TECHNICAL PROTOCOL

FOR THE FRESHWATER THREATS ASSESSMENT

WWF-CANADA

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CONTENTS

1 INTRODUCTION

WWF-Canada's Freshwater Threats Assessment provides a set of key indicators that identify the current stressors across all of Canada's freshwater systems. Using metrics and a scientifically credible methodology, the framework provides a broad scale analysis and classification of current threats and stresses to freshwater systems. The threats assessment is aimed to be used in combination with WWF-Canada's Freshwater Health Assessment. While the health assessment provides information to help understand *what* the current state of the watershed is, the threats assessment aims to inform *why* a watershed is in that state. For instance, a watershed that may see low scores in water quality in the Freshwater Health Assessment, will likely also see High Threat of Pollution in the Freshwater Threats Assessment. All together, the purpose of the two assessments is to help identify priority actions to ensure all waters in Canada are in good ecological condition by 2025.

There are seven threat indicators identified in this framework: pollution, habitat loss, fragmentation, water use, invasive species, alterations to water flow, and climate change. These indicators were developed in accordance with current literature on threats to freshwater systems, including Environment Canada's report on Threats to Sources of Drinking Water and Aquatic Ecosystem Health in Canada (Environment Canada, 2001). Other examples of identifying and mapping threats to freshwater habitats include work on cumulative stress in the Great Lakes (Allan, et al., 2012), mapping threats to Florida's freshwater habitats (Rickets & Stys, 2008), threats to imperiled freshwater fauna (Richter, Braun, Medelson, & Master, 1997) and a global assessment to human water security and river biodiversity (Vorosmarty, et al., 2010). The framework was also reviewed and vetted by several leading experts and academics, who aided in the process of refining our methodology in accordance with current analysis techniques in freshwater hydrology, ecology, and geomorphology.

Of the seven indicators, four are comprised of sub-indicators which quantitatively measure the level of a given component of a threat. The quantitative analysis was based on the data available, the quality of the data, and scientific rationale based on previous literature. The sub-indicators were then "rolled-up" to a final indicator score, and eventually to a final threat score. The analysis for each sub-indicator and indicator was conducted at the sub-watershed level, based on the Water Survey of Canada (WSC) "Sub-Drainage Area" (Natural Resources Canada, 2009). Eventually, the scores of the sub-drainage areas were amalgamated to the "Pearse" watershed level (Pearse, Bertrand and Maclaren, 1985).

The current version of the Freshwater Threats Assessment focuses on river systems, but has relevance to all freshwater ecosystems, including lakes and wetlands. Additionally, the Freshwater Threats Assessment is national in scope and is intended to provide a consistent framework across the entire country at a broad scale. Therefore, national datasets were used in the analysis. Variations in geology, and local or hyper local data and threats were not used in the analysis. Finally, the analysis was conducted as a relative ranking of threats across the country. For instance, a watershed with a low score indicates that the watershed ranks relatively low compared to all the watersheds in Canada. Absolute thresholds to quantify threat levels have not yet been defined.

Table 1: Indicators and sub-indicators used in WWF-Canada's Freshwater Threats Assessment

INDICATOR	DESCRIPTION	SUB-INDICATOR
POLLUTION	The presence in or introduction into the environment of a substance or thing that has harmful or poisonous effects. Includes pollution from industry (factories, mines, oil & gas), wastewater treatment, pulp and paper mills, agricultural production, etc.	Point-source pollution Pipeline incidents Transportation incidents Risk of water contamination from agricultural by nitrogen phosphorous, and pesticides
HABITAT LOSS	Loss of freshwater habitat (wetlands, bogs, fens, etc.) due to land conversion to agriculture, urban areas, and industry.	Land use/Land Cover Forest loss
FRAGMENTATION	Loss of connectedness between freshwater habitats due to intersection of roads, rail, and dams.	Fragmentation by dams Fragmentation by road and rail
WATER USE	Total amount of water removed from freshwater systems for urban, agricultural, and industrial uses.	Ratio of water intake to water yield
INVASIVE SPECIES	Species introduced intentionally or accidentally outside of their natural range, often resulting in loss of native species	Presence of invasive species
ALTERATION TO WATER FLOWS	The presence of large dams and reservoirs can cause ecological damage, degradation, harm natural habitats, and alter the natural flow of a river system.	Reservoirs/dam size
CLIMATE CHANGE	Change in amounts and temperature of water due to changing climate, affecting water availability and the natural history of the species living within the system.	Summer maximum temperature anomaly Winter mean temperature anomaly Spring precipitation anomaly Summer precipitation anomaly

2 POLLUTION

Water pollution poses significant risks and threats to water quality for drinking water and aquatic ecosystem health. Scientists and managers at the National Water Research Institute identified a total of 12 pollution related threats to our freshwater system (Environment Canada, 2001). These include: nutrients, acidification, endocrine disrupting substances, genetically modified organisms, pathogens, algal toxins, pesticides, long-range atmospherically transported pollutant, municipal waste-water effluents, industrial waste water discharges, urban runoff, and solid waste management practices (Environment Canada, 2001). Our goal in the Freshwater Threats Assessment was to quantify these pollution threats through developed metrics. Thus, the *Water Pollution* indicator was created through four sub-indicators: 1) point source pollution; 2) pipeline incidents; 3) transportation incidents of dangerous goods; and 4) agricultural run-off. The maximum threat level from the four sub-indicators was used for the final *Pollution* indicator results.

2.1 Point Source Pollution

Point source pollution has an impact on the water quality and overall health of a watershed. The release of pollutants to land, air, or water, makes its way into a water system and flows throughout the system, impacting the watershed downstream from the point-source. The National Pollutant Release Inventory is “Canada’s legislated, publicly accessible inventory of pollutant releases (to air, water and land), disposals and transfers for recycling” (Environment Canada, 2014).The inventory is mandated under CEPA, 1999, and includes over 6500 facilities across Canada, 346 substances, and reporting data from 1993-2013. Facilities include, but are not limited to: manufacturing facilities, coal-fired electricity generating stations, base metal smelters, crude oil refineries, steel mills, cement manufacturing facilities, pulp mills, oil sands facilities, and incinerators.

Data was collected on all substances released to water and land per facility. Emissions into air were omitted for the purpose of this analysis due to the complexity of tracking where air pollutant emissions may be deposited. For example, air emission in one watershed may result in the pollutant being deposited in a neighbouring watershed, depending on climatological variables and the substance released. The total releases into land and water were calculated per facility between the years of 1993-2013. Since the database is mandated and released units are standardized to metric tonnes, this made calculating a total release per facility possible despite the various release of substances. Substance releases provided in g or kg were standardized to metric tonnes. Dioxins and furans were excluded in this analysis as the total releases was reported in Toxic Equivalence, and therefore could not be standardized to tonnes.

In order to quantify threat within a watershed, a facility’s relative threat was weighted based on two factors: 1) total emissions into land and water and; 2) location in a watershed (downstream distance to basin outlet). If a facility was located in the upper catchment area of a watershed, it can be assumed to have a greater downstream impact within that watershed as the pollutant travels through the system. Conversely, if a facility was located closer to the outlet of a watershed, that facility has a shorter downstream distance and therefore less of an impact within that watershed. Inter watershed analysis was not conducted; thus it was assumed that a facility impacted only the watershed it was located in and had no impacts on nearby and neighbouring watersheds.

The downstream length from the facility to the basin outlet was calculated in each sub-drainage area. The downstream lengths were then reclassified into 4 categories using percentiles, and each percentile was given a weighting from 1 to 4. For instance, if the distance of the facility to the outlet was in the 4th percentile (longer distance), it was given a distance weighting of 4. Similarly, if the distance was in the 1st percentile (shorter distance), it was given a distance weighting of 1.

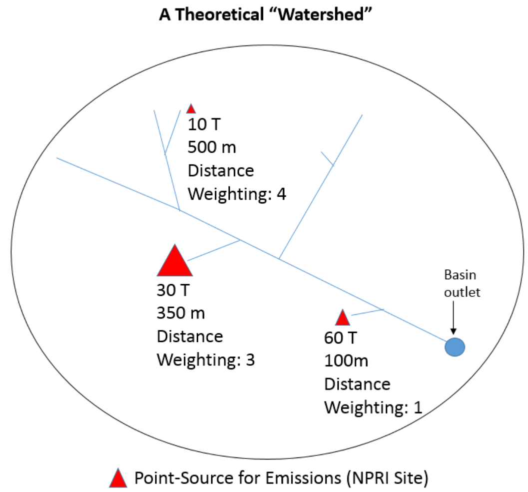


Figure 1: Theoretical example of distance weightings

The total release to land and water was multiplied by distance weighting. Total weightings were then summed per sub-drainage area. Finally, the sums were ranked in ArcGIS using percentiles (Appendix 1 Table 3).

2.2 Pipeline Incidents

Pipelines transport products such as crude oil, petroleum and natural gas from one point to another. A spill or leak of these products are toxic and harmful to freshwater species, plants and habitats and can have adverse effects on birds, fish and humans (The Pembina Institute: Sustainable Energy Solutions, 2009). Heavier oils will stick to sediments, rocks and debris at the base of the river bed and release toxins slowly over a long period of time. Lighter materials usually float along the surface and can take up to three days before evaporating. Failures from natural gas tend to be less harmful as the substance dissipates more quickly (The Pembina Institute: Sustainable Energy Solutions, 2009). Whether the spill occurs on land or in water, there is a risk that the products of the spill will find its way into our freshwater systems through groundwater or runoff. Pipeline spills and leaks are difficult and expensive to clean up and thus may have chronic affects over a long period of time (Vanderklippe, 2011).

Complete national databases on pipeline incidents are difficult to retrieve. Prior to April 2015, the National Energy Board (NEB), the federal regulator that oversees pipelines across provincial borders, had incomplete and unusable pipeline data. The *Pipeline Incidents* sub-indicator was developed using the dataset compiled by CBC in 2012. In 2012, the Canadian Broadcasting Corporation (CBC) retrieved data from the NEB through access-to-information request, and retrieved data that had several blanks, and data with non-standardized units. CBC cleaned the dataset and normalized the volumes of release, which NEB notes in a variety of units. CBC worked with experts to calculate the volume density for each substance type and ran the converted numbers by NEB. A total of 1,047 incidents were documented between 2000 and 2012. Pipeline incidents were mapped to the nearest town or populated area, since no geographic coordinates of the spill location were documented. Incidents were documented into several categories, including release of product, serious injury, fatality, equipment failure, fire/explosion, pipeline rupture, security, other event, or sometimes no event type was reported. Most of the incidents were documented to be in several of these categories. In many instances, despite the records noting a release, the total release volume was left as blank.

Only incidents with a reported spill volume were used in the analysis. Because of the difficulty in determining the threat of an incident if a spill size was not reported, these incidents were treated as "unknown threats". The total volumes released per event were summed per sub-drainage area. Finally, the relative threat of each watershed was determined using percentiles in ArcGIS (Appendix 1 Table 3). If all the pipeline incidents in a given watershed had no release volume, the watershed received an "Unknown Threat" score. Watersheds that had no reported pipeline incidents received a "No Threat" score.

The data source and extra information published by the CBC about issues of reporting can be found in the following links:

http://www.cbc.ca/news2/interactives/pipeline-incidents/

http://www.cbc.ca/news/pipeline-project-from-grainy-documents-to-interactive-map-1.2251803

2.3 Transportation Incidents

Similar to pipeline incidents, accidents related to the transport of dangerous goods via road and rail are harmful to freshwater systems. If leaks and spills are not cleaned up in time, dangerous and harmful products may find their way into our freshwater system through groundwater flow or surface runoff. Thus, these products can directly harm a freshwater species or habitat as it enters the freshwater system.

Data on the transport incidents from roads & rail was retrieved from an access-to-information request from Transport Canada Dangerous Goods Accident Information System. The database is mandated by the Transport Dangerous Goods Directorate, and regulates that any significant accidents be reported and documented. All accidents from dangerous goods were retrieved from 2000 to March 2015. Incidents included all forms of transportation (air, road, and rail) and locations of incidents were mapped to the nearest populated area.

For the purpose of our study, the total incidents were filtered to include only types that included the keyword of "spill" or "leak" and all other incidents were omitted. Incidents were also filtered to only include the consequence(s) of an incident that related to the environment. Incidents that were apparent to only have consequences to humans, property, or lost products were omitted. Finally, the database included a potential severity outcome of the accidents. The assessment is based on the known outcomes of the accident and the likelihood of a more severe effects in the future. The potential severity was classified into the following 5 categories by DGAIS:

1 –**Minor:** refers to an accident of little or no consequence under normal conditions. Little chance of escalation, little danger to life or serious long term environmental damage (aquifer, reservoir, water supply) unless grossly mismanaged.

2 –**Moderate:** refers to a potentially dangerous incident, not likely to be catastrophic, which poses a danger to life or environment (aquifer, reservoir, water supply) if not handled properly.

3 –**Major:** refers to a definitely dangerous incident which could be catastrophic under certain conditions of traffic, weather or inadequate response. Could easily escalate to catastrophic situation.

4 –**Severe:** refers to a high catastrophic potential, high probability of loss of life, serious injury or long term damage to environment (particularly aquifer, reservoir or water supply).

5 –**Catastrophic:** refers to considerable loss of life, serious injuries, and serious damage to the environment (particularly aquifer, reservoir or water supply) is certain or avoidable only with extreme good luck.

(DGAIS, 2015)

No information on the volume of release was provided. The final threat score was calculated using the potential severity ranking by DGAIS. Each incident was weighted by its potential risk. For example, a minor incident was given a score of 1, and a catastrophic incident was given a score of 5. The weighted score of each incident was then summed per sub-drainage area, to create a sub-drainage area score. The final classification for the *Transportation Incidents* sub-indicator was conducted using Jenks Natural Breaks in ArcGIS (Appendix 1 Table 3).

2.4 Agricultural Run-Off

Highly intensive agriculture can result in agricultural run-off of major contaminants into freshwater systems. These contaminants include the discharge of manure, fertilizers and pesticides, often used to improve agricultural crop yield. Three of the top contaminants from agricultural runoff include: nitrogen, phosphorous, and pesticides. The runoff of these contaminants can create adverse effects to freshwater, including algae blooms, and impacts to human health (Environment Canada, 2001).

The relative threat of agricultural run-off in each sub-drainage area was determined as a composite of 3 sub-sub indicators: 1) risk of water contamination by nitrogen; 2) risk of water contamination by phosphorous; and 3) risk of water contamination by pesticides. A dataset for each of the 3 sub-sub-indicators was retrieved from Agricultural Canada. The datasets downloaded had information on the relative risk of agricultural runoff based on polygons from the Soil Landscapes of Canada, which were classified from “Very Low” to “Very High”.

The polygon areas of the Soil Landscapes of Canada did not align with the Water Survey of Canada sub-drainage areas, and therefore the original shapefiles downloaded from Agriculture Canada were converted to raster format. The total area per class per contaminant was tabulated for each sub-drainage area, and divided by the total area of the sub-drainage area (equation 1).

$$SDA\ Risk_{xy} = \frac{Area_{xy}}{Total\ Area\ of\ Sub\ Watershed}$$

Equation 1

where x is the class (“Very Low”, “Low”, “Moderate”, “High”, or “Very High”) and y is the contaminant (nitrogen, phosphorous, or pesticide).

Finally, a weighted sum was taken from each classification (equation 2).

$$SDA\ Threat_y = (1 \times SDA\ Risk_{very\ low\ y}) + (2 \times SDA\ Risk_{low\ y}) + (3 \times SDA\ Risk_{moderate\ y}) + (4 \times SDA\ Risk_{high\ y}) + (5 \times SDA\ Risk_{very\ high\ y})$$

Equation 2

The weighted sum was calculated for nitrogen, phosphorous and pesticides individually, and were reclassified using percentiles to reflect “Very low” to “Very High” risks per sub-drainage area per contaminant. Finally, the maximum class from the 3 sub-sub-indicators was used as a final classification for the *Agricultural Run-Off* indicator (equation 3).

$$SDA\ Threat = Max(SDA\ Threat_{nitrogen}, SDA\ Threat_{phosphorous}, SDA\ Threat_{pesticides})$$

Equation 3

3 HABITAT LOSS

Land altered by humans and for human use can have significant impacts on the health of a freshwater system. Impervious surfaces (land that prevents filtration of water into the soil) can increase threats to freshwater wildlife. While the natural habitat is able to filter water before entering a watershed, increased paved surfaces, such as roofs, driveways, roads and parking lots reduce the natural function of the ecosystem (Theobald, Goetz, Norman, & Jantz, 2009; Stanfield & Kilgour, 2006). This reduction in natural function leads to increased run-off and pollutants entering the water. Additionally, altering the habitat for human use poses risk to species in the watershed. Urbanization, industrialization, loss of forestry, and increased agricultural lands are a threat to biodiversity and are a key indicator in the human development footprint. Metrics such as forest loss (Booth, Hartley, & Jackson, 2002; Environment Canada, 2001), land-use/land cover (Kilgour & Barton, 1999), and agricultural lands (Environment Canada, 2001) are often used for quantifying threats to the freshwater ecosystem.

For our analysis, habitat loss in each watershed was quantified through two sub-indicators: 1) The percent of the total watershed that has been converted to agricultural lands and artificial surfaces (urban and industrial areas); and 2) Percent of the total watershed that has experienced forest loss. Each sub-indicator was classified into 5 threat categories (“Very Low”, “Low”, “Moderate”, “High”, and “Very High”) using Jenks Natural Breaks in ArcGIS. The final *Habitat Loss* indicator was determined as a maximum threat of the two sub-indicators.

3.1 Land Use/Land Cover – Artificial Surfaces and Cultivated Lands

The *Land Use/Land Cover* sub-indicator was developed using artificial surfaces and cultivated lands as the key metrics. Converting natural landscapes to artificial surfaces and cultivated lands increased the overall imperviousness of the landscape, and thus decreases the natural ability of the ecosystem to filter rainfall, resulting in increased run-off. This runoff often carries the pollutants from urban, industrial, and agricultural landscapes and finds its way into our freshwater systems (Stanfield & Kilgour, 2006).

The percentage area of the watershed converted to cultivated lands and artificial surfaces was calculated per sub watershed. The data used for this analysis was retrieved from the GlobeLand30-2010 database developed by the National Geomatics Center of China. The GlobeLand30-2010 database uses Landsat TM5 and ETM + imagery at 30m resolution for land use classification across Canada in 2010. The land use and land cover is classified into 10 different classes: cultivated land, forest lands, grasslands, shrublands, water bodies, wetland, tundra, artificial surfaces, bareland, and permanent snow and ice. Of these 10 classes, cultivated lands and artificial surfaces are lands that have been altered by humans from their original natural state. The data can be downloaded in raster format, with tiles covering the entire globe, in WGS84 coordinate system. The overall accuracy of the Global30-2010 dataset reaches 80.33%.

Using the GlobalLand30-2010 dataset, the total area of cultivated land and artificial surfaces per sub-drainage area was found. The sum of these areas was then divided by the total land area of the sub watershed, to provide a percentage land converted for human use. The equation used is found below:

$$\%\ Human\ altered\ land\ = \frac{A_{CL} +\ A_{AS}}{A_{TL}} \times 100$$

Equation 4

where A_{CL} is the total area of cultivated land, A_{AS} is the total area of artificial surfaces, and A_{TL} is the total area of the sub-drainage area.

The land use/land cover sub-indicator was reclassified using Jenks Natural Breaks in ArcGIS using 5 categories (Appendix 1 Table 4).

Some key things to note in this analysis include that as a result of the use of percent change, a larger sub-drainage area may have received a lower score than a smaller sub-drainage area, despite having equivalent total area of land converted. In addition, the distribution of the altered land was not taken into consideration, i.e., concentrated areas of land conversion versus distributed altered lands across a watershed, therefore the risk may not be uniformly distributed. Finally, distance of converted land from the nearest river network was not considered in the analysis.

3.2 Forest Loss

Forests play a vital role in ensuring that a freshwater ecosystem remains healthy. Forests trap and store pollutants from rain, reduce storm runoff, and filter other pollutants such as sediments and fertilizers from urban and agricultural areas. In addition, forests ensure that the natural landscape along a river is kept stable by reducing soil erosion.

The *Forest Loss* sub-indicator was developed using the Global Forest Change Dataset, which was developed by the University of Maryland. The dataset is updated annually and is a time series analysis using Landsat images that characterizes forest change and forest extent at 30 m resolution. The dataset compiles both forest loss and forest gain. Forest cover Loss is defined as a disturbance from forest to non-forest state during the period of 2000-2013. Forest gain is defined as the inverse of loss.

The sub-indicator was developed using net forest loss per forested area of sub-drainage area. Since some watersheds are naturally less forested than others, using the total forested area of the watershed helped reduce this bias. The following equation was used to calculate the forest lost indicator:

$$\%\ Net\ Forest\ Loss = \frac{A_{FL} - A_{FG}}{A_{TF}} \times 100$$

Equation 5

where A_{FL} is the total area of forest lost in a sub-drainage area, A_{FG} is the total area of forest gain in a sub-drainage area, and A_{TF} is the total forested area of the sub-drainage area.

If a given cell had experienced both gain and loss within the given time frame, the cell was assumed to have a zero net percent forest loss, since no measure of the degree of loss or gain was provided in the dataset. The sub-indicator was reclassified using Jenks Natural breaks in ArcGIS into 5 categories (Appendix 1 Table 4).

4 FRAGMENTATION

River fragmentation and loss of connectivity between freshwater habitats creates significant impacts to the natural flow of a water system, alters riverine environments, and often results in isolated populations of species. The *Fragmentation* indicator was developed with two sub-indicators: 1) fragmentation by dams and; 2) fragmentation by roads and rail. Each sub-indicator was classified into 5 threat categories ("Very Low", "Low", "Moderate", "High", and "Very High") using percentiles. The final *Fragmentation* indicator was determined as an average threat of the two sub-indicators.

4.1 Fragmentation by Dams

Dams located in freshwater systems alter the migration patterns among fish populations, impact habitats, and isolates various freshwater species. Dams results in changes in species ecological process and vital life-cycle stages, change fish spawning habitats, change the quantity of water, and alter the flow of natural nutrients in the system (Poff, et al., 1997). The loss of connectivity can also disconnect species from their floodplains, wetlands, and other riparian habitat.

The primary dataset on which the fragmentation analysis was conducted was the comprehensive survey of Canada's inland surface water features known as the National Hydrological Network (NHN). This GIS dataset was broken up into several feature classes that together provide the best available description of both Canadian rivers and hydrologic infrastructure such as dams (WWF, 2012).

This dataset was critical in providing river length, flow direction, and watershed (SDA) information required for analysis. Additionally, the NHN also contained attributes on flow status and direction. WWF-Canada conducted a Strahler order analysis in-house in order to aid the fragmentation work. Since virtually every aspect of the fragmentation assessment project relies on the information contained in the NHN dataset, ensuring the quality of this data is essential to the integrity of the project as a whole. For this reason, visual inspection of the dataset was conducted to resolve issues of river segment connectivity and ensuring all Strahler orders were correctly assigned.

Fragmentation by dams was measured as the proportion of total river length in each sub-drainage area impacted by dams, compared to the total river length, weighted by Strahler order. This measure would be totaled for each sub-drainage area and then normalized to produce the final fragmentation measurement (equation 6).

$$f = \frac{\left\{\left(\frac{G_1}{G_1 + B_1} \times S_1\right) + \left(\frac{G_2}{G_2 + B_2} \times S_2\right) + \cdots + \left(\frac{G_x}{G_x + B_x} \times S_x\right)\right\}}{(S_1 + S_2 + \cdots + S_x)}$$

Equation 6

where f is the fragmentation metric, G_x is the total length of fragmented river within a specific Strahler order, B_x is the total length of free-flowing river within a specific Strahler order, and S_x is the weighting of specific Strahler Order.

The final metric selected was ideal as it is based on the methods used by the WWF in previous free-flowing river assessments (WWF, 2009), and is comparable to approaches taken in academic studies (Anderson, Pringle, & Freeman, 2008). Fragmentation by dams was then classified using percentiles (Appendix 1 Table **5**)

4.2 Fragmentation by Roads and Rail

Similar to dams, road and rail crossings over rivers can fragment the natural ecosystem and change the migratory and spawning behaviours of freshwater species, losing the connectivity needed for a healthy habitat (Poff, et al., 1997). In order to perform the Canada-wide stream intersection analysis of road and rail crossings, datasets representing both Canada's river network, and transportation networks were essential. While the visually inspected NHN dataset used in previous analysis was still readily available to supply hydrological features, data on transportation features needed to be located from an open-source provider. After referring to the methodology of a similar project conducted by Blanton and Marcus (2011), it was decided that GeoBase's National Railway Network (NRWN) and National Road Network (NRN) could be combined to create an appropriate network of transportation features. These datasets were ideal not only because they were extremely detailed, including features such as logging and mining roads, but also because they were produced at a scale of

1:10,000, well above the minimum scale of 1:2,000,000 suggested by Blanton and Marcus (2011).

Additionally, one major benefit of using the NHN dataset within the intersection analysis was its inclusion of Strahler order attributes. While previous studies have lacked stream ranking attributes (e.g. Strahler order), it has been noted that utilizing such information to weight results to reflect that the varying significance intersections have on different sized streams could enable even greater insights into ecosystem health (Blanton & Marcus, 2011; Wang, Liu, Deng, & Yang, 2014)

In order to assess the extent to which rivers are affected by road/ rail transportation networks, taken from Blanton and Marcus (2011) use a simple yet appropriate metric of intersection densities per km^2 was (equation 7):

$$D = \frac{C}{A}$$

Equation 7

where D is density, C is the total number of transportation network river crossings within the sub-drainage area, and A is the sub-drainage area (km^2).

In comparison, the inclusion of a metric that incorporates the varying impact intersections can have on different sized rivers was more challenging. While previous studies have suggested the usefulness of such a measure (e.g. Blanton & Marcus, 2011; Wang *et al*., 2014), the absence of information on river size (e.g. Strahler order) within these studies meant that no standard assessment approach had been previously created. For this reason, the development of a new weighted metric was required, as seen in equation 8:

$$W = \left\{ \frac{\left((I_1 \times S_1) + (I_2 \times S_2) + \cdots + (I_x \times S_x) \right)}{(S_1 + S_2 + \cdots + S_x)} \right\} \Big/ A$$

Equation 8

where W is the intersection density metric, I_x is the total number of transportation network river crossings with a specific Strahler order, and S_x is the weighting of a specific Strahler order. Once the metric was calculated per sub-drainage area, the analysis was results were classified using percentiles (Appendix 1 Table 5).

5 WATER USE

Canada has some of the world's largest volumes of renewable freshwater; however, the supply of our freshwater is unevenly distributed and also changing over time (Statistics Canada, 2013). Canada relies on water for our livelihoods, but also for socioeconomic uses, such as industrial and manufacturing activities (Statistics Canada, 2013). Over using our water can result in a decrease in the quantity of our water for both healthy freshwater ecosystems, and also as a source of safe drinking water for humans.

The *Water Use* Indicator was developed using an existing dataset and analysis from Statistics Canada (2013). Statistics Canada has developed a report and map that quantifies the relationship between the timing and demand of a water supply. The map illustrated by Statistics Canada compares water intake for August 2005 with the 34-year median water yield for August (see Figure 2). Water intake data was collected from Statistics Canada survey, and includes intake from manufacturing, thermal-electric power generation, mining, quarrying, oil and gas and agriculture (irrigation) industries, drinking water plants, as well as data on household reliance on non-municipal water (Statistics Canada, 2013). The data was then summed per drainage region and divided by the water yield in each drainage region. The final dataset is presented in 4 categories: 1) 0% to <10%; 2) 10% to <20%; 3) 20% to <40%, and 4) ≥ 40%.

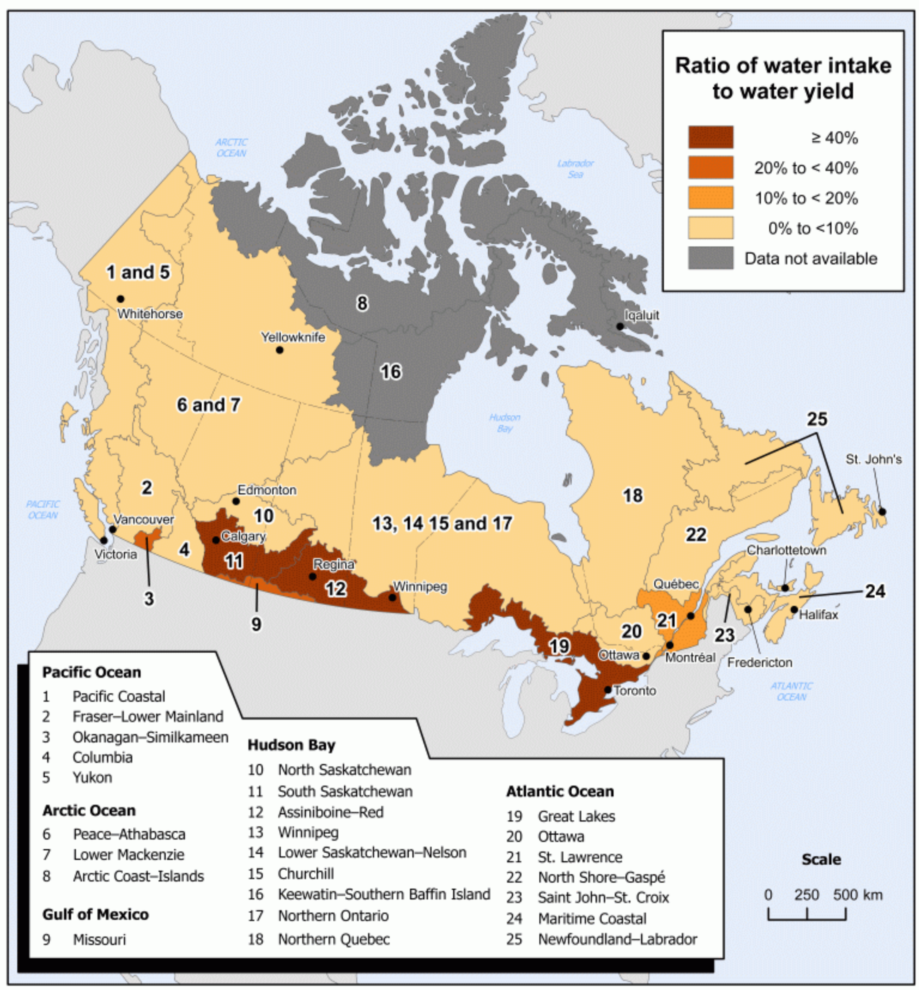


Figure 2: Data used for Water Use indicator, developed and retrieved from (Statistics Canada, 2013)

The categories from the map were taken to develop the water use indicator. Since no raw data was available, the dataset was taken and applied to all sub watersheds that are within the drainage area. The 4 categories were ranked from “Low” to “Very High”, with the “Data not available" category being reclassified as "Unknown Threat". Future analysis aims to create a water use map that provides higher resolution of detail, being able to provide sub-drainage area specific information and threats categories.

6 INVASIVE SPECIES

Invasive species can out compete and/or predate upon native species, thus changing the structure of the biological community. Furthermore, invasive species can physically alter the ecosystem, making it unsuitable for native species that traditionally have lived there. Invasive species are a common indicator included in other stressor based and cumulative effects analyses (Allan et al, 2012; Florida Fish and Wildlife Conservation Commission, 2008)

A critical part of the accuracy of the invasive species indicator was to ensure that the correct species were included. We were not able to identify a comprehensive and accurate list of invasive species Canada-wide. Many invasive species lists publicly available primarily include high risk potential invaders to encourage public awareness and facilitate early detection. For the purposes of this analysis, we were only concerned with invasive species already known to be present in a watershed, not species that pose a risk of future invasion (e.g. Asian carp in the Great Lakes). The final list of invasive species to be included in the analysis was generated by the Ricciardi lab from McGill University; Dr. Ricciardi specializes in aquatic invasions in Canada. Because invasions are regional (ex. what is invasive on the East coast of Canada may be native on the West coast), the list of invaders had to be broken down geographically. Therefore, the final list was broken down by province/territory, with a separate list of invasive species for each province/territory. In each provincial/territorial list, invaders were given an impact score from 1-4; 1 = no known impact, 2 = known impact in another country; 3 = known impact in another province; 4 – known impact within the province/territory. These impact scores were used to weight the species.

Occurrence data for each species were gathered across Canada from several sources including the Global Biodiversity Information Facility (GBIF), EDDMapS, and where possible, provincial Conservation Data Centers. Individual species datasets were amalgamated into one dataset. Data were screened to ensure that only occurrence points from provinces in which a species was identified as invasive were included; all data points within provinces in which a species is not considered invasive were removed. Analysis occurred at the sub-drainage area level. In cases where a sub-drainage area straddled a provincial boundary, the provincial assignments for the species found within it were made based on the province in which the majority of the sub-drainage area lies.

Due to the nature of invasive species sampling in Canada, we elected to use species richness as a measurement instead of species occurrences. The max impact score was captured for each individual species within a given sub-drainage area. The sum of the impact scores across all species found within a given sub-drainage area were summed to give a total invasive indicator score.

Because systematic sampling is not done consistently across the country, we were only able to confirm presence, not absence of invasive species. As a result, in areas where occurrences were not found, we assigned an impact score of "Unknown" rather than "None". There are two exceptions to this rule – according to the provincial/territorial invasive species lists, there are no invasive species observed in the Northwest Territories or Nunavut. As a result, the sub-drainage areas in these territories were assigned a score of “No recorded impact”.

Final categorical threat indicators scores were determined by using a Jenks Natural Breaks classification scheme.

7 ALTERATION TO FLOWS

Water infrastructure has significant impacts to water flow. Dams and other water infrastructure impact the connectivity of a freshwater system by creating a barrier for the natural flow, impacting water quality and quantity. The alteration of the flow changes flow pulses and flood patterns, and also impacts the migratory patterns of many species (WWF, 2011) .

The *Alteration to Flows* indicator aims to quantify the level of threat that large reservoirs and dams pose to flows in freshwater systems. The Global Reservoir and Dam (GRanD) Database provides the location and storage capacity of reservoirs and dams of greater than 0.1km in point and polygon format. The dataset is cross-validated, with error checking, to ensure that all information is up to date and properly referenced. The GRanD database is provided by the Department of Geography at McGill University in Montreal, Canada. Internationally, the database contains 6,862 records of reservoirs and dams, with 233 in Canada.

The *Alteration to Flows* indicator was classified by the total storage capacity area (in square km) per sub-drainage area. Where more than one reservoir or dam existed in a sub-drainage area, their total area was combined. Finally, the total area of reservoirs and dams per sub-drainage area was classified from “Very Low” to “Very Low” in ArcGIS using Jenks Natural Breaks.

8 CLIMATE CHANGE

Changes in the quantity and temperature of water due to a changing climate affects the water availability within a water system, the water quality, as well as the natural history of species living within the ecosystem. (Environment Canada, 2001). Climate change also results in indirect changes, such as changes in agricultural productivity, increasing use of pesticides and nutrients in agriculture, and thus increased risk of agricultural run-off.

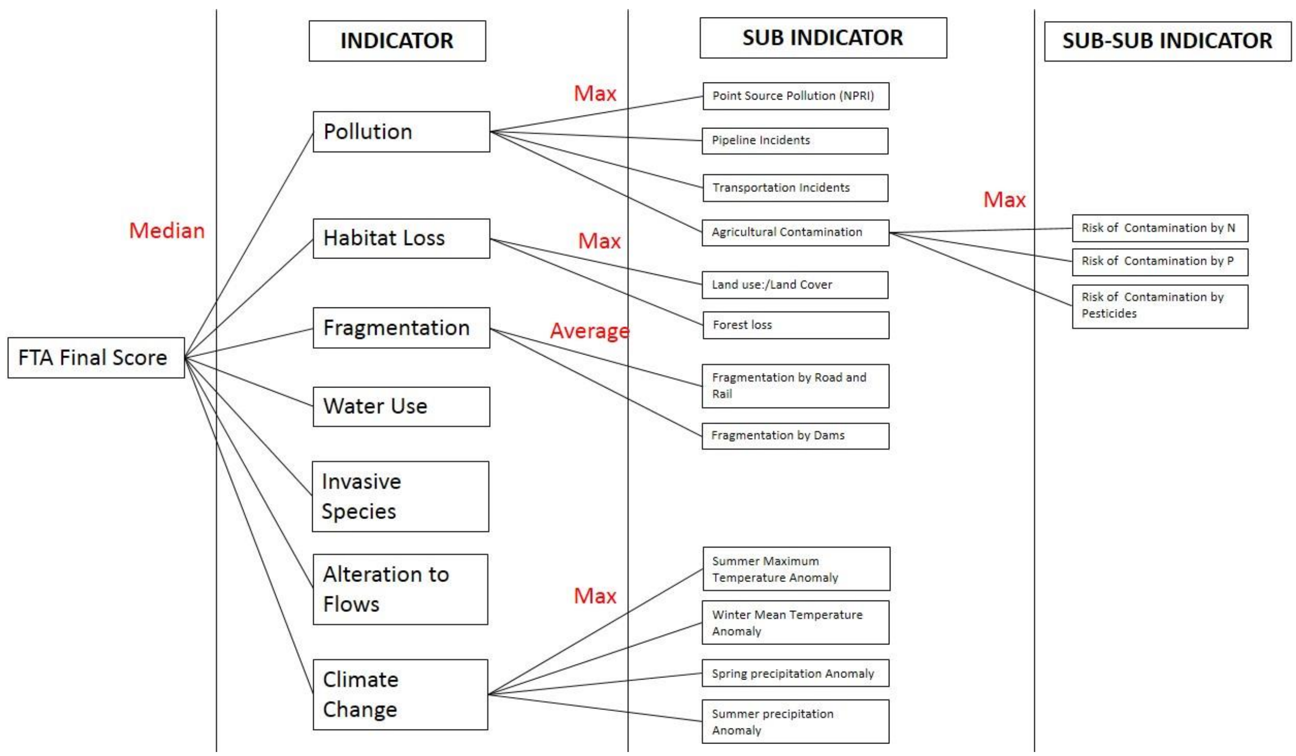
To assess the threat of climate change to the freshwater system, the *Climate Change* indicator was developed using the Canadian Gridded Temperature and Precipitation Anomalies from Environment Canada (2014). The dataset is a historical data of temperature and precipitation anomalies, with a reference period of 1961-1990. They are computed based on unevenly distributed weather stations and are interpolated to evenly spaced 50km grid boxes. The anomalies are computed monthly, seasonally, and annually at each observing station and for each year by subtracting the relevant baseline average from the relevant monthly, seasonal and annual values. They are then normalized by dividing by the mean reference period and expressed as a percentage score (Environment Canada, 2014).

In order to develop the *Climate Change* indicator, 4 sub-indicators were used: 1) summer maximum temperature anomaly; 2) winter mean temperature anomaly; 3) spring precipitation anomaly and 4) summer precipitation anomaly. For each, we found the five year median and mean for the time period of 2008-2012. The median of the anomalies was then classified into 3 threat categories (“Low”, “Moderate” and “High”) by determining the number of standard deviations away the median was from the mean (Appendix 1 Table 9). The final classification for the *Climate Change* indicator was taken as the maximum threat of the 4 sub-indicators.

9 ROLLING UP TO OVERALL SUB-DRAINAGE AREA SCORES

Once all the analysis was complete for each indicator and sub-indicator, it was essential to our study to create an overall score for each SDA as well as an overall score for each Pearse Drainage basin. First, a decision tree was created to evaluate how best to roll up sub-indicators into indicator scores. Either an average or maximum of the sub-indicators threat score was taken to create a final indicator score (see figure 2).

Figure 3: Decision tree for rolling up sub-indicators to indicator scores, and to a final sub-drainage area score.



Since some indicators did not have the same number of classes, it was first necessary to standardize all the indicator scores. While most indicators had a total of 5 classes, *Water Use* and *Climate Change* had 4 classes and 3 classes, respectively. For each indicator, the class score was divided by the total number of classes and given a percentage score. For instance, if a SDA received a class score of 4, with a total of 5 classes, the standardized score was 80%. The following formula was used:

$$SDA_i = \frac{Class\ Score_i}{Total\ Number\ of\ Classes_i} \text{ x } 100$$

Equation 9

where i is the indicator. The scores were then reclassified per indicator at the SDA level using equal intervals (Appendix 1 Table 10). Once the score for each indicator was standardized, a median score was taken across the 7 indicators per SDA. The medians were then reclassified using equal intervals (see Appendix 1 Table 10 for break values).

10 ROLLING UP TO PEARSE DRAINAGE BASIN SCORES

Once standardized scores were determined for each SDA, a Pearse drainage basin score was also calculated. For each indicator, the following formula was used to create an overall Pearse score based on the scores of the SDA:

$$PDB_i = \sum \frac{A_{SDA}}{A_{PDB}} \times SDA_i$$

Equation 10

where A_{SDA} is the area of the sub-drainage area, A_{PDB} is the area of the Pearse drainage basin, and SDA_i is the indicator score at the SDA level. The sum of all the area weighted scores within that Pearse drainage basin was taken to find the indicator score. If more than 50% of the total Pearse basin area had a “Null” score for an indicator, the Pearse basin also received a “Null” score for that indicator. The indicator scores were then reclassified using the same breaks used at the SDA level.

The final the overall score of the Pearse drainage basin, the median value was taken of all the indicator scores. The median scores were then reclassified using the same breaks used at the SDA level.

11 DATA QUALITY

As a part of the analysis, we also went through a rigorous data quality assessment. While collecting data and conducting our analysis, it was clear that some datasets were more complete and suitable to our study than others. In certain instances, we determined that datasets were incomplete, the quality of the data was low, and that the dataset itself was not sufficient to be used for our Freshwater Threats Assessment. Therefore, we only used datasets that met our minimum criteria (Appendix 2 Table 11). Nevertheless, some issues still arose with certain datasets, and we feel it is important to note that a lack of good data may influence overall results.

Table 2: Criteria used for grading datasets used in the Freshwater Threats Assessment

Criteria	Description
Most recent year of data collection	How recent is the data?
Temporal range of data collection	Number of years collected
Temporal resolution	How frequently data is collected/updated?
Geographic precision	Point data– does the data have accurate geographic coordinates?
	Raster/Polygon data – What is the resolution and how easily can be applied to the watershed scale
Metadata available	Complete metadata?
Standardized units	Is raw data available, and is it reported at standardized units?
Systematically surveyed vs. random data collection?	Was the sampling done in a systemic way, or were data collected randomly?

Once each dataset was ranked, we gave each indicator a "Sufficient" or "Partially Sufficient" score based on the suitability of the all the datasets used for each indicator in our study.

Indicator	Overall Sufficiency for Use
Habitat Loss	Sufficient
Pollution	Sufficient
Fragmentation	Sufficient
Water Use	Partially Sufficient
Invasive Species	Partially Sufficient
Alteration of Water Flows	Sufficient
Climate Change	Sufficient

Our goal is that that we are able to update results for certain indicators when more readily available data becomes available.

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13 APPENDIX 1 – CLASSIFICATION OF INDICATORS AND SUB-INDICATORS

Table 3: Classification for Water Pollution sub-indicators

Indicator	Sub-Indicator	Classification scheme	Value Ranges		Class	Threat Category
			Minimum	Maximum		
Water Pollution	Point Source Pollution	Percentiles	0	0	0	No threat
			0.01	95.37	1	Very Low
			>95.37	1,375.53	2	Low
			>1,375.53	4,978.74	3	Moderate
			>4,978.74	24,068.78	4	High
			>24,068.78	671,981.19	5	Very High
	Pipeline Incidents	Percentiles	-	-	Unknown	Unknown
			0	0	0	No threat
			200	11,000	1	Very Low
			>11,000	129,100	2	Low
			>129,100	2,932,733	3	Moderate
			>2,932,733	57,817,264	4	High
			>57,817,264	1,513,562,880	5	Very High
	Transportation Incidents	Jenks Natural Breaks	0	0	0	No threat
			2	9	1	Very Low
			10	22	2	Low
			23	45	3	Moderate
			46	66	4	High
			67	107	5	Very High
	Agricultural Contamination	Percentiles	0.00	0.00	0	No threat
			0.01	0.10	1	Very Low
			>0.10	0.34	2	Low
			>0.34	0.80	3	Moderate
			>0.80	1.73	4	High
			>1.73	4.82	5	Very High

Table 4: Classification for Habitat Loss sub-indicators

Indicator	Sub-Indicator	Classification scheme	Value Ranges		Class	Threat Category
			Minimum	Maximum		
Habitat Loss	Land Use/ Land Cover	Jenks Natural Breaks	0%	0%	0	No threat
			0.01%	1.96%	1	Very Low
			>1.96%	10.37%	2	Low
			>10.37%	30.78%	3	Moderate
			>30.78%	59.22%	4	High
			>59.22% -	85.18%	5	Very High
	Forest Loss	Jenks Natural Breaks	< 0 %	0%	0	No threat
			>0%	1.51%	1	Very Low
			>1.51%	4.15%	2	Low
			>4.15%	8.34%	3	Moderate
			>8.34%	16.76%	4	High
			>16.76%	60.82%	5	Very High

Table 5: Classification for Fragmentation sub-indicators

Indicator	Sub-Indicator	Classification scheme	Value Ranges		Class	Threat Category
			Minimum	Maximum		
Fragmentation	Fragmentation by dams	Percentiles	0	0	0	No threat
			200	11,000	1	Very Low
			>11,000	129,100	2	Low
			>129,100	2,932,733	3	Moderate
			>2,932,733	57,817,264	4	High
			>57,817,265	1,513,562,880	5	Very High
	Fragmentation by roads and rail	Percentiles	0	0	0	No threat
			1	9	1	Very Low
			>9	22	2	Low
			>22	47	3	Moderate
			>47	71	4	High

Table 6: Classification for Water Use sub-indicators

Indicator	Sub-Indicator	Classification scheme	Value Ranges		Class	Threat Category
			Minimum	Maximum		
Water Use	Ratio of water intake to water yield	Pre-classified	Data not available		N/A	Unknown
			0%	<10%	1	Low
			10%	<20%	2	Moderate
			20%	<40%	3	High
			≥40%		4	Very High

Table 7: Classification for Invasive Species sub-indicators

Indicator	Sub-Indicator	Classification scheme	Value Ranges		Class	Threat Category
			Minimum	Maximum		
Invasive Species	Presence of invasive species	Percentiles	Known invasives in province, but no sightings in watershed		N/A	Unknown
			No known invasives in province, no sightings in watershed		0	No threat
			>0	8	1	Very Low
			>8	19	2	Low
			>19	37	3	Moderate
			>37	57	4	High
			>57		5	Very High

Table 8: Classification for Alteration to Water Flows sub-indicators

Indicator	Sub-Indicator	Classification scheme	Value Ranges		Class	Threat Category
			Minimum	Maximum		
Alteration to Water Flows	Area of reservoirs/dam	Jenks Natural Breaks	0	0	0	No threat
			0.01	14.4	1	Very Low
			14.5	105.7	2	Low
			105.8	616.5	3	Moderate
			616.6	1,991.2	4	High
			1,991.3	19,518.8	5	Very High

Table 9: Classification for Climate Change sub-indicators

Indicator	Sub-Indicator	Classification scheme	Value Ranges		Class	Threat Category
			Minimum	Maximum		
Climate Change	1) Summer maximum temperature anomaly; 2) winter mean temperature anomaly; 3) spring precipitation anomaly and 4) summer precipitation anomaly	Standard Deviations	< 1SD or > -1SD		1	Low
			>1SD or < -1SD		2	Moderate
			>2SD or < -2SD		3	High

Table 10: Final indicator classification for sub-drainage area indicators and Pearse Drainage Area. Classes for sub-indicators were standardized by number of classes and reclassified according to an equal interval classification scheme

Indicator	Classification scheme	Value Ranges		Class	Threat Category
		Minimum	Maximum		
Habitat Loss	Equal Interval	0		0	No threat
		>0	20	1	Very Low
		>20	40	2	Low
		>40	60	3	Moderate
		>60	80	4	High
		>80	100	5	Very High
Pollution	Equal Interval	Unknown		N/A	Unknown
		0		0	No threat
		>0	20	1	Very Low
		>20	40	2	Low
		>40	60	3	Moderate
		>60	80	4	High
		>80	100	5	Very High
Fragmentation		0		0	No threat

	Equal Interval	>0	20	1	Very Low
		>20	40	2	Low
		>40	60	3	Moderate
		>60	80	4	High
		>80	100	5	Very High
Water Use	Equal Interval	Unknown		N/A	Unknown
		0		0	No threat
		>0	25	1	Low
		>25	50	2	Moderate
		>50	75	3	High
		>75	100	4	Very High
Alteration to Water Flows	Equal Interval	0		0	No threat
		>0	20	1	Very Low
		>20	40	2	Low
		>40	60	3	Moderate
		>60	80	4	High
		>80	100	5	Very High
Invasive Species	Equal Interval	Unknown		N/A	Unknown
		0		0	No threat
		>0	20	1	Very Low
		>20	40	2	Low
		>40	60	3	Moderate
		>60	80	4	High
		>80	100	5	Very High
Climate Change	Equal Interval	0		0	None
		33.33		1	Low
		66.67		2	Moderate
		100		3	High
Overall Score	Equal Interval	0		0	No threat
		0	<20	1	Very Low
		20	<40	2	Low
		40	<60	3	Moderate
		60	<80	4	High
		80	<100	5	Very High

14 APPENDIX 2 – DATA SOURCES

Table 11: All data sources used for the analysis in the Freshwater Threats Assessment

INDICATOR	SUB-INDICATOR	Source
POLLUTION	Point-source pollution	Environment Canada. (2014). National Pollutant Release Inventory. Retrieved from https://www.ec.gc.ca/inrp-npri/
	Pipeline incidents	Pereira, M. (2013, October 22). Pipeline map: Have there been any incidents near you? CBC. Retrieved from http://www.cbc.ca/news2/interactives/pipeline-incidents/ National Energy Board. (2015, January 8). ARCHIVED - 2000-2013 Pipeline Incident Reporting. Retrieved from http://www.neb-one.gc.ca/sftnvrnmnt/sft/archive/pplnncdntgrprtng/pplnncdts/pplnncdts-eng.html National Energy Board. (n.d.). National Energy Board pipeline incident database, Jan. 1, 2000 - Nov. 21, Canadian Regulated Pipeline: Rupture Excel spreadsheet, 2012.
	Transportation incidents	Transport Canada. (2015, March). Dangerous Goods Accident Information System (D.G.A.I.S.). Data retrieved through an Information Request
	Risk of water contamination from agricultural by nitrogen phosphorous, and pesticides	Agriculture and Agri-Food Canada. (2013). NAHARP - Risk of Water Contamination by Nitrogen (IROWC-N). Retrieved from http://open.canada.ca/data/en/dataset/b777ecd1-606c-4847-8741-2366471c220f Agriculture and Agri-Food Canada. (2013). NAHARP - Risk of Water Contamination by Pesticides (IROWC-Pest). Retrieved from http://open.canada.ca/data/en/dataset/6d90d5f7-09ff-417a-86eb-b12b7586d22d Agriculture and Agri-Food Canada. (2013). NAHARP - Risk of Water Contamination by Phosphorus (IROWC-P). Retrieved from http://data.gc.ca/data/en/dataset/2d119ab0-6096-442a-a9db-c489a354d125
HABITAT LOSS	Land use/Land Cover	National Geomatics Center of China. (2010). GlobeLand30. National Geomatics Center of China. Retrieved from http://www.globallandcover.com
	Forest loss	Hansen, M. C., Potapov, P. V., Moore, R., Hancher, M., Turubanova, S. A., Tyukavina, A., . . . Townshend, J. R. (2013). High-Resolution Global Maps of 21st-Century Forest Cover Change. *342(15-November)*, 850-853. (Science, Ed.) Data available from: http://earthenginepartners.appspot.com/science-2013-global-forest.
FRAGMENTATION	Fragmentation by dams	Geobase. (2011, April 11). *National hydro network (NHN)*. Retrieved December 1, 2013, from http://www.geobase.ca/geobase/en/data/nhn/description.html
	Fragmentation by road and rail	Geobase. (2011, April 11). *National hydro network (NHN)*. Retrieved December 1, 2013, from http://www.geobase.ca/geobase/en/data/nhn/description.html

		Geobase. (2013, January 10). *National railway network (NRWN)*. Retrieved April 2, 2014, from http://www.geobase.ca/geobase/en/data/nrwn/description.html Geobase. (2013, January 10). *National road network (NRN)*. Retrieved April 2, 2014, from http://www.geobase.ca/geobase/en/data/nrn/description.html
WATER USE	Ratio of water intake to water yield	Statistics Canada. (2013). *Ratio of August 2005 water intake to the August median water yield for 1971 to 2004* . Retrieved from http://www.statcan.gc.ca/pub/16-201-x/2010000/m022-eng.htm
INVASIVE SPECIES	Presence of invasive species	Global Biodiversity Information Facility. (2015). Data retrieved January 2015 from http://www.gbif.org/ EDDMapS. 2015. Early Detection & Distribution Mapping System. The University of Georgia - Center for Invasive Species and Ecosystem Health. Available online at http://www.eddmaps.org/; last accessed January 27, 2015. Fisheries and Oceans Canada. Reported Observations of Aquatic Invasive Species. (2013). Data retrieved through an email request. Atlantic Canada Conservation Data Centre (2014). Species occurrence data for Butomus umbellatus, Esox niger, Myriophyllum spicatum, and Petromyzon marinus. Data retrieved September 24, 2014, through email request. Cowie, Faye. 2007. Surveyed Lakes in New Brunswick. Canadian Rivers Institute, 781 recs. Blaney, C.S.; Mazerolle, D.M. 2010. Fieldwork 2010. Atlantic Canada Conservation Data Centre. Sackville NB, 15508 recs. Erskine, D. 1960. The plants of Prince Edward Island, 1st Ed. Research Branch, Agriculture Canada, Ottawa., Publication 1088. 1238 recs. MacQuarrie, K.E., H. Schaefer, and K. Schoenrank. 2001. A Floral inventory of the Central and Schooner Pond Areas of Greenwich, Prince Edward Island National Park. Parks Canada Agency, Parks Canada Technical Reports in Ecosystem Science, No 030. Benedict, B. Connell Herbarium Specimen Database Download 2004. Connell Memorial Herbarium, University of New Brunswick. 2004. Benjamin, L.K. (compiler). 2007. Significant Habitat & Species Database. Nova Scotia Dept Natural Resources, 8439 recs.. Clayden, S.R. 1998. NBM Science Collections databases: vascular plants. New Brunswick Museum, Saint John NB, 19759 recs.. Cowie, F. 2007. Electrofishing Population Estimates 1979-98. Canadian Rivers Institute, 2698 recs. Gautreau-Daigle, H. 2007. Rare plant records from peatland surveys. Coastal Zones Research Institute, Shippagan NB. Pers. comm. to D.M. Mazerolle, 39 recs. Biogeoclimatic Ecosystem Classification Program of British Columbia. 2015. BECMaster ecosystem plot database [Email correspondance]. W.H. MacKenzie [editor]. B.C. Min. For., Lands, and Nat. Res. Ops.,

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ALTERATION TO WATER FLOWS	Reservoirs/dam size	Lehner, B., Liermann, R., Revenga, C., Vörösmarty, C., Fekete, C., Crouzet, P., & Döll, P. (2008). High resolution mapping of the world's reservoirs and dams for sustainable river flow management. *GRanD Database (V1.)*. Frontiers in Ecology and the Environment. Source: GWSP Digital Water Atlas. Retrieved from http://atlas.gwsp.org
CLIMATE CHANGE	Summer maximum temperature anomaly	Environment Canada. (2014). Canadian Gridded Temperature and Precipitation Anomalies CANGRD . Retrieved from http://open.canada.ca/data/en/dataset/3d4b68a5-13bc-48bb-ad10-801128aa6604
	Winter mean temperature anomaly	
	Spring precipitation anomaly	
	Summer precipitation anomaly	

15 APPENDIX 3 – FULL INVASIVE SPECIES LIST

SPECIES	COMMON NAME
Alosa aestivalis	Blueback herring
Alosa pseudoharengus	Alewife
Alosa sapidissima	American shad
Ameiurus melas	Black bullhead
Ameiurus nebulosus	Brown bullhead
Cipangopaludina chinensis	Chinese mystery snail
Bithynia tentaculata	Faucet snail
Butomus umbellatus	Flowering rush
Bythotrephes longimanus	Spiny waterflea
Carassius auratus	Goldfish
Cercopagis pengoi	Fishhook waterflea
Corbicula fluminea	Asian clam
Cyprinus carpio	Common carp
Daphnia galeata galeata	Waterflea
Dorosoma cepedianum	Gizzard shad
Dreissena bugensis	Quagga mussel
Dreissena polymorpha	Zebra mussel
Echinogammarus ischnus	Ponto-Caspian amphipod
Egeria densa	Brazilian elodea
Esox masquinongy	Muskellenge
Esox niger	Chain pickerel
Eubosmina coregoni	Cladoceran
Eurytemora affinis	Calanoid copepod
Gambusia affinis	Mosquito fish
Gasterosteus aculeatus	Threespine stickleback
Gymnocephalus cernuus	Eurasian ruffe
Hemimysis anomala	Bloody-red shrimp
Hydrocharis morsus-ranae	European frog-bit
Impatiens glandulifera	Himalayan balsam
Iris pseudacorus	Yellow flag iris
Lepomis gibbosus	Pumpkinseed
Lepomis humilis	Orangespotted sunfish
Lithobates clamitans	Green frog
Lythrum salicaria	Purple loosestrife
Micropterus dolmieui	Smallmouth bass
Micropterus salmoides	Largemouth bass
Morone americana	White perch
Morone chrysops	White bass

Myriophyllum spicatum	Eurasian watermilfoil
Neogobius melanostomus	Round goby
Nymphoides peltata	Yellow floating heart
Oncorhynchus clarki	Cutthroat trout
Oncorhynchus gorbuscha	Pink salmon
Oncorhynchus kisutch	Coho salmon
Oncorhynchus mykiss	Rainbow trout
Oncorhynchus tshawytscha	Chinook salmon
Orconectes limosus	Spinycheek crayfish
Orconectes rusticus	Rusty crayfish
Orconectes virilis	Northern crayfish
Osmerus mordax	Rainbow smelt
Perca flavescens	Yellow perch
Petromyzon marinus	Sea lamprey
Phalaris arundinacea	Reed canarygrass
*Phragmites australis*spp. *australis*	Common reed
Pimephales promelas	Fathead minnow
Pisidium amnicum	Pea clam
Pisidium henslowanum	Henslow's pea clam
Pisidium supinum	Humpback pea clam
Poecilia latipinna	Sailfin molly
Potamogeton crispus	Curly-leaf pondweed
Potamopyrgus antipodarum	New Zealand mudsnail
Proterorhinus semilunaris	Tubenose goby
Rana catesbeiana	Bullfrog
Richardsonius balteatus	Redside shiner
Rorippa nasturtium-aquaticum	Common water cress
Rorippa sylvestris	Creeping yellow cress
Salmo salar	Atlantic salmon
Salmo trutta	Brown trout
Salvelinus alpinus	Arctic char
Salvelinus fontinalis	Brook trout
Salvelinus malma	Dolly varden
Scardinius erythrophthalmus	Rudd
Sphaerium corneum	Fingernail clam
Tinca tinca	Tench
Trapa natans	Water chestnut
Typha angustifolia	Lesser cattail
Typha x glauca	Hybrid cattail
Valvata piscinalis	European valve snail
Viviparus georgianus	Banded mystery snail