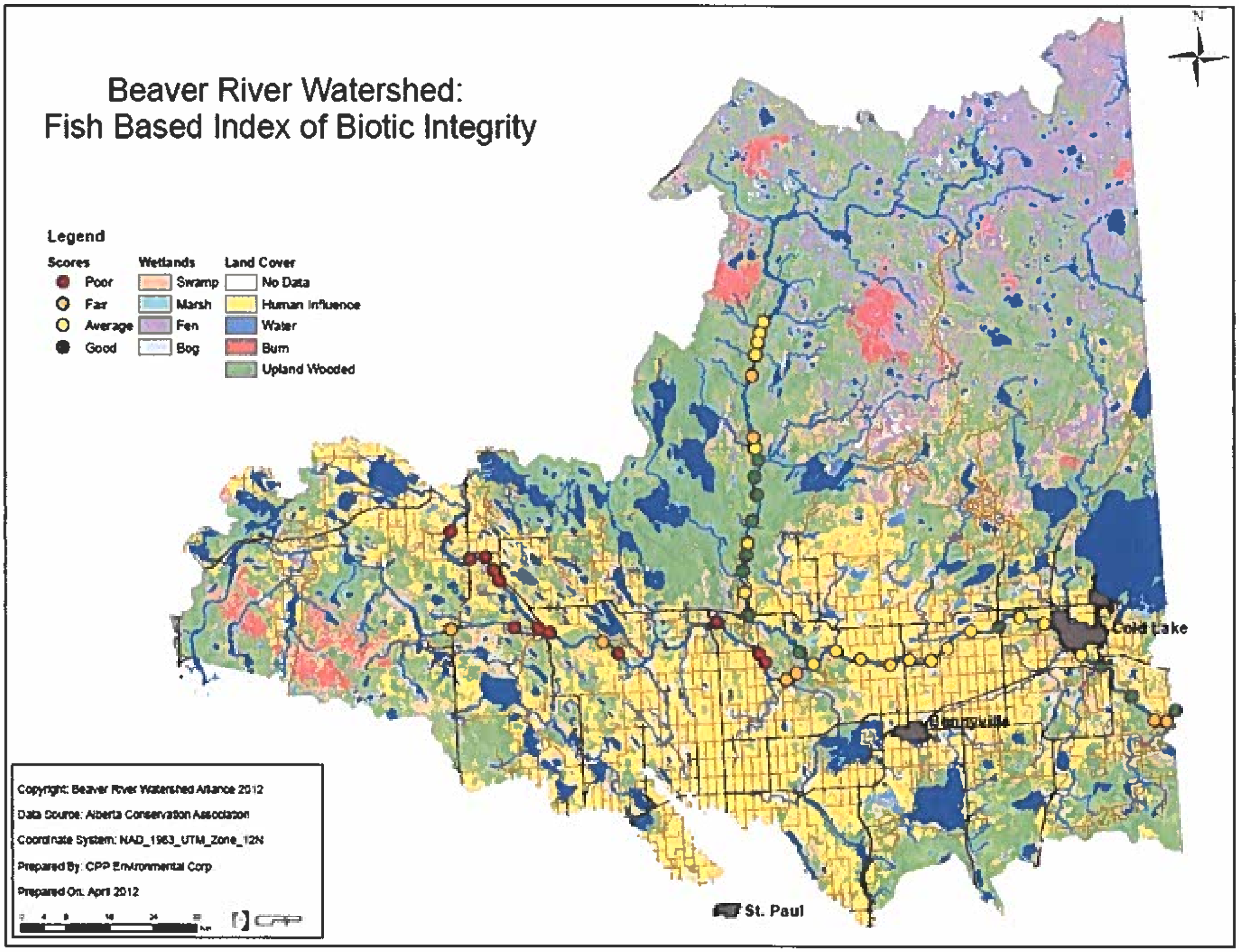


Beaver River Watershed:
Surface Water
Legend
Lakes
Wetlands
Metis Settlements
First Nations Reserve
Paved Roads
Streams
Cold Lake
Bonnyville
St. Paul
Copyright: Beaver River Watershed Alliance 2012
Data Source: Ducks Unlimited Canada and Alberta Environment
Coordinate System: NAD_1983_UTM_Zone_12N
Prepared By: CPP Environmental Corp.
Prepared On: April 2012



Beaver River Watershed:
Land Cover
Legend
Wetlands
Swamp
Marsh
Fen
Bog
Land Cover
No Data
Human Influence
Lake
Burn
Upland Wooded
Cold Lake
Bonnyville
St. Paul
Copyright: Beaver River Watershed Alliance 2012
Data Source: Ducks Unlimited Canada
Coordinate System: NAD_1983_UTM_Zone_12N
Prepared By: CPP Environmental Corp
Prepared On: April 2012


Beave River Watershed:
Agricultural Intensity
N
Agricultural Intensity
by natural breaks
0.538 - 0.945
0.415 - 0.537
0.371 - 0.414
0.311 - 0.370
0.262 - 0.310
0.230 - 0.261
0.180 - 0.229
0.165 - 0.179
0.124 - 0.164
0.0416 - 0.123
No Data (assumed low intensity)
Copyright: Beaver River Watershed Alliance 2012
Data Source: Alberta Agriculture & Rural Development
Coordinate System: NAD_1983_UTM_Zone_12N
Prepared By: Eric Dillgeard for CPP Environmental Corp.
Prepared On: March 2013
0 5 10 20
km


Beaver River Watershed:
Fish Based Index of Biotic Integrity
Legend
Scores
Poor
Fair
Average
Good
Wetlands
Swamp
Marsh
Fen
Bog
Land Cover
No Data
Human Influence
Water
Burn
Upland Wooded
N
Cold Lake
St. Paul
Copyright: Beaver River Watershed Alliance 2012
Data Source: Alberta Conservation Association
Coordinate System: NAD_1983_UTM_Zone_12N
Prepared By: CPP Environmental Corp
Prepared On: April 2012

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Appendix B – Summary of Foundational Publications

Found et al. (2008)

Examined habitat characteristics associated with presence or absence of 16 waterbird species on 113 lakes in the Boreal Transition Zone from 2001-2006. GIS was used to measure the amount of forested vegetation and land-use development within a 500 m buffer surrounding each of the study lakes. Several other variables identified in the literature as being potentially important predictors of waterbird occurrence and breeding activity (e.g., recreational index, occurrence of fish species, water pH, water clarity) were also included in habitat models. Univariate analyses were first used to examine the relationship between occurrence and each habitat variable. Logistic regression was used to predict the overall and breeding occurrences of each waterbird species. These were ranked using Akaike's information criterion (AIC_c). The best predictive models were selected based on the lowest AIC_c value. Models in this study have highlighted several habitat features that are important predictors of where waterbirds will occur, such as forested buffers, sufficient prey base, and emergent vegetation. The best habitat models showed that vegetated lake buffers and minimal anthropogenic development were key features for some waterbirds. We included in our model these species (Common Loon, Common Mergansers, and Great Blue Herons). Common Loons, in particular, have been repeatedly documented to be sensitive to human presence and shoreline development (Kelly 1992; Stockwell and Jacobs 1992; Newbrey et al. 2005), and thus is a good indicator of anthropogenic disturbance.

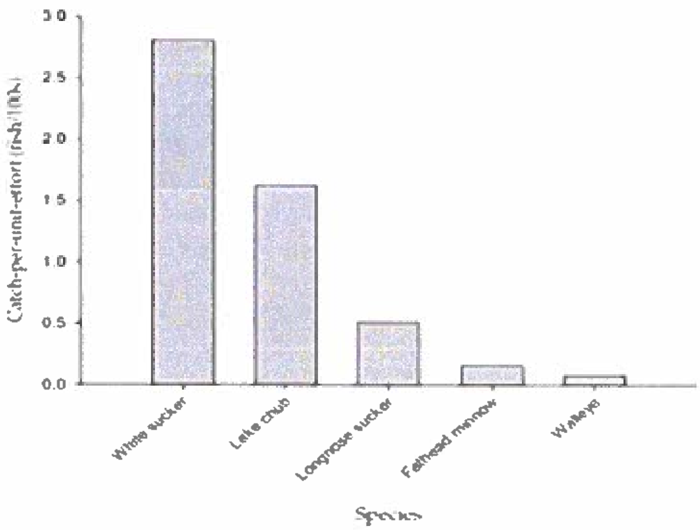
CPP Environmental (2013a)

Relationships were derived between the water quality of 25 lakes (sampled between 2002 and 2011) in the Beaver River Watershed and landscape metrics encompassing lake morphometry, watershed geography, and land cover and use. Metrics within each landscape group were analyzed against water quality variables to determine potential landscape indicators of each water quality parameter. Simple linear regressions were performed between each water quality and landscape metric to identify candidate landscape metrics to include in subsequent model analyses. Stepwise Akaiki's Information Criteria (AICc) was then performed to test each water quality parameter against several candidate landscape metrics. A Spearman's correlation matrix was performed that included all landscape metrics and highly-correlated metrics ($p < 0.05$) were not redundantly included in AIC models. Final variables from the AIC model were included in a multiple regression model for each water quality parameter. In general, both natural landscape factors, such as lake depth and watershed size, as well as human disturbance factors, such as agricultural intensity other land uses, were significantly related to nutrients, ions and metals in lakes.

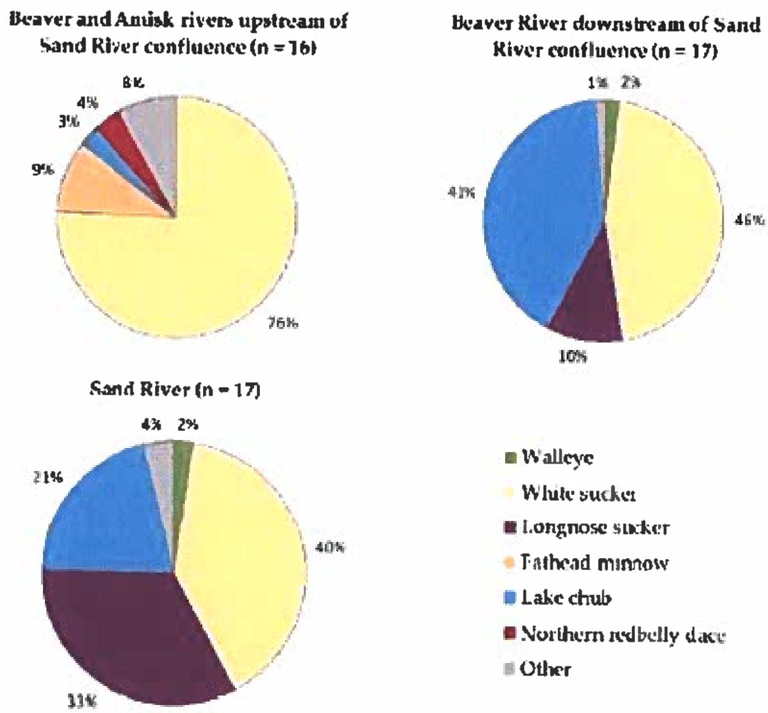
Cantin and Johns (2011)

Using boat electrofishing, Cantin and Johns (2011) sampled fish at 50 sites on the Beaver River, the Sand River, and the Amisk River, in the Beaver River watershed. The fish community was rolled up into a multi-metric Index of Biotic Integrity (IBI). They developed 13 candidate metrics based on the fish community and screened them for responsiveness to disturbance using multiple regression and Akaike's Information Criterion (AICc). To avoid redundancy, the 13 candidate metrics were screened using a Spearman's rank correlation test. Five metrics (percentage of invertivorous cyprinids, percentage of benthic invertivores, percentage of omnivores, percentage of lithophils, and percentage of carnivores) were significantly related to human disturbance and were used to calculate the IBI. Road density had the strongest relationship with the IBI (thus, the fish community).The upper Beaver and Amisk rivers had the lowest IBI values, reflecting poor aquatic health, characterized by a high number of fish species that are tolerant of habitat degradation.

Seventeen fish species were caught and a total of 5,719 fish were caught. Of these, 52% were white sucker, 31% were lake chub, 9% were longnose sucker, 3% were fathead minnow, and 1% were walleye. Sportfish species (walleye and northern pike) represented less than 2% of the catch. The pattern of species composition observed in 2009 to 2011 was similar to those reported during the 1970s and 1980s; sucker species dominated the catch. However, back then, the relative abundances of walleye and northern pike were much higher (as high as 7% and 23%, respectively). Indeed, interviews with long-time anglers in the watershed indicate that sportfish have decreased in size and abundance over the past 30 years.



The distribution of fish species were described for 3 reaches of the Beaver River: 1) Beaver and Amisk rivers upstream of the Sand River confluence; 2) Sand River; and 3) Beaver river downstream of the Sand River confluence. This data shows that white sucker was the predominant fish species throughout the tributaries. The lower Beaver River and Sand River have similar fish communities, comprised primarily of lake chub, longnose sucker, and while sucker. The upper Beaver and Amisk rivers have a much different fish community, dominated by species that are tolerant of pollution and stress (i.e., white sucker, fathead minnow). Fathead minnow makes a notable appearance in this reach. This reach also does not currently support long-lived sport species.



CPP Environmental (2013b)

In February 2013, a winter oxygen survey was completed on sites along the Beaver River. Essentially, oxygen concentrations are at concentrations detrimental to fish health in the upper reach of the Beaver River. The Sand River has the highest oxygen concentrations in the watershed, which keeps the lower Beaver River at above critical levels. This is reflective of total phosphorus concentrations, which are 3 times higher in the upper Beaver River reach (average of 0.21 mg/L), as compared to the other two reaches (average of 0.07 mg/L). In the summer, oxygen concentrations are reasonably high (about 8 mg/L on average) in all reaches.