Phosphorus Dynamics in Southwestern Nova Scotia Lakes

by

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ABSTRACT

Eutrophication and algal blooms caused by anthropogenic sources of nutrients is an issue in freshwater systems all over Canada. Several lakes in southwestern Nova Scotia have experienced reoccurring algae blooms and possess elevated concentrations of phosphorus (P). In this thesis a mass balance modeling approach was used to understand the relative contribution of P sources within these watersheds and lakes. Primary sources of P included land runoff, septic systems, agricultural activities such as mink fur farming, aquaculture, and internal loading. These sources were quantified through literature and spatial analysis for three different study years: 1983, 2008, and 2017. These study years were chosen based on availability of water quality data, and to understand the relative impact of the mink industry as it rapidly expanded during this time period. Agricultural census data and spatial analysis were used to estimate the annual mass of P generated from mink farming in each watershed. A suite of loading scenarios was simulated using a steady state mass balance model, examining P concentrations and sources for baseline (no anthropogenic sources), no mink farming, and varying levels of P retention on mink farms (25%, 50%, 75%). An additional scenario was also constructed which involved calibrating mink farm P retention coefficients using available water quality data. Baseline modeling scenarios predicted that without anthropogenic sources of phosphorus, all lakes in the system would be oligotrophic, indicating that cultural eutrophication of these lakes has occurred. In the no mink farming scenario, it was predicted that all study lakes would be oligotrophic except for Hourglass Lake, which was predicted to be mesotrophic due to inputs from an aquaculture facility. These findings suggest that the P from mink farms are the primary driver of cultural eutrophication in the study lakes. Results from the calibrated mass balance models demonstrated that for lakes with mink farms in their subwatersheds, the majority of P inputs are from the mink farms, and in lakes downstream of these subwatersheds, the majority of P loading originates from these upstream inputs. It is recommended that lake remediation efforts continue to focus on reducing P inputs from mink farms, and on controlling P loading from any new anthropogenic development in these watersheds. Internal loading of P from lake sediments was also identified as an important P loading mechanism, which can be exacerbated by climate change. Further efforts should also focus on monitoring of internal loading dynamics.

List of Abbreviations and Symbols

%	Percentage
CanSIS	Canadian Soil Information System
CCME	Canadian Council of Ministers of the Environment
DEM	Digital Elevation Model
g	Gram
ha	Hectare
HABs	Harmful Algal Blooms
kg	Kilogram
L	Litre
m	Meter
m2	Meter squared
m3	Meter cubed
mg	Milligram
mm	Millimeter
N	Nitrogen
NSDLF	Nova Scotia Department of Lands and Forestry
NSE	Nova Scotia Environment
NSPM	Nova Scotia Phosphorus Model
OECD	Organization for Economic Co-operation and Development
OWS	Onsite wastewater system
P	Phosphorus
PLM	Phosphorus Loading Model
POWSIM	Phosphorus Onsite Wastewater Simulator

SVM	Support Vector Machine
TP	Total Phosphorus
TREPA	Tusket River Environmental Protection Association
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
yr	Year

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1 INTRODUCTION

1.1 CONTEXT

Lakes in southwestern Nova Scotia have experienced eutrophication and reoccurring cyanobacteria blooms for many years. A group of 10 lakes in Digby and Yarmouth Counties of Nova Scotia have been the subject of ongoing water quality surveys and studies in response to these water quality concerns (Stantec Consulting, 2017; Sollows, 2017; Brylinsky and Sollows, 2014; Brylinsky, 2011). The majority of the study lakes were first sampled in the 1980s and then not sampled again until 2008 in response to public concerns related to algae blooms. Several of the study lakes were classified as hyper-eutrophic, whereas others were classified as oligotrophic, suggesting that the increase in trophic state was due to cultural eutrophication, as opposed to natural eutrophication.

The region is sparsely developed with limited agricultural activities, except for fur farming. Fur farming was first introduced to the area in the 1930s and was considered an efficient way to utilize fish wastes generated in nearby fish processing facilities (Newell, 1999). Fur farming in this area is mink farming, in particular the standard black mink or *Mustela vison* (Newell, 1999). Mink farming is considered an intensive system, with many mink being farmed on a small land base. In Nova Scotia, the fur farming industry peaked in 2012, with 1.5 million pelts produced in the province, valued at $128 million (Statistics Canada, 2019). Mink pelts were the largest agricultural export in Nova Scotia, surpassing blueberries and dairy (Nova Scotia Agricultural and Agri-Food Snapshot, 2014).

In more recent years, production of mink pelts in the province has lessened, largely due to increased international competition (Puddicome, 2016), pushback from environmental and animal rights activists, and the introduction of the Fur Industry Act in 2013. Mink farming was identified as a potential contributor to nutrient enrichment of lakes in the region (Brylinsky, 2011), which led to the development of the new regulations. The Fur Industry Regulations made under Section 36 of the Fur Industry Act prescribe requirements for animal housing, feces storage, feed storage, carcass disposal, setback distances from watercourses, and surface and groundwater monitoring (Province of Nova Scotia, 2015). Nova Scotia Environment (NSE) began site inspections in 2016 and encouraged facilities that did not comply with the regulations to upgrade their facilities (NSE, 2017). In 2018, Nova Scotia produced 767,000 pelts for a value of $19.6 million (Statistics Canada, 2019).

Nutrients from anthropogenic sources have been linked to eutrophication of freshwater systems around the world. Nutrients are chemical elements required by plants and animals to grow. Nitrogen (N) and phosphorus (P) are the most abundant nutrients and any excess of these nutrients can cause eutrophication and growth of algae blooms. In Canada, P is generally the limiting nutrient and is the key driver for productivity in freshwater systems (Government of Canada, 2015). Excess P can result in formation of harmful algal blooms (HABs) and can shift the assemblages of fish and invertebrates, sometimes creating ideal environments for pollution tolerant and invasive species (Government of Canada, 2015).

In addition to agricultural activities there are several other potential sources of P within rural lake systems, including runoff from managed forested landscapes, residential on-site wastewater systems (OWS), and internal loading of P from lake sediments. Although water quality monitoring surveys have documented elevated P within certain lakes in the region, the relative contribution of P sources to these lakes has not been evaluated. This information is required to understand the efficacy of current and proposed watershed management strategies in reducing P concentrations.

Phosphorus Loading Models (PLM) are steady state mass balance models that consider all watershed sources of P and the hydrology of the system to predict lake P concentrations. This type of model can be used to evaluate the relative contribution of different potential P sources in mixed land use watershed systems and evaluate lake management and restoration approaches.

1.2 Objectives

The overall goal of this research was to understand the contribution of various sources of P to lakes in watersheds where mink farming is a predominant land use. The specific objectives of the study were as follows:

- Characterize and quantify all P sources in the study watersheds through literature review and spatial analysis;

- Construct and validate a P loading model to predict total P (TP) concentrations in the study lakes; and
- Utilize the P loading model to better understand the relative contribution of different P sources, and to inform lake restoration planning.

1.3 Project Scope and Limitations

The project scope included an assessment of P sources within the study watersheds and development of a P loading model to predict lake TP concentrations for a variety of loading scenarios. The P loading model used is a mass balance steady-state model designed to predict average annual TP concentrations. The model relies on many assumptions and has limitations, as listed below:

- The model predicts an average annual lake TP concentration, it is not intended to predict temporal changes on a time scales less than a year;
- The model predicts spatially averaged TP concentration and assumes the lake is completely and evenly mixed;
- Potential additional sources/sinks of P, such as waterfowl and recycling of nutrients by aquatic plants, were not included in the model;
- Model validation was limited due to availability of historic water quality data; and
- Delineation and characterization of mink farms was based on satellite imagery and agricultural census data. It was assumed that all identified farms were in operation in the study year and that mink were evenly dispersed throughout each identified mink farm.

2 LITERATURE REVIEW

2.1 TROPHIC STATE DEFINITION

The trophic status of a lake refers to the level of biological productivity within the lake (Brylinsky, 2004). Generally, the three trophic states are oligotrophic, mesotrophic, and eutrophic. Oligotrophic lakes are characterized by low nutrient levels, high levels of dissolved oxygen conditions, low levels of productivity, and deep photic zones. Eutrophic lakes typically have high levels of nutrients, biomass and algae, and low levels of dissolved oxygen (Dodds et al, 1998; Brylinksy, 2004). Lakes can naturally transition from an oligotrophic state to a eutrophic state due to a natural accumulation of nutrients over hundreds to thousands of years (Anderson, 2002). However, this process can be accelerated due to anthropogenic sources of nutrients within a watershed in a process called cultural eutrophication.

The Organization for Economic Co-operation Development (OECD) created trophic state trigger ranges after conducting a large-scale lake sampling program in the 1960s (Vollenweider and Kerekes, 1982). The Canadian Council of Ministers of the Environment (CCME) subdivided the OECD mesotrophic category into mesotrophic and meso-eutrophic to better encapsulate the variability of Canadian waters (CCME, 2004). The key parameters used to characterize trophic state are typically TP, chlorophyll *a* and Secchi depth. The CCME (2004) trophic state classification, which uses TP, is provided in Table 1.

Table 1: CCME trophic states and TP trigger ranges

Trophic State	TP (μg/L)
Ultra-oligotrophic	<4
Oligotrophic	4 – 10
Mesotrophic	10 – 20
Meso-eutrophic	20 – 35
Eutrophic	35 – 100
Hyper-eutrophic	>100

2.2 LAKE EUTROPHICATION AND ALGAE BLOOMS

Aquatic ecosystems all over the world have seen an increase in frequency and magnitude of harmful algal blooms (HABs) over recent decades (Pick, 2016). Many lakes in Canada have experienced HABs. The first HABs in Lake Erie were observed in the 1960s and blooms lessened after the creation of the Great Lakes Water Quality Agreement (Environment and Climate Change Canada, 2020). However, HABs in the lower Great Lakes have been seen regularly since the early 2000s. Harmful algal blooms also occur in smaller lakes throughout Canada. In recent years, the Halifax Regional Municipality had to close multiple beaches due to the presence of HABs (Global News, 2018; CBC, 2019).

Algae blooms are associated with a number of water quality issues. Many species of cyanobacteria can produce hepatotoxins and neurotoxins (USEPA, 2014). Impacts of cyanotoxins include fish and shellfish death, human illness and death (either from consuming toxic fish and shellfish or through water contact and ingestion), and death of marine animals, seabirds, and other animals (Anderson, 2002). In Atlantic Canada, the deaths of multiple dogs were attributed to swimming in and ingesting water from waterbodies with HABs (CBC, 2019). The HAB species that do not produce toxins can still have negative water quality impacts due to the amount of biomass produced. Large algae biomass can produce foams and scums that can interfere with drinking water treatment, deplete dissolved oxygen levels as they decompose, and shade submerged vegetation causing a destruction of fish and shellfish habitat (Anderson, 2002; USEPA, 2014).

The occurrence of HABs is directly correlated to elevated nutrient concentrations in lakes (Pick, 2016; Anderson, 2002). HABs are made up of photosynthetic algae that require nutrients such as N and P to grow. The amount of growth and algae biomass depends on the limiting nutrient. In Nova Scotian lakes the limiting nutrient is typically P, with N:P molar ratios greater than 16 (Schoor, 1996).

2.3 LAKE THERMAL REGIMES AND MIXING PROCESSES

Lakes often become stratified due to differences in water temperature caused by warming from the sun, separating into different layers due to temperature and density gradients. In Nova Scotia, this stratification occurs during the summer in lakes of sufficient depth (>7 m). A stratified lake would typically possess three distinct zones: the epilimnion, the hypolimnion, and the metalimnion (CCME, 2004). The epilimnion is the zone nearest the surface, contains the warmest water and is evenly mixed. The hypolimnion is the zone nearest the sediment surface, contains the coldest water and is evenly mixed. The middle zone is the metalimnion or thermocline and is the region of greatest temperature change between the two other zones (Socolofsky & Jirka, 2004).

Since water temperature is driven by heat from the sun, the temperature of the water depends on the season and lakes often mix at different times of the year. A common lake mixing type is dimictic. This is when lakes mix twice per year, once in the spring and once in the fall, and are stratified during the winter and summer (Fafard, 2018). Winter stratification occurs when the lake is ice covered or if the epilimnion is less than 4°C, as this is the temperature when water is the densest (Socolofsky & Jirka, 2004). Polymictic lakes mix frequently throughout the year due to the depth, size, and shape of the lake. In shallow lakes, sunlight may be able to reach the hypolimnion and provide enough energy for turnover (Fafard, 2018). Monomictic lakes mix once per year, generally in the fall, and includes lakes such as the Great Lakes. Lake mixing processes are important in terms of lake eutrophication since during stratification, the hypolimnion often becomes anoxic. Since this layer is only mixed within itself, if the dissolved oxygen in this layer begins to decline, it can easily become hypoxic or fully anoxic (Socolofsky & Jirka, 2004). Anoxic conditions at the sediment surface allows for resuspension of P back into the water column (see section 2.5.5).

2.4 Climate Change Effects

Many studies have examined the link between climate change and lake trophic state. Climate change can affect lakes in many ways, as it can change dynamics in the lake itself or in the lake's watershed. Changes in climate such as temperature changes and wind speed changes can affect the lake temperature, lake mixing, and stratification. Climate change can also affect how long a lake remains ice covered, which also effects the stratification. Stronger lake stratification can cause increased internal loading of P, thus changing the trophic state of the lake (Jeppesen, 2010).

Favot et al (2019) studied a remote oligotrophic lake in Algonquin Provincial Park that experienced algae blooms in 2014 and 2015. Since the lake had no surrounding anthropogenic activity, the algae blooms could not be contributed to cultural eutrophication. An analysis of historical climate data documented increasing air temperatures, declines in wind speed, and a longer ice-free period, which they speculated had caused an increase in primary production in the lake. They also concluded that short term climate variability was the ultimate trigger of the algae bloom in this lake; one spring of anomalous weather conditions resulted in rapid onset of stratification which contributed to elevated levels of internal P loading.

Magee and Wu (2017) studied three morphometrically different lakes in Wisconsin, USA, and hindcasted water temperatures and stratification dynamics over the past century. They also found that air temperature has increased, and wind speed has decreased. This combination led to increased epilimnion temperatures, cooler hypolimnion temperatures, and longer periods of stratification. They also found that shallow lakes were more susceptible to changes in climate.

Climate change is also projected to result in changes to watershed hydrology and nutrient loading. Jeppesen (2010) stated that climate change will change temperature and rainfall, which will lead to changes in agricultural practices such as soil cultivation, timing and rates of fertilization, and rates of irrigation. Climate change effects such as extreme rainfall events and periodic droughts (resulting in increased irrigation in agricultural watersheds) may also lead to increased nutrient losses from watersheds into freshwater systems (Schindler, 2001).

2.5 WATERSHED SOURCES OF PHOSPHORUS

2.5.1 PHOSPHORUS CYCLE

Phosphorus is a macronutrient that is required for biologic metabolism and can be exchanged between three different forms: inorganic P, dissolved organic P, and particulate organic P. Lake P can originate from a variety of sources within a watershed, and it also cycles within several compartments in the lake and watershed (Figure 1). The main sources of P in a watershed are atmospheric deposition, point sources, and non-point sources (CCME, 2004). Atmospheric deposition sources include inputs such as aerosols, dust, and rain. Point sources include sources that input directly into a watercourse such as wastewater treatment effluent or drainage ditches (Paterson et al., 2006). Non-point sources are diffuse sources that originate over large landscape areas such as storm water runoff, agricultural runoff, and managed forested land runoff. Non-point sources can also originate from within the watercourse itself, such as internal loading from lake sediments (CCME, 2004).

Elemental P is very rare in the natural environment and is normally found in a phosphate molecule (PO_4^{3-}), that can be in either an organic or inorganic form, depending on what molecule it is associated with (USEPA, 2012). Aquatic plants take in dissolved inorganic P, as displayed in Fig. 1, and convert it to organic P to be taken up by birds, animals, and bacteria. Bacteria and other various processes return dissolved inorganic P to the soil and water, completing the natural P cycle. TP refers to the measurement technique of measuring all forms of P, include dissolved and suspended, organic and inorganic.

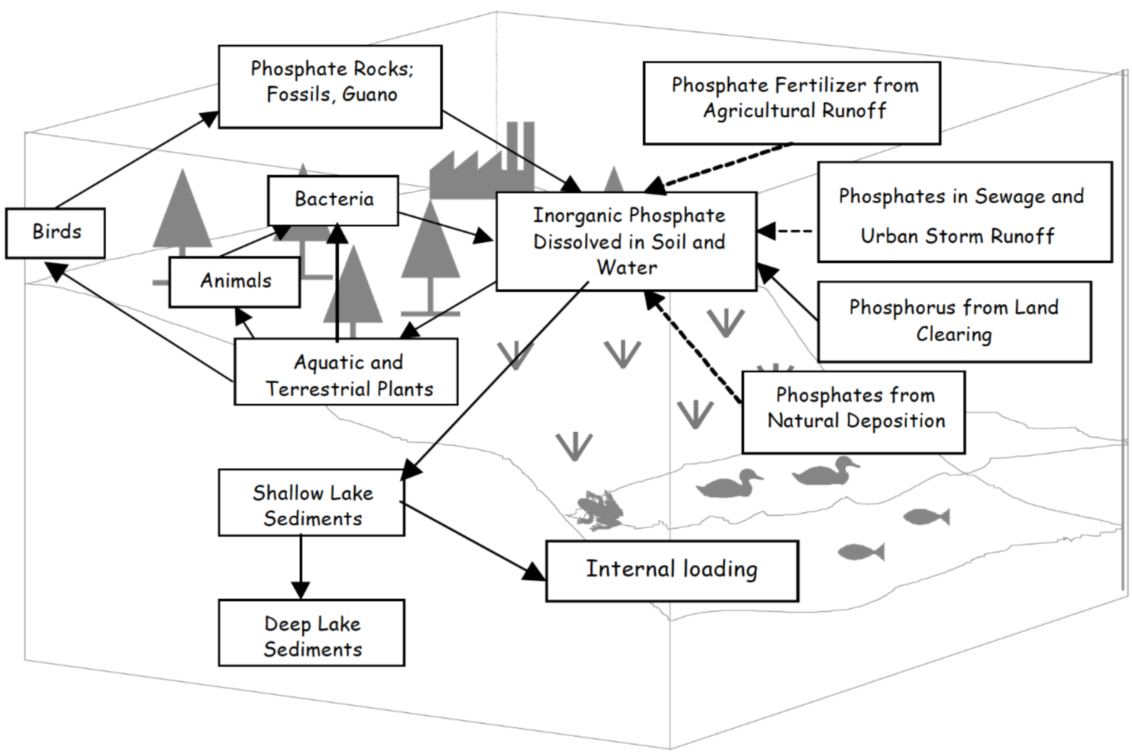

Figure 1: Watershed P cycle (figure from CCME, 2004)

2.5.2 Land Export

Land export of P is the process in which P is carried to a waterbody by both surface and subsurface runoff. The amount of P exported depends on the geology, soil type, and land use of the specific area, as well as precipitation characteristics. Many studies have determined P export coefficients for various combinations of geology, soil type, and land use. Reckhow et al (1980) produced a compilation of P export coefficients (Table 2) and generated the following general patterns:

- Climate can have a large impact as warm and wet climates tend to have higher export than cool dry climates;
- The amount, intensity, and duration of rainfall events directly impacts the amount of P exported from land;
- Loamy soils contain more nutrients and are more likely to erode when compared to sandy or gravel soils;
- Clay soils adsorb more P and have low infiltration rates, resulting in higher export;
- P export from forests is low, however deforestation and young forests have higher export;
- Cultivated lands have high P export, especially lands that are heavily fertilized and tilled; and
- Urban runoff has high P export and municipal storm systems rapidly transmit runoff to receiving water bodies.

Table 2: P export values (adapted from Reckhow et al., 1980)

Land Use	Range ($g/m^2/yr$)	Mean ($g/m^2/yr$)
Forested	0.0019 – 0.0083	0.0024
Row crops	0.0026 – 0.1860	0.0446
Non-row crops	0.0010 – 0.0290	0.0108
Grazing/pastureland	0.0014 – 0.0490	0.0150

Phosphorus export in Nova Scotia watersheds has been quantified in several studies. Scott et al (2000) monitored 26 forested watersheds throughout Nova Scotia and determined general export values (Table 3).

Table 3: P export coefficients for forested watersheds in Nova Scotia (Scott et al., 2000)

Watershed Type	Export Coefficient ($g/m^2/yr$)
Igneous forested	0.0069
Igneous forested with >15% cleared/wetland	0.0083
Sedimentary forested	0.0088
Sedimentary forested with >15% cleared/wetland	0.0115

Lowe (2002) studied ten catchments in the Gaspereau River watershed. The estimated P export coefficients were slightly higher than those determined by Scott et al (2000). P export coefficients for Maine are also available, and Maine shares many similar climactic, geologic, and soil characteristics with Nova Scotia (Brylinsky, 2004). The export coefficients determined by the Maine Department of Environmental Protection (2000) are presented in Table 4.

Table 4: P export coefficients from Maine Department of Environmental Protection (2000)

Land Use	Export Coefficient ($g/m^2/yr$)
Managed forest (15% clearcut/10% selective cut)	0.050 – 0.075
Unmanaged forest	0.0035 – 0.0050
Agriculture (rotation crops)	0.150 – 0.350
Agriculture (soil conservation practices)	0.010 – 0.030
Residential lots	0.025 – 0.035
Logging roads	0.35
Public highways	0.35
Private roads	0.35

2.5.3 *SEPTIC SYSTEMS*

In most rural communities, residences are not connected to the municipal sewer system and have their own septic system or onsite wastewater system (OWS). In Canada, approximately 14% of the population relies on an OWS, and in Nova Scotia that number rises to 34% of the population (Statistics Canada, 2015). A typical OWS includes a septic tank that discharges into a tile drainage disposal field. The disposal field is underlain with either the natural soil or an imported soil media. Up to 85% of septic effluent is in the soluble form of P, as particulate P is settled in the tank (McCray et al, 2005). The main removal process in the disposal field is sorption and precipitation (McCray et al., 2009). Figure 2 shows a typical OWS set up and the P transport paths to the nearest waterbody.

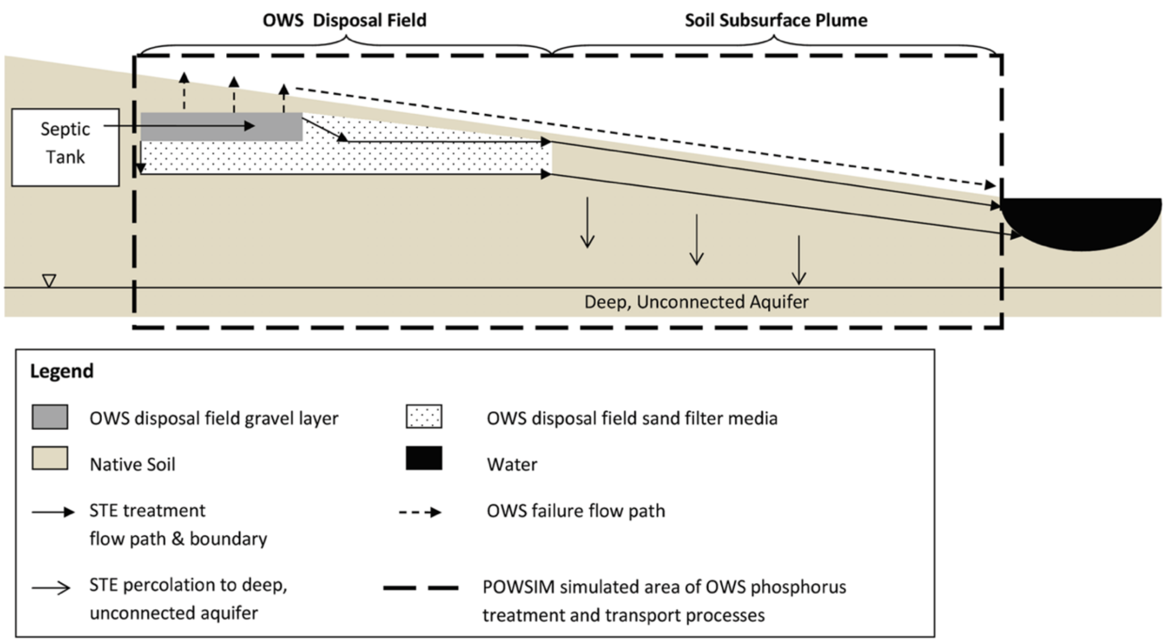

Figure 2: Profile diagram of an OWS and P flow paths to surface water (figure from Sinclair et al., 2014)

The traditional approach to estimating the amount of P from septic systems is to determine the amount of P produced per capita and then determine the proportion of P that enters the lake. Brylinsky (2004) recommends the use of the following equation:

$$Jr = Nd \times Nu \times Npc \times Si \times (1 - Rsp)$$

where Nd is the number of residences in the drainage basin, Nu is the average number of people occupying each residence, Npc is the fraction of the year residences are occupied, Si is the P load per capita per year (g/person/yr), and Rsp is the septic system retention coefficient. Nd, Nu, Npc are all parameters that are often determined from surveys or local planning offices. A common estimate of Si is 800 g/person/yr (Paterson et al., 2006) and higher values are often used in areas where phosphate detergents are still used (Brylinsky, 2004). The final parameter in this equation, Rsp, is a measure of the adsorption capacity of the soil. It depends on the age of the system, frequency of maintenance, and soil characteristics of the soil surrounding the system (Brylinsky, 2004). The adsorption capacity of the soil is often estimated, or if conservative predictions are being made, is will be assumed to be zero.

Instead of using estimated parameters, the P On-Site Wastewater Simulator (POWSIM) developed by Sinclair et al (2014), uses information such as OWS design class, OWS sand type and attributes, household STE flow rate, depth from disposal field to groundwater table, site slope, native soil attributes, system age, and distance to watercourse to estimate the mass of P entering the watercourse. Sinclair et at (2014) used POWSIM in conjunction with the Soil and Water Assessment Tool (SWAT) to produce a better simulation of baseflow TP loads in a mixed residential and agricultural land use watershed in the Annapolis Valley of Nova Scotia. POWSIM has three separate computational components: selection of OWS disposal field design and calculation of treatment media mass, disposal field treatment dynamics, and soil subsurface plume treatment dynamics (Sinclair et al., 2014).

2.5.4 Mink Farming

The major agricultural activity in Digby and Yarmouth counties is fur farming, specifically mink farming (Newell, 1999). Mink farming in this area began in the 1930s, with the first Mink Breeders Association meeting held in 1938 (NS Mink Breeders). This area of the province was chosen as the location for many mink farms since the farms were able to utilize fish waste from nearby aquaculture and fish processing facilities as feed (Newell, 1999). The Nova Scotian mink industry peaked in 2012, with Nova Scotia producing $128 million worth of pelts (Statistics Canada, 2019). According to the Nova Scotia Agriculture and Agri-food Snapshot (2014), mink pelts were Nova Scotia's largest agricultural export, followed by blueberries. Pelts were exported mainly to Russia, China and South Korea (Globe and Mail, 2012), and even “the catwalks of New York, Milan, and Paris” (NS Mink Breeders). Following the peak in 2012, there has been a decline in the mink industry, with $19.6 million worth of pelts produced in Nova Scotia in 2018 (Stats Can, 2019). This can be attributed to a number of factors including the rise of animal activism, increased international production, and the introduction of the Fur Industry Regulations in 2013 (Province of Nova Scotia, 2013).

Traditional mink farms consist of outdoor sheds that house the mink cages. These cages are open to the ambient environment and allow for waste to fall to the ground below the cages (Newell, 1999). Newer mink farms consist of enclosed barns and have waste collection systems that transport and store the waste until it can be used as manure and applied to fields (Mullen, 2019, personal communication). Currently, both types of farms are in use across the province. Many of the older sheds have been retrofitted to comply with the Fur Industry Regulations. Over $1 million in funding from the provincial government has been approved for use in site improvements, and the industry has also accessed support from federal grants (NSE, 2017). Prior to 2000, only one mink could be housed in one cage, however due to changes in pelting practices, multiple mink (two to three) could be housed together in one cage without impacting the price of the pelts (Mullen, 2019, personal communication). This change in pelting practices allowed for mink farmers to double or even triple the number of mink housed in the same facility.

Newell (1999) investigated nutrient intake and excretion within mink farms. He found that mink excrete between 40 to 50% of their dietary P intake when fed a diet of 15% cereals and 85% fish and meat by-products and determined that each pelted mink produces 0.15 kg P per year. The most recent Statistics Canada Agricultural Survey stated that there were 767 000 pelted mink in 2018 in Nova Scotia. This equates to approximately 115 000 kg P produced by mink.

2.5.5 Internal Loading

Internal loading is the process by which P trapped in the sediment becomes resuspended in the water column. During periods of high external loading, organic and inorganic forms of P can become trapped in the sediment (Søndergaard, 2003). Figure 3 shows the P pathways when entering a lake. The various forms of P in the sediment include both dissolved and particulate forms. Dissolved forms include phosphate and organic P, whereas particulate forms include iron, aluminum, calcium, clay, and organic compounds (Søndergaard, 2003).

One of the major mechanisms of P release from sediment and into the water column is through redox reactions. Mortimer (1941), was one of the first researchers to determine the methods of how P is released from the sediment and found that it was largely due to redox-sensitive iron dynamics. P can be sorbed onto iron (III) compounds and sedimented out of the water column. However, in anoxia, iron (III) is reduced to iron (II) and both iron and sorbed P are returned to the water column. Other factors that can influence P solubility and release include resuspension, temperature, pH, chemical diffusion, mineralization, microbial processes, and submerged macrophytes (Søndergaard, 2003).

Nurnberg and Peters (1984) found that P tends to accumulate in the anoxic hypolimnion of culturally eutrophied lakes. P from internal loading remains in the hypolimnion and is positionally unavailable to cyanobacteria until the erosion of the thermocline. After fall turnover, Nurnberg and Peters (1984) found that the surface P concentrations can increase and was correlated to the hypolimnetic P before turnover.

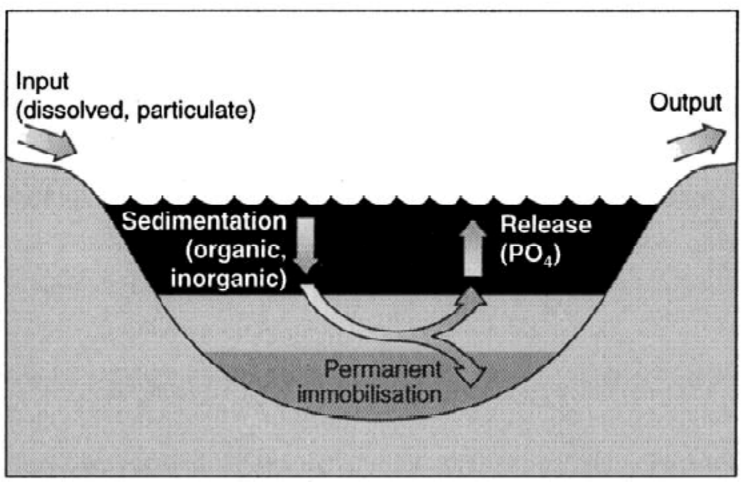

Figure 3: P pathways when entering a lake (figure from Søndergaard, 2003)

Estimating the amount of P released in internal loading is difficult and there are many methods of estimation. Many of the problems in quantifying the internal load include undetected or unknown internal load, ambiguity about the origin and form of the released P, and inexact definitions (Nurnberg, 2009). Nurnberg (2009) suggests multiple approaches to quantifying the internal load, such as *in situ* quantification from hypolimnetic P increases, mass balance approaches, and estimates from active anoxic area and P release.

2.6 PHOSPHORUS LOADING MODELS

Phosphorus Loading Models (PLMs), sometimes termed Lakeshore Capacity Models, have been widely used to predict and manage P within lakes and their associated watersheds (Paterson, 2006). There are several variations of PLMs, but all use climate, watershed characteristics, and lake morphology to predict the concentration of P within a lake using a mass balance approach. Climate and watershed characteristics control how much P and water enter the lake, and lake morphology and stratification controls how much P remains is retained or settled from the water column (Brylinsky, 2004).

These models are characterized as steady state mass balance models, with an assumption that each lake or basin is completely mixed. Formulation of a model requires construction of water and P budgets for each lake, or control volume. The Nova Scotia Phosphorus Model ((NSPM; Brylinsky, 2004) is based on these concepts (Figure 4) and is used in Nova Scotia to assess how land use change and development could influence P concentrations in lakes.

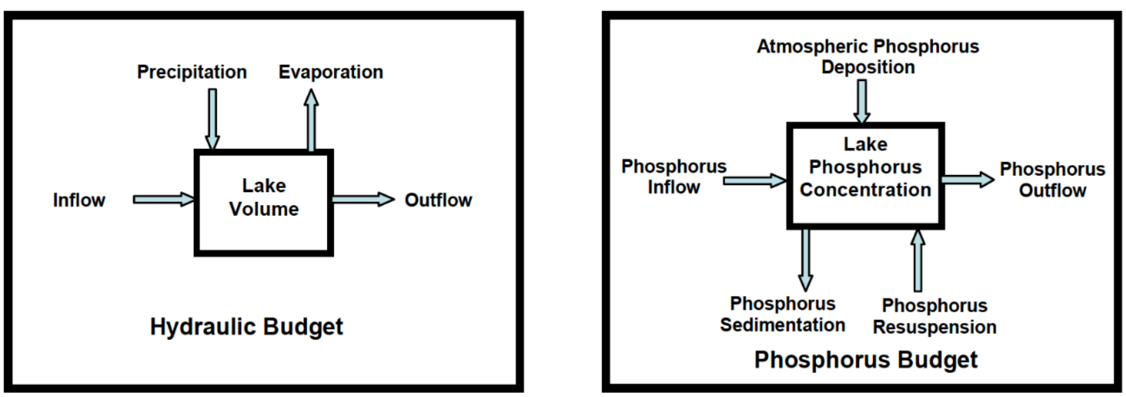

Figure 4: Summary of the inputs and outputs of the hydraulic and P budget used in the NSP (figure from Brylinsky, 2004)

The governing expression used in the NSPM to predict lake P concentrations is based on mass balance formulas developed by Bifi (1963), Piontelli and Tonolli (1964), and Vollenweider (1968, 1975). The concentration of P in a lake is computed as the difference between the mass of P entering the lake and the mass of P lost to sediments and outflow. The steady state solution to this equation is:

$$PV = \frac{M/V}{(Q/V)+\sigma} \tag{1}$$

where PV is the total mass of P in the lake (g), M is the annual mass of P entering the lake (g/yr), V is lake volume (m^3), Q is annual water outflow from the lake (m^3/yr), and σ is the sedimentation coefficient (1/yr). Many studies have assessed methods to estimate the sedimentation coefficient. A common method of estimation is the P retention formula developed by Kirchner and Dillon (1975):

$$Rp = \frac{v}{v+q_s} \tag{2}$$

where Rp is the proportion of P lost to sediments, v is the settling velocity (m/yr), and q_s is the aerial hydraulic load (m/yr). A value of 12.4 is recommended for v if the lake has oxic hypolimnion, and a value of 7.2 is the lake has an anoxic hypolimnion (Dillon et al, 1994). Equation 2 can then be substituted as the sedimentation coefficient in equation 1, resulting in the following mass balance equation. This governing mass balance equation can then be expressed as:

$$P = \frac{M \times (1-Rp)}{Q} \tag{3}$$

where P is the lake P concentration (g/m^3), M is the annual mass of P entering the lake (g/yr), Rp is the proportion of P lost to sediments, and Q is the annual volume of outflow from the lake (m^3/yr). The use of equation (2) in the general equation allows for a prediction of P concentration without requiring the depth or volume of the lake and can be applied to all lakes even if bathymetry is not available.

3 METHODOLOGY

3.1 OVERVIEW OF MODELING APPROACH

In order to estimate the TP in each study lake, the Nova Scotia Phosphorus Model (NSPM) (Brylinsky, 2004) was used. As previously discussed, this model implements a mass balance approach to predict the concentration of P in the lake. In order to do this, many aspects of the study lakes need to be known. The morphology, hydrology, and P inputs for each lake need to be quantified. This data was determined by first performing a spatial analysis to delineate the lake watersheds, characterize land uses in the watersheds, determine location and number of OWS, and the location of agricultural activities. Review of past sampling efforts provided information on lake morphology and hydrology. A spatial analysis, using publicly available datasets, was used to identify and generate specific P loads from each source in the study watersheds. All these elements came together in the NSPM to predict the concentration and loading of P in the lakes, which was then validated with measured TP concentrations.

This modeling approach was replicated for three study years in order to understand how P loading, and lake P concentrations, have changed through time. Current conditions are represented by the 2017 model. This year was chosen as it is the most recent year with all required sampling information. The next study year was chosen to be 2008, since this was the first year of intensive sampling throughout the watershed. The final model was constructed based on sampling done in the 1980's. Three headwater lakes (Nowlans, Provost, and Hourglass) were sampled in 1983, while four downstream lakes (Parr, Ogden, Fanning, and Sloans) were sampled in 1986.

3.2 STUDY SITE DESCRIPTION

The study focused on ten lakes located in Digby and Yarmouth Counties (Figure 5). The lakes are located in three different secondary watersheds. Nowlans Lake flows into the Meteghan River watershed while Provost Lake flows into the Sissiboo River watershed. The remaining eight lakes are all located in the Carleton River watershed. In drainage order, these lakes are: Hourglass, Placides, Porcupine, Parr, Ogden, Fanning, Sloans, and Vaughan. Nowlans, Provost, Hourglass, and Sloans are all headwater lakes.

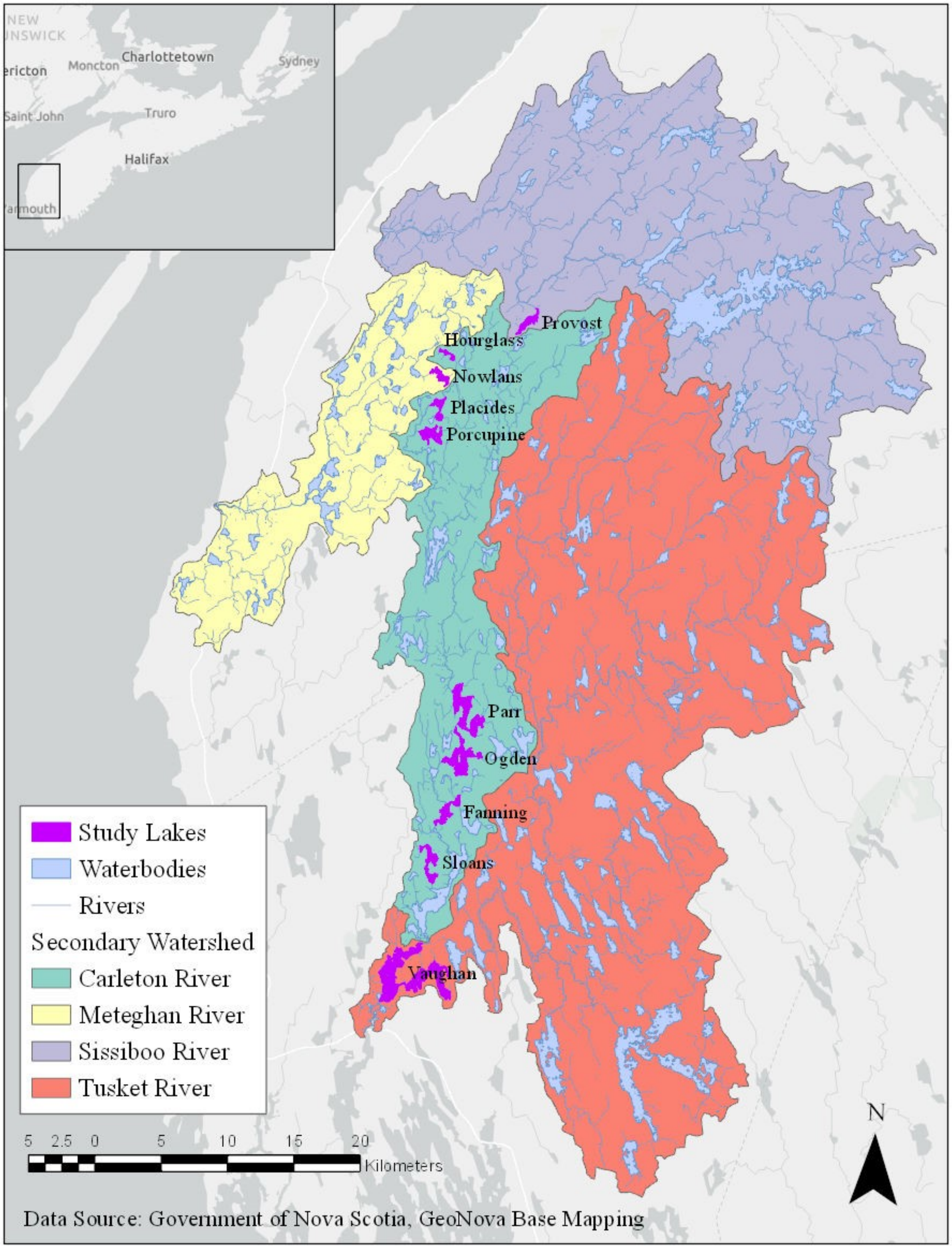

Figure 5: Map of study area in southwestern Nova Scotia. Inset: the province of Nova Scotia with nearby portions of bordering provinces.

These lakes have been the subject of various water quality studies, beginning in 2008. From 2008 to 2011, the water quality surveys were carried out by Nova Scotia Environment

(NSE), in partnership with Acadia University's Centre for Estuarine Research. Beginning in 2013, NSE supported efforts to create a community volunteer based long-term water quality monitoring program. This water quality monitoring program was carried out by the Tusket River Environmental Protection Association (TREPA) in 2013 and 2014, and by the Carleton River Watershed Area Water Quality Monitoring Steering Committee since 2015. The Carleton River Watershed Area Water Quality Monitoring Steering Committee consists of representatives from various provincial and federal government departments, municipalities, the mink farm industry, NGO's, and concerned citizens. The water quality surveys consist of sampling of various parameters at different locations within the lake such as the inlet, outlet, and deep stations. Figure 6 shows the measured TP values of the study lakes. The concentration is a depth-weighted average where available, and some values are surface grab samples. All measured TP values are summarized in Appendix B.

In addition to the lakes included in the water quality surveys, several other lakes in the watersheds were identified as lakes that could be storing and releasing P. Many of these lakes have also been sampled, however not as consistently as the main study lakes. These lakes were included in the P model to better simulate the hydrology and flow of nutrients in the system, as illustrated in Figure 7.

Lake Vaughan also receives flow from the Tusket River watershed. This watershed was not modeled, and the implications of this will be discussed in the Section 4.1.2.

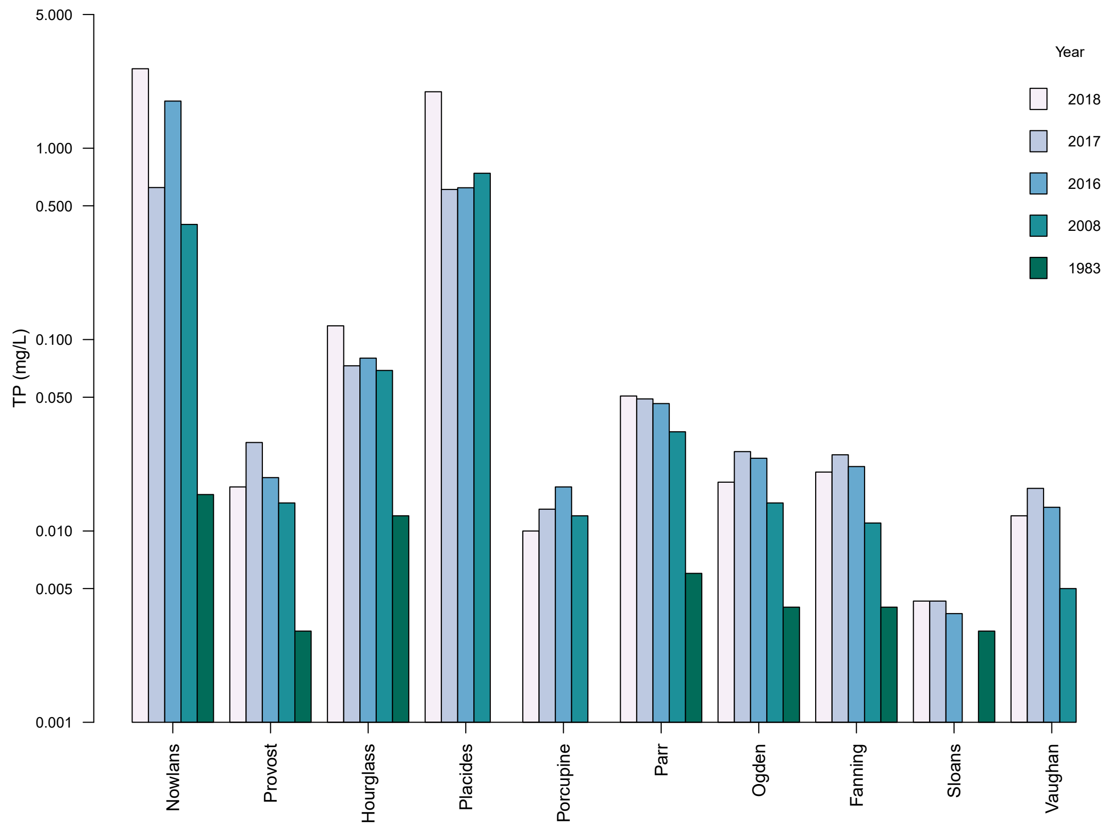

Figure 6: Measured lake TP for all study lakes. Presented on a log-scale

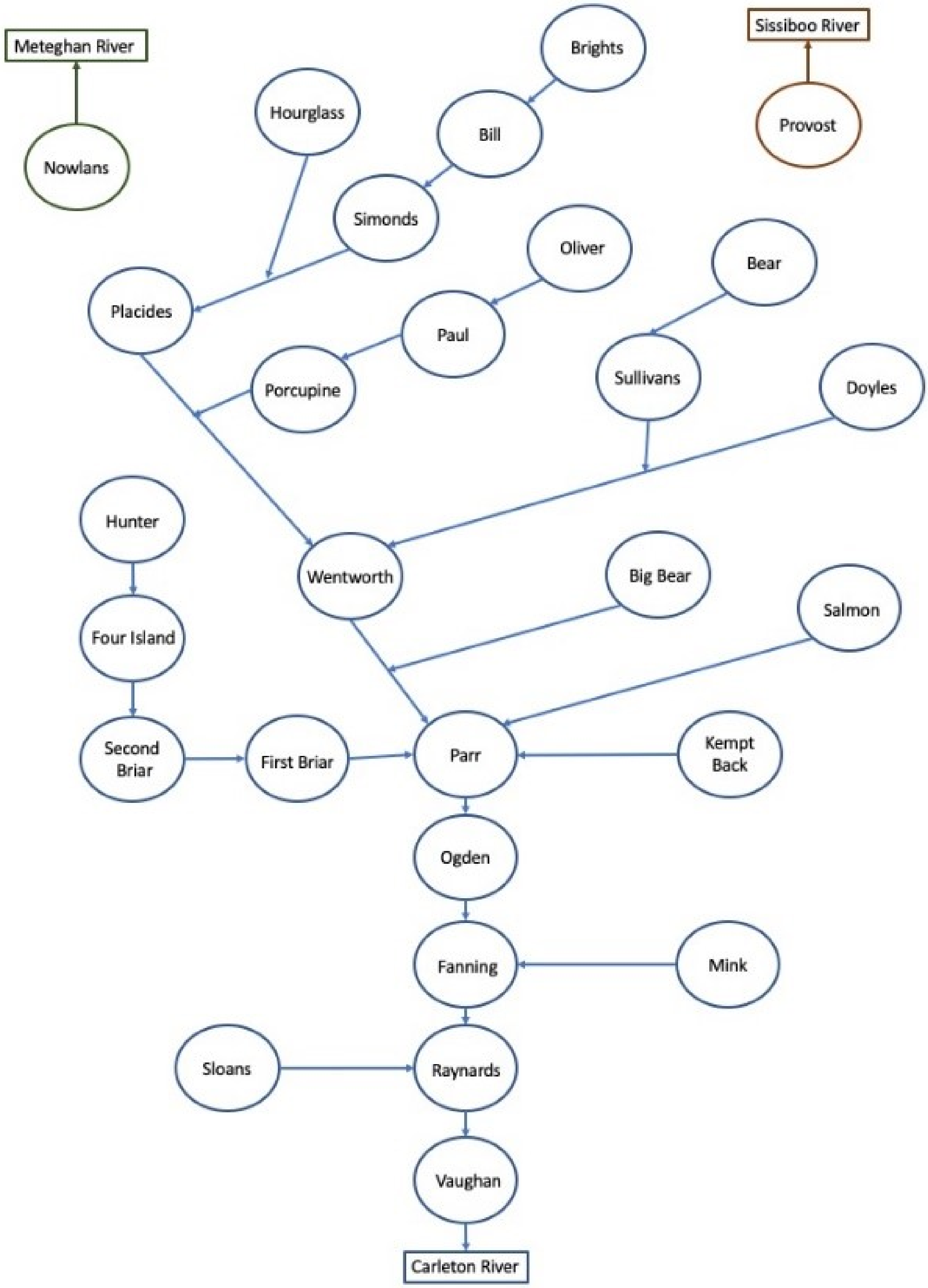

Figure 7: Flow chart illustrating the topology of lakes included within the P model

3.3 WATERSHED SPATIAL ANALYSIS

3.3.1 DATA SOURCES

A variety of publicly available data sources were used to parameterize the P loading model (Table 5).

Table 5: Summary of data sources used in the spatial analysis

Dataset	Description	Source
Enhanced Digital Elevation Model	Hydrologically correct 20 m DEM	Nova Scotia Department of Lands and Forestry (NS DLF)
Shaded Relief Map of Nova Scotia	Shaded Relief Map of Nova Scotia	NS DLF
Municipal Boundaries	Boundaries of all 18 counties in Nova Scotia	Province of Nova Scotia
Nova Scotia Hydrographic Network (Water Features)	Point, line, and polygon 10K water features	Province of Nova Scotia
Forest Inventory Layer for Nova Scotia	Forested and non-forested areas with freshwater wetlands and coastal habitat area classifications	NS DLF
Digital Property Layer for Nova Scotia	Geometry and attribute info for unique PIDs	Province of Nova Scotia
Bedrock Geology Map of Nova Scotia	Map of bedrock geology	NS DLF
Surficial Geology Map of Nova Scotia	Map of surficial geology	NS DLF
Detailed Soil Survey	Detailed soil survey of Nova Scotia at a scale of 1:75,000	Canada Soil Information System (CanSIS)
Nova Scotia Topographic Database – Structures	Polygon feature including structures and buildings maintained from aerial photos and field inspections	Province of Nova Scotia
Bathymetry	Bathymetric maps of all study lakes with the exception of Provost Lake	Nova Scotia Department of Fisheries

3.3.2 WATERSHED DELINEATION

The watershed for each lake included in the P model was delineated using ArcHydro in ArcGIS 10.5. The Nova Scotia Enhanced Digital Elevation Model 20 m (Nova Scotia Department of Lands and Forestry) and a centreline version of the Nova Scotia

Hydrographic Network obtained from Nova Scotia Environment were used as inputs. Watershed and subcatchment areas are presented in Table 6 and in Figure 8. Additional headwater lakes were also included in the analysis (Figure 8, map of all catchments).

Table 6: Catchment areas of all study lakes

Lake	Sub-catchment Area, including lake (ha)	Cumulative Catchment Area, including lakes (ha)
Nowlans	277	277
Provost	801	801
Hourglass	311	311
Placides	1043	2516
Porcupine	978	1215
Parr	5777	25134
Ogden	1311	26439
Fanning	2492	29630
Sloans	606	606
Vaughan	1447	35033

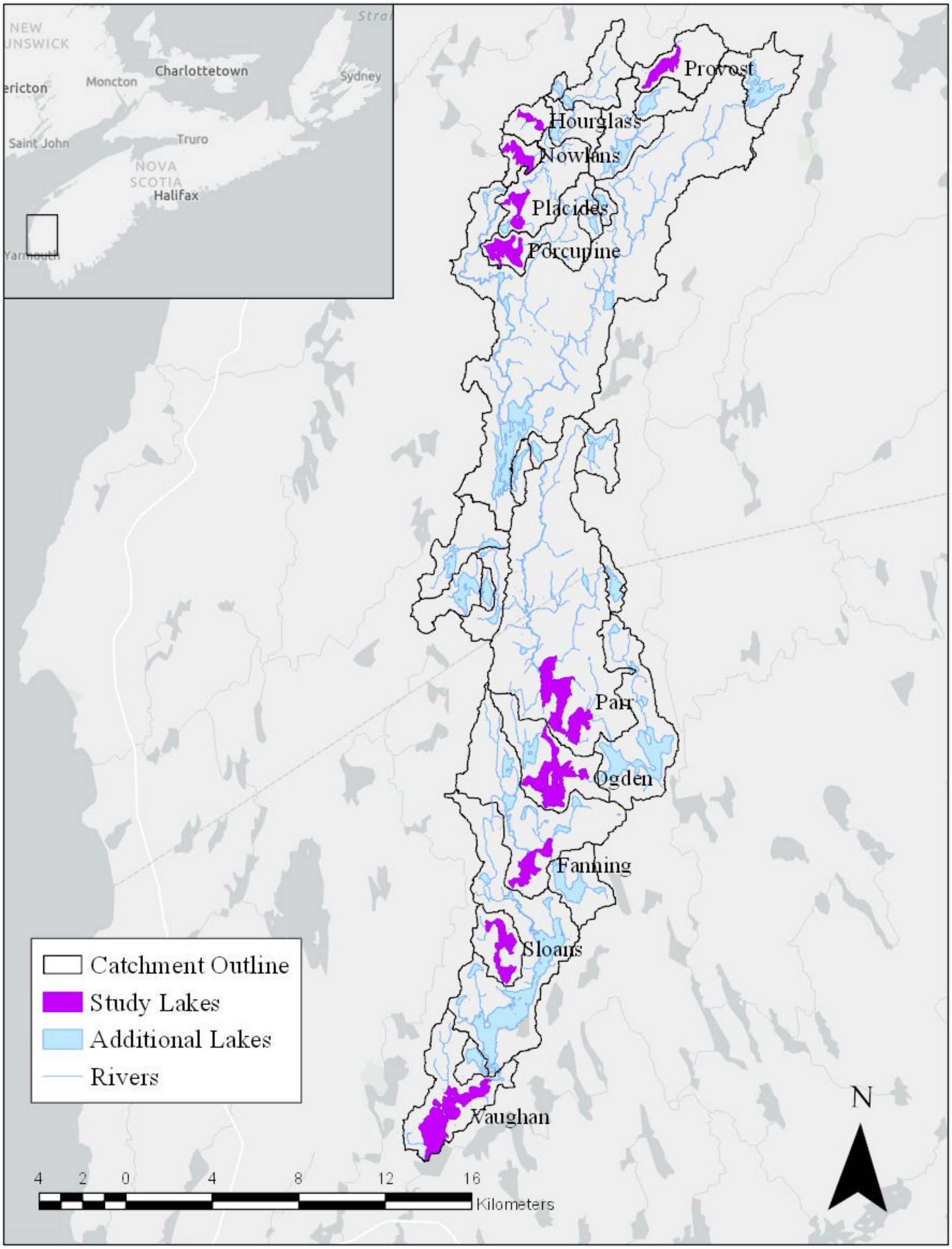

Figure 8: All lakes with their sub-catchment area outlined

3.3.3 *Land Cover Analysis*

Current land cover in the watersheds was identified using the Nova Scotia Forest Inventory shapefile (NSDLF, 2017). This shapefile contains polygons described as either forested or non-forested, along with more specific land uses. The 49 specific land covers in this shapefile (FORNON values and descriptions) were grouped into land cover classes (Table 7). These classes were chosen based on availability of P export coefficients in the literature.

Table 7: NS Forest Inventory shapefile FORNON values and corresponding land cover class

Land Cover Class	FORNON Value	FORNON Description
Waterbodies	77, 78	Lakes and rivers
Wetland	70, 71, 72, 73, 74, 75	General wetlands, beaver flowage, open bogs, treed bogs, lake wetlands
Developed/agriculture/barren	76, 84, 85, 86, 87, 91, 92, 93, 94, 95, 96, 97	Cliffs/dunes/coastal rocks, rock barren, barren, agriculture, urban, land fill, beach, gravel pit, pipeline corridor, powerline corridor, miscellaneous
Clearcut/dead	2, 6, 7, 8, 9, 13, 14, 60	Burn, wind throw, dead, clearcut
Reforestation	12, 20, 61	Treated, plantation, partial depletion
Forest	0, 1, 3, 5, 33, 38, 39, 83	Natural stand, treated, Christmas trees, old field, bush, alders, brush
Roads	98, 99	Road corridor, rail corridor

Land cover for earlier sampling years was determined using satellite images, as not all of the required land cover data was available through the NSDLF databases. A supervised classification process was employed using the Nova Scotia Forest Inventory shapefile to identify training samples. Landsat 8 images obtained from the USGS Earth

Explorer website were used. Images were selected to have very little cloud cover and were taken in late summer, to best correspond with water sampling events. The images were then imported into ArcGIS Pro.

Once in ArcGIS Pro, the natural colour band combination was selected for classifying the images. Using the Forest Inventory shapefile, areas of specific land uses were selected to be used as training sample sites. In order to ensure the uniqueness of the spectral bands, a spectral profile of the training samples was created. Based on the initial spectral profile of the training samples, the spectral profile of the reforestation training samples was not unique and overlapped with the other training samples. If the image had been classified with these training samples, then many pixels would be inaccurately classified as a different land use. To address this, the reforestation class was merged with the clearcut class, the training samples were reselected, and another spectral profile was created (Figure 9).

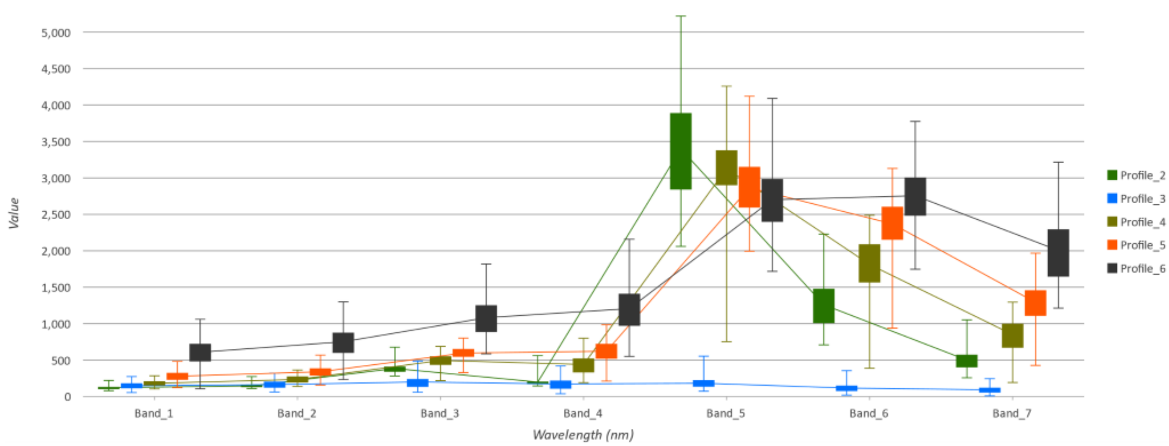

Figure 9: Spectral profiles of the various training samples. Profile 2 corresponds to forested, profile 3 with waterbodies, profile 4 to wetlands, profile 5 to clearcut or barren, and profile 6 to residential

The spectral profile in Figure 9 illustrates that the profile in each band is fairly unique and there was minimal overlap, therefore the selected training samples were used for the classification.

Spectral bands to be used in the classification were identified by creating an image scatter plot and selecting band combinations that had the least statistical correlation. Bands 5, 6, and 4 had the lowest R^2 values when compared against each other, were the least correlated, and were chosen to display red, green, and blue, respectively. These bands are known as the Land/Water analysis or false colour combination (ESRI, 2013). This band combination is best for distinguishing land from water (USGS, n.d.). It was important to ensure adequate distinction between land and water, as many lakes in the watershed appear green in satellite imagery due to algae growth and were classified as land when using the natural colour band combination.

The Support Vector Machine (SVM) classifier was used to conduct the supervised classification. This tool is a powerful supervised classification method that can handle raster inputs, and is less influenced by noise, correlated bands, and unbalanced number of training samples (ESRI, 2016). The accuracy assessment involved selecting 300 accuracy assessment points in each image, split evenly between the upper, middle, and lower portions of the image. The accuracy assessment points were then ground truthed by comparing the assigned classification to the NS Forest Inventory layer and satellite imagery. A confusion matrix was created and illustrated the user's accuracy or errors of commission and the producer's accuracy or errors of omission. These errors were summarized by the Kappa index of agreement, which provides an overall assessment of the accuracy of the classification. Generally, if a Kappa value is above 0.8, the image is considered to be accurately classified. All classified images had a kappa value greater than 0.8. Once accurately classified, the images were converted from a raster to polygon, and then clipped to the watershed polygons. The total area of each land cover type in each watershed was then determined.

3.3.4 Septic Systems

The Digital Property layer for Nova Scotia (Province of NS) was used to identify residences within the watersheds. On this layer, residences appear as points. The residences were then clipped to each watershed. A buffer of 300 m was applied to each lake, as it was assumed that septic systems farther than 300 m from a watercourse would not have an impact (Brylinsky, 2004). Maps of each study lake including residences within the 300m buffer are presented in Appendix D (Figures 32-41). The number of residences within 300 m of each lake were totalled.

The POWSIM (Sinclair et al., 2014) was used to predict P loading from septic systems. Several additional parameters were needed for POWSIM; for each watershed this included the average distance between residences and the lake, average slope, dominant soil type, and average system age. Slope was determined from the DEM and soil type was determined from a provincial soil survey (CANSIS). Approximate system age was determined by examining Statistics Canada census data (Statistics Canada, 2016) for Digby and Yarmouth counties and calculating the average year of construction. For example, if 44.7% of the houses in Digby county were constructed in 1960 or earlier, than 44.7% of the houses were assumed to have an approximate age of 60 years. The average residence age in Digby and Yarmouth counties was determined to be 42 years, and it was assumed that this represented the mean age of septic systems in all watersheds.

3.3.5 AGRICULTURE

Phosphorus inputs from mink farms were determined based on the assumption that 0.15 kg of P is produced in mink manure for every pelt produced during a growing season (Newell, 1999). Statistics Canada agricultural census data (Statistics Canada, 2018), was first examined to determine that approximately 30% of Canada's mink farms are located in Nova Scotia and approximately 72% of Nova Scotia's mink farms are located in Digby and Yarmouth counties. The agricultural census also included data for the number of mink produced in the country and in each province (Statistics Canada, 2017) on an annual basis dating back to 1972. From these two datasets the number of mink produced in Digby and Yarmouth counties was estimated for each of the study years.

To identify mink farms in each watershed the Buildings Layer of the Nova Scotia Topographic Database (Province of Nova Scotia, 2015) was clipped to the Digby and Yarmouth county polygons. Polygons labelled as "Fur Farm" or "Fur Farm with Building" were then selected. The selected polygons were compared with current Landsat satellite imagery to confirm that they were a mink farm. Mink farms have a distinct shape as they are clusters of buildings that are approximately 3 m x 50 m.

For each study year the total number of mink produced in Digby and Yarmouth counties was divided by the total area of mink sheds in Digby and Yarmouth counties to determine the average number of mink produced per m^2 of mink shed. This value was then multiplied by the mass of P produced per mink to determine the mass of P produced per m^2 of mink shed (Table 8). For the 2008 and 1983 study years satellite images were examined to confirm when mink farms were present in each watershed (i.e the mink shed polygon layer was compared with the 1983 satellite image, and if a mink farm in the polygon layer did not appear on the satellite image then that farm was founded more recently than 1983).

Table 8: Computed P inputs from mink farms for the three study years

Year	Area of Mink Sheds (m^2)	Number of Mink	Mink/m^2	kg P/m^2
2017	233,621	1,154,088	4.9	0.74
2008	224,166	888,084	4.0	0.59
1983	116,656	165,331	1.4	0.21

The mink shed polygon layer was then clipped to each watershed and the area of mink farms in each watershed was multiplied by the kg P/m^2 coefficient for that year to determine how much P was generated in mink waste in each watershed. The mass of mink farm P generated in each watershed was multiplied by an export coefficient to calculate the mass of mink farm P that is exported to a watercourse (Section 3.4.3.4).

3.4 Parameterization of the P Loading Model

3.4.1 Lake Morphology

Morphological characteristics were determined using available bathymetric information (Brylinsky, 2011) (Table 9). Bathymetric information was available for nine of the study lakes, but not available for Placides Lake and all additional lakes. All available bathymetric maps are included in Appendix C. Based on Equation 3 in Section 2.3.1, the concentration of P in the lake can still be estimated without the volume or mean depth being known, so lakes without bathymetry could still be included in the analysis.

Table 9: Morphological characteristics of the study lakes

Lake	Surface Area (ha)	Mean Depth (m)	Max. Depth (m)	Volume (m^3)
Nowlans	77	3.3	8	925,834
Provost	93	3.1	9	1,057,810
Hourglass	35	2.1	7	666,581

Lake	Surface Area (ha)	Mean Depth (m)	Max. Depth (m)	Volume (m^3)
Placides	84	N/A	N/A	N/A
Porcupine	138	9.6	13	14,100,410
Parr	367	3.2	9	10,529,820
Ogden	310	4.4	18	11,674,510
Fanning	138	4.2	11	5,010,224
Sloans	152	6.7	22	10,469,700
Vaughan	495	5.1	18	23,696,802

3.4.2 HYDROLOGY

Hydrology inputs included annual precipitation, annual lake evaporation and annual runoff. The annual precipitation was determined using data from the nearest Environment and Climate Change Canada climate station, which was determined to be the Yarmouth station (Climate ID 8206495). The annual precipitation was 1228 mm in 2017, 1321 mm in 2008, and 1370 mm in 1983. The average annual lake evaporation was estimated using climate normals generated from the Kentville climate station (Climate ID 8202800), which was 583 mm/yr for the 1981-2010 time period. An average annual runoff of 900 mm/yr was estimated from an isogram of mean annual runoff for Nova Scotia (Environment Canada, 1985).

3.4.3 PHOSPHORUS INPUTS

3.4.3.1 Land Runoff Loading

For each land cover present in the study watersheds, P export coefficients were identified from literature (section 2.2.1). Table 10 presents a summary of P export coefficients for different land uses and the literature reference. There is considerable variability in reported export coefficients for some land covers, therefore a calibration process was applied using a headwater lake with no anthropogenic sources of P (Clearwater Lake). The calibration process is summarized in section 3.6.

Table 10: Summary of P export coefficients

Land Use	P Export Coefficient Range ($g/m^2/yr$)	Reference
Developed	0.025 – 0.035	Maine Department of Environmental Protection (2000), Brylinsky (2004)
Clearcut	0.0078 – 0.0233	Dillon and Kircher (1975), Scott et al (2000), Hart et al (1978)
Forest	0.0054 – 0.0117	Dillon and Kircher (1975), Scott et al (2000), Dillon and Molot (1997), Dillon et al (1991),
Wetlands	0.03	CWRS (2017)

3.4.3.2 Internal Loading Rates

Internal loading of P from lake sediments was estimated using regression and predictive equations developed by Nurnberg (1986, 1987, 1995, 1997). The release rate of P was estimated by:

$$RR = (12.116 \times \log TP) - 9.708 \qquad (4)$$

where RR is the release rate ($mg/m^2/d$), and TP is the total P concentration (mg/L).

The anoxic factor (AF) is a measure of how many days in a year the sediment surface of a lake is anoxic, and was estimated by:

$$AF = -35.4 + [44.2 \times (\log TP + 0.95) \times MI] \qquad (5)$$

where MI is the morphometric index. It is computed as:

$$MI = \frac{z}{\sqrt{A}} \qquad (6)$$

where z is the average lake depth (m) and A is the lake area (km^2). The release rate and the anoxic factor were then multiplied to determine the internal loading factor, in units of $mg/m^2/yr$, which is the amount of P released per square metre of anoxic sediment surface per year. A summary of this factor is presented in Table 11. Internal loading for Placides Lake could not be calculated since a bathymetric survey of this lake has not been completed and the mean depth is unknown.

Table 11: Internal P loading factors for the study lakes using 2017 TP measurements

Lake	Release Rate	Morphometric Index (mg/m^2/day)	Anoxic Factor (days/yr)	Internal Load Factor (mg/m^2/yr)
Nowlans	24.1	3.8	92	2215
Provost	8.0	3.2	32	259
Hourglass	12.9	3.5	50	647
Placides	24.0	N/A	N/A	N/A
Porcupine	3.8	8.2	22	82
Parr	10.8	1.7	41	440
Ogden	7.4	2.5	29	219
Fanning	7.2	3.6	30	215
Sloans	-2.0	5.4	0	0
Vaughan	5.1	2.3	21	106

The internal load factor was then multiplied by the surface area of anoxic lake sediments in each lake. Historical temperature and dissolved oxygen profiles (Appendix A) measured during the study years were reviewed to determine if a lake became anoxic (< 2 mg/L). Once the depth of anoxia was known, bathymetric maps were used to determine the surface area of lakebed sediment that would have been exposed to anoxic conditions. The internal load factor was multiplied by this area to determine the mass of P released per year. Table 12 summarizes the predicted internal loading from the 2017 and 2008 study years. Internal loading for the 1983 model was not calculated as dissolved oxygen profiles were not available.

Table 12: Estimated internal P load for the 2017 and 2008 study years

Lake	2017 Internal P Load (g/yr)	2008 Internal P Load (g/yr)
Nowlans	0	721,343
Provost	0	0
Hourglass	5293	33,461
Placides	0	0
Porcupine	0	18,522
Parr	0	0
Ogden	2579	10,774
Fanning	3576	31,051
Sloans	0	0
Vaughan	0	937

Internal P loading was estimated to be greater in 2008 than 2017, as 2008 was a drier, warmer summer with greater levels of hypolimnetic anoxia.

3.4.3.3 Septic System Loading

The POWSIM model was used to produce an annual P load from septic systems for each watershed (Table 13). These loads were included in the P loading model as a point source input.

Table 13: Estimated annual P loading from septic systems in each watershed. P loads were estimated for the latest study year (2017) to simulate worst case scenario

Lake	Annual P Load (kg/yr)
Nowlans	2.0
Provost	4.1
Hourglass	3.2
Placides	0.0
Porcupine	2.4
Parr	5.0

Lake	Annual P Load (kg/yr)
Ogden	17.8
Fanning	18.6
Sloans	7.7
Vaughan	43.8

3.4.3.4 Mink Farm Loading

Total P loading from mink farms was estimated by multiplying the P loading coefficients (Table 8) by the area of mink sheds in each watershed (Table 14). This table only shows the mass of P produced in each study lake subcatchment, however, the mass of P produced in the subcatchments of each additional lake was also calculated and included in the model.

Table 14: Estimated P production from mink farms in the study lake subcatchments

Lake	Mass Phosphorus Produced (kg/yr)		
	2017	2008	1983
Nowlans	20253	14910	3157
Provost	4005	2975	250
Hourglass	2733	2192	0
Placides	65373	50268	5425
Porcupine	9806	7864	172
Parr	0	0	0
Ogden	0	0	0
Fanning	0	0	0
Sloans	1971	0	0

Lake	Mass Phosphorus Produced (kg/yr)		
	2017	2008	1983
Vaughan	9531	7643	1902

These values represent the mass of P generated by mink farms in each watershed before accounting for retention of P in waste management systems and drainage pathways between the mink farm and the lake. A P export coefficient was also included in the model to simulate the attenuation of P loads from mink farms. Three different export coefficients (0.25, 0.50 and 0.75) were applied in the model to simulate a range of P export and retention on mink farms. Export coefficients were also determined using a fitting process; the solver tool in Microsoft Excel was used to adjust the retention coefficient for each lake until the predicted TP concentration matched the measured TP concentration for that study year.

3.4.3.5 Aquaculture Loading

There is an aquaculture facility on Hourglass Lake that discharges effluent to the lake. Effluent flow rates and TP concentrations in influent and effluent have been monitored since 2013 and were used to compute annual P loads. The average difference in TP concentration between the influent and effluent was computed to be 0.04 mg/L. The facility uses two pumphouses, so the average flow rate from each was determined and summed to find the total average flow rate. The total average flow rate was multiplied by 0.04 mg/L to estimate the annual P load, which was then used as a point source input in the P loading model.

3.5 Model Computations

3.5.1 Hydrologic Computations

The precipitation input to each lake was computed as:

$$Ppti = Pr \times Ao \tag{7}$$

where Ppti is the total precipitation input (m^3/yr), Pr is the annual precipitation (m/yr), and Ao is the surface area of the lake (m^2). Similarly, the evaporation loss from the lake was computed as:

$$Eo = Ev \times Ao \tag{8}$$

where Eo is the total evaporation loss (m^3/yr), and Ev is the annual evaporation (m/yr). The hydraulic surface runoff is a measure of the amount of water entering the lake from surface runoff. It was computed as:

$$Ql = Ru \times Ad \tag{9}$$

where Ql is the total hydraulic surface runoff (m^3/yr), Ru is the annual unit runoff (m/yr), and Ad is the drainage basin area (m^2). The total hydraulic input is the sum of all water inputs into the lake and was computed as:

$$Qt = Ppti + Ql + Qi \tag{10}$$

where Qt is the total hydraulic input (m^3/yr), and Qi is the total upstream hydraulic inputs (m^3/yr). The areal hydraulic load is the amount of water entering the lake relative to the surface area of the lake. It was computed as:

$$qs = \frac{Qt - Eo}{Ao} \tag{11}$$

where qs is the areal hydraulic load (m^3/yr). The total annual hydraulic outflow was computed as:

$$Qo = Qt - Eo \tag{12}$$

where Qo is the total hydraulic outflow (m^3/yr). Qo also acts as the total upstream hydraulic input (Qi) for the next lake in the system.

3.5.2 *Phosphorus Mass Balance Computations*

The second set of model outputs contains the predicted P concentration and the loads from various sources. The first parameter is the atmospheric P input. This is the mass of P deposited atmospherically each year. It was computed as:

$$Jd = D \times Ao \tag{13}$$

where Jd is atmospheric P input (g/yr), D is the annual unit atmospheric deposition ($g/m^2/yr$), and Ao is the lake surface area (m^2). The annual unit atmospheric deposition was assumed to be 0.0173 $g/m^2/yr$ (CWRS, 2017). The total surface runoff P input was computed as:

$$Je = \sum Ad_i \times E_i \tag{14}$$

where Je is the surface runoff P (g/yr), Ad is the area of each land use (m^2), and E is the P export coefficient ($g/m^2/yr$) for the corresponding land use for i number of land uses. The development P input was computed as:

$$Jr = Ps_i + Ps_s + Ps_m + Ps_a \tag{15}$$

where Jr is the development P input (g/yr), Ps_i is the internal load point source (g/yr), Ps_s is the septic system point source (g/yr), Ps_m is the mink point source (g/yr), and Ps_a is the aquaculture point source (g/yr).

The total P input is the sum of all previously mentioned P inputs and is computed as:

$$Jt = Ji + Jd + Je + Jr \tag{16}$$

where Jt is the total P input (g/yr), and Ji is the upstream P input (g/yr). The lake P retention factor (Rp) is the percentage of input P that is lost to the sediment. This P becomes trapped in the sediment and does not contribute to the concentration of P in the water column. This factor is computed as:

$$Rp = \frac{v}{v+q_s} \tag{17}$$

where Rp is the lake P retention factor, v is the P retention coefficient, and qs is the areal hydraulic load (m/yr). The P retention coefficient is 12.4 for lakes with oxic hypolimnion and 7.2 for lakes with an anoxic hypolimnion (Brylinsky, 2004). The lake P retention was computed as:

$$Ps = Jt \times Rp \tag{18}$$

where Ps is the lake P retention (g/yr). The total P outflow was computed as:

$$Jo = Jt - Ps \tag{19}$$

where Jo is the total P outflow (g/yr). This value is also the upstream P input into the next lake in the system. The concentration of phosphorus in the lake was computed as:

$$[P] = \frac{Jo}{Qo} \tag{20}$$

where [P] is the concentration of P in the lake (mg/L).

All the above equations were input into an excel model (Appendix A). Models for each lake in the watershed, both study lakes and additional lakes, were constructed on individual worksheets. The lakes were connected in series by linking the hydraulic and P outputs of one lake as the inputs of the next lake. A breakdown of the relative contribution of each P source was also completed in the excel model. The entire modelling process was repeated for each of the three study years.

3.6 CALIBRATION OF P EXPORT COEFFICIENTS

Calibration of the land runoff P export coefficients was conducted on the Clearwater Lake watershed, as it possessed minimal residential and agriculture development. Values of the P export coefficients from within the literature ranges (Table 10) were selected until an acceptable fit between predicted and measured TP concentrations was achieved. The calibrated coefficients are presented in Table 15.

Table 15: Calibrated land runoff P export coefficients

Land Use	P Export Coefficient ($g/m^2/yr$)
Developed	0.03
Clearcut	0.0175
Forest	0.0095
Wetlands	0.03

With the calibrated coefficients, Clearwater Lake had a predicted TP concentration of 0.0039 mg/L, with a -2.7% difference when compared to the measured TP concentration of 0.004 mg/L. These coefficients were applied to all other lakes in the model. Model performance was assessed for other study lakes by computing the percent difference between predicted and measured TP concentrations, as presented in Table 16. This table illustrates the model performance of the 2017 model and evaluates three of the mink loading scenarios.

Table 16: Model performance of three mink P loading scenarios in the 2017 model

Lake	Measured TP (mg/L)	No Mink		25% Export		Fitted Mink Export Coefficients	
		TP (mg/L)	% Diff	TP (mg/L)	% Diff	TP (mg/L)	% Diff
Nowlans	0.6233	0.003982	-99.36	0.428306	-31.28	0.6233	0.00
Provost	0.029	0.006479	-77.66	0.062783	116.49	0.029	0.00
Hourglass	0.073	0.019612	-73.13	0.155993	113.69	0.073	0.00
Placides	0.63	0.00904	-98.57	0.714231	13.37	0.63	0.00
Porcupine	0.013	0.005758	-55.71	0.098706	659.28	0.013	0.00

Lake	Measured TP (mg/L)	No Mink		25% Export		Fitted Mink Export Coefficients	
		TP (mg/L)	% Diff	TP (mg/L)	% Diff	TP (mg/L)	% Diff
Parr	0.049	0.007029	-85.65	0.044735	-8.70	0.038974	-20.46
Ogden	0.061	0.006788	-88.87	0.038982	-36.10	0.034064	-44.16
Fanning	0.025	0.006989	-72.04	0.034624	38.50	0.030544	22.18
Sloans	0.0037	0.004344	17.41	0.026308	611.04	0.004344	17.41
Vaughan	0.0167	0.005725	-65.72	0.028527	70.82	0.018973	13.61

As seen in Table 16, the no mink model underpredicted TP concentrations in all lakes except for Sloans Lake. Sloans Lake, however, is within the generally accepted range of ± 20% difference (Brylinsky, 2004). In the 25% export model, TP concentrations in most lakes are overpredicted. When the mink export coefficients were calibrated, which involved using the Excel Solver Tool to adjust the mink farm P retention parameter to match the measured and predicted TP values in headwater lakes, the downstream lakes generally were modeled with reasonable accuracy.

4 RESULTS AND DISCUSSION

4.1 2017 MODELING SCENARIOS

4.1.1 PREDICTED TOTAL PHOSPHORUS CONCENTRATIONS

The predicted TP concentrations, for the various modeling scenarios, are illustrated in Table 17 and Figure 10. The baseline model represents a scenario with no anthropogenic sources of P in the watersheds and indicates that TP concentrations in all of the study lakes would be in the oligotrophic range. The no mink farming scenario includes all anthropogenic P sources except for the mink farm P inputs. Similar to the baseline condition, all lakes were predicted to possess P concentrations in the oligotrophic range, with the exception of Hourglass Lake. The inputs of P from the aquaculture facility on Hourglass Lake were predicted to shift this lake into a mesotrophic state.

The remaining three modeling scenarios included P inputs from mink farms assuming varying levels of P retention. Scenarios utilizing export coefficients of 0.75 (25% retention), 0.50 (50% retention) and 0.25 (75% retention) were generated to assess the sensitivity of model outputs to mink farm P retention. Nowlans Lake and Placides Lake were predicted to have the highest TP concentrations and were the most sensitive to additional P from mink farm sources (Figure 7, Table 17). The watersheds of these two headwater lakes contain the highest number of mink (Table 14). It was found that the relationship between mink farm density in a watershed and the measured TP had a strong linear correlation, with an R^2 value of 0.95.

The addition of the mink farm sources to the model resulted in increases in predicted TP concentrations in both headwater and downstream lakes, with a change in trophic state predicted to occur in all lakes. The model scenario with mink farm P inputs and an export coefficient of 0.25 (75% retention) generated predicted TP concentrations, and trophic state classifications, that best represented measured TP concentrations. It should be noted that available measured TP concentrations were limited to a single sampling event in August, whereas the model is providing an estimate of the average annual TP concentration, therefore direct comparisons should be undertaken with caution.

Table 17: Predicted lake TP concentrations for different loading scenarios in the 2017 model. Colour coded to show trophic state (oligotrophic, mesotrophic, meso-eutrophic, eutrophic, and hypereutrophic).

Lake	Lake TP (mg/L)					
	Measured	Baseline	No Mink	75% Retention	50% Retention	25% Retention
Nowlans	0.6233	0.003	0.004	0.428	0.853	1.277
Provost	0.029	0.005	0.006	0.063	0.119	0.175
Hourglass	0.073	0.005	0.020	0.156	0.289	0.418
Placides	0.63	0.006	0.009	0.714	1.419	2.123
Porcupine	0.013	0.004	0.006	0.099	0.192	0.285
Parr	0.049	0.006	0.007	0.045	0.082	0.120
Ogden	0.061	0.005	0.007	0.039	0.071	0.103
Fanning	0.025	0.005	0.007	0.035	0.061	0.088
Sloans	0.0037	0.003	0.004	0.026	0.048	0.070
Vaughan	0.0167	0.004	0.006	0.029	0.051	0.073

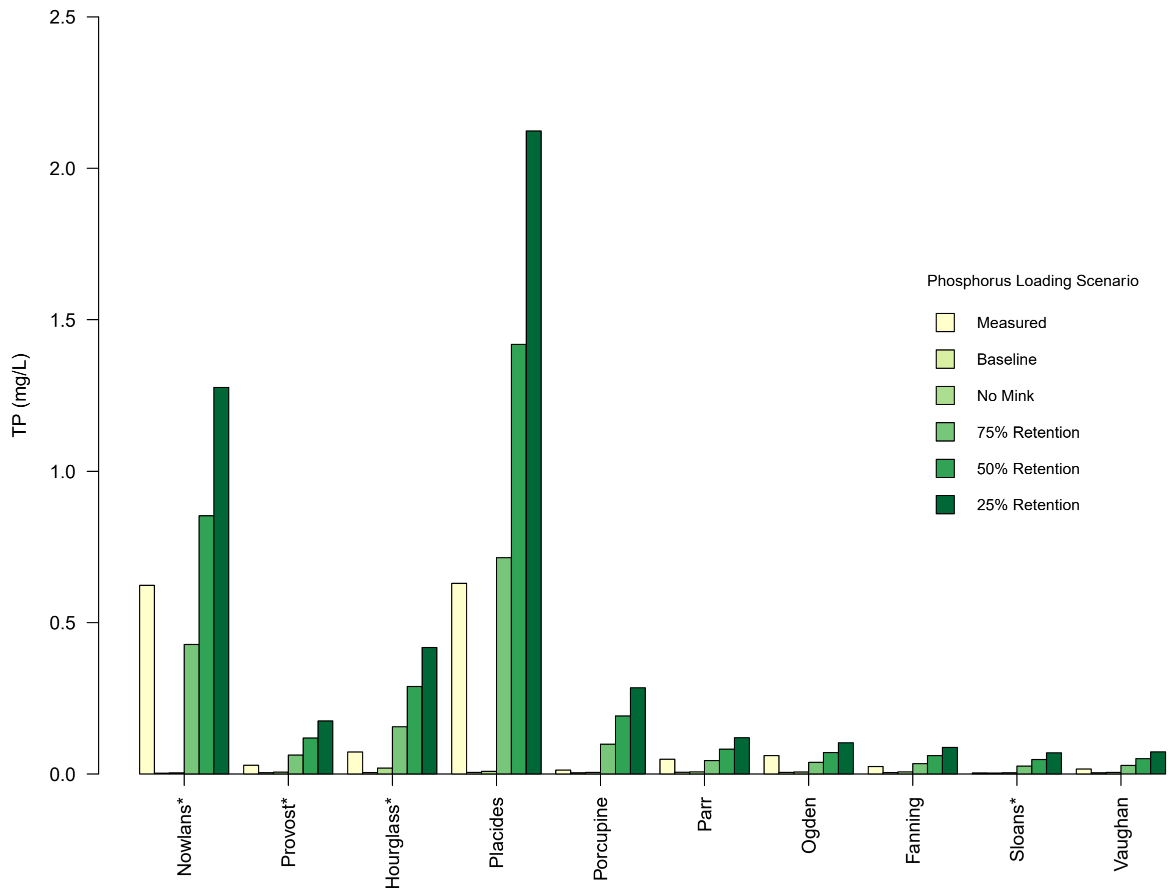

Figure 10: Predicted TP concentration for various P loading scenarios in the 2017 model

4.1.2 Phosphorus Sources

Outputs from the NSPM were used to further characterize the relative contributions of P from the various sources in each subcatchment. The P loads to each lake were broken into the following categories: upstream inputs, atmospheric deposition, internal loading, land runoff, septic systems, mink farms, and aquaculture and the fraction originating from each source were graphically displayed (Figures 11 – 13).

For the no mink scenario (Figure 11), headwater lakes such as Nowlans, Provost, Placides, Porcupine, and Sloans would obtain the majority of their P from land runoff. Phosphorus loads to downstream lakes with larger watersheds such as Parr, Ogden, Fanning, and Vaughan are dominated by upstream P inputs. The aquaculture facility adjacent to Hourglass Lake provides approximately 50% of the P load to this lake. Septic system P inputs were generally less than 10% of the P load in all subcatchments.

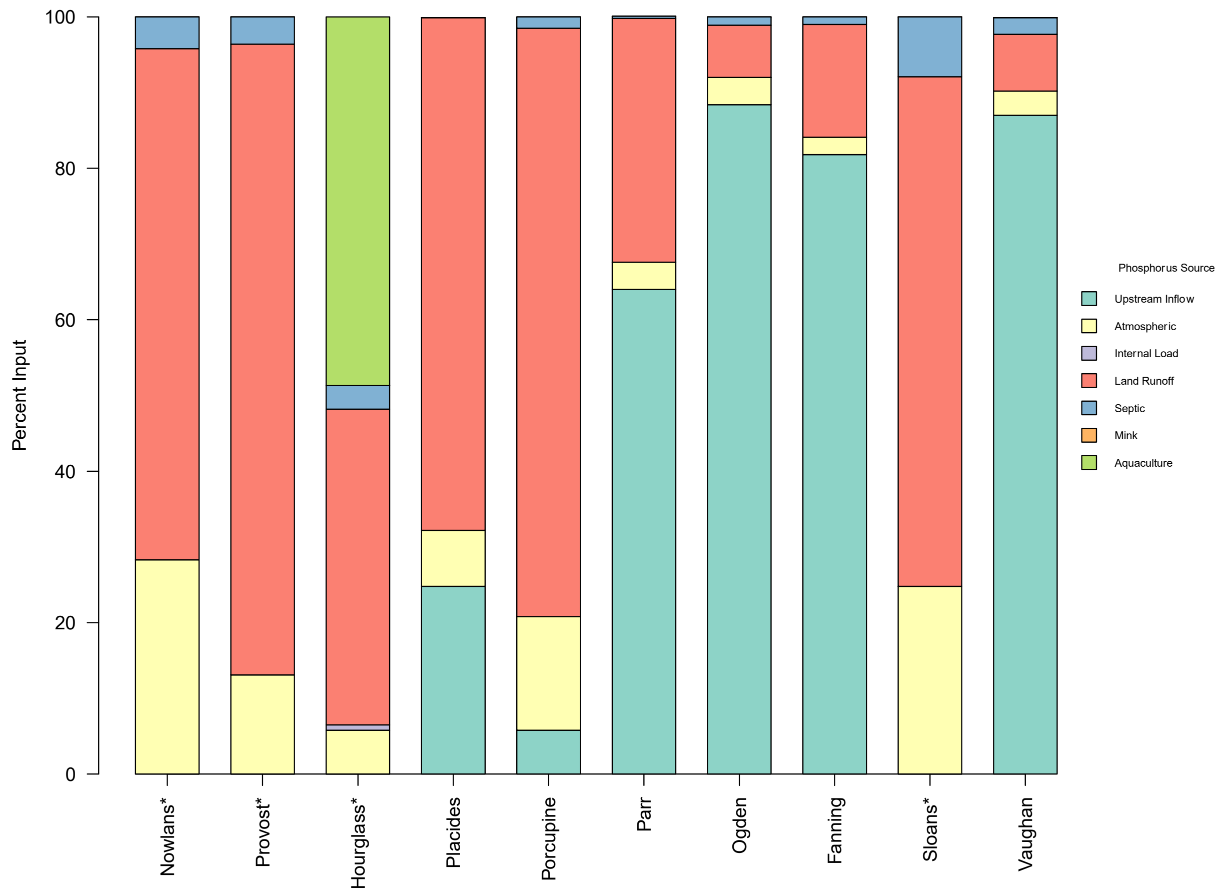

Figure 11: Percent input of P sources in the no mink modeling scenario in the 2017 model

With the addition of P from mink farms, assuming 50% retention (Figure 12), all lakes that were dominated by P inputs from land runoff were now dominated by P inputs from mink farms. Nowlans, Provost, Hourglass, Placides, Porcupine, and Sloans Lake were all predicted to obtain greater than 90% of their lake P inputs from mink farms. Parr, Ogden, and Fanning do not contain any mink farms in their subcatchments (Table 14), therefore the majority of their P loads originate from upstream inputs. Lake Vaughan shows similar results as the other large downstream lakes; however it contains 9000 m^2 of mink farms and retains 28% of the P from mink farms.

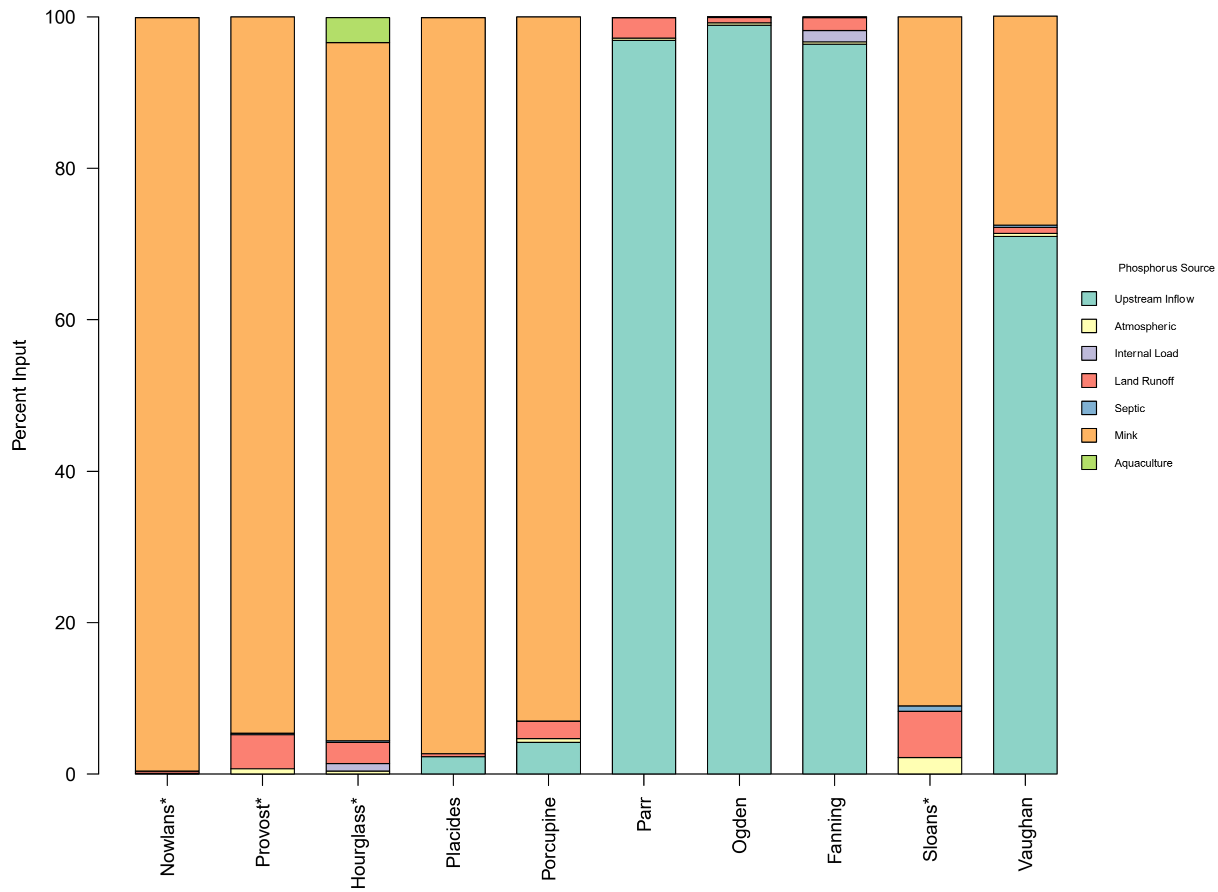

Figure 12: Percent input of P sources in the 50% mink export scenario in the 2017 model.

Figure 13 illustrates the partitioning of P sources for the model scenario where the mink farm P export coefficients were optimized to achieve agreement between measured and predicted TP concentrations. This scenario would provide the best representation of current partitioning of P loads within the study watersheds. The export coefficients and the predicted P concentrations are summarized in Table 18.

Sloans Lake and Lake Vaughan both possessed low measured TP concentrations, resulting in a fitted mink export coefficient of zero (100% retention) for both lakes. Even with the mink export coefficient set to zero, TP concentrations in both lakes were slightly overpredicted. The over prediction in Vaughan could also be due to the inflow it receives from the Tusket River. The Tusket flows into Vaughan near its outlet, however this additional unaccounted hydraulic input could explain why Lake Vaughan was consistently over predicted in this model.

Table 18: Fitted mink farm export coefficients and the percent difference between predicted and measured P for the 2017 model, asterisk denotes lakes that contain mink farms in their direst subcatchments.

Lake	Export Coefficient	Predicted P (mg/L)	Measured P (mg/L)	Percent Difference
Nowlans*	0.36	0.62	0.62	0
Provost*	0.10	0.029	0.029	0
Hourglass*	0.09	0.073	0.073	0
Placides*	0.22	0.63	0.63	0
Porcupine*	0.02	0.013	0.013	0
Parr	0	0.039	0.049	-20.46
Ogden	0	0.034	0.061	-44.16
Fanning	0	0.031	0.025	22.18
Sloans*	0	0.004	0.004	17.41
Vaughan*	0	0.019	0.017	13.61

In this scenario headwater lakes with mink farms in their watersheds also received the majority of their P from mink farm sources (Figure 13). Fitted export coefficients in the Hourglass and Porcupine Lake were low (9% and 2%, respectively), however, mink farms were still estimated to be the dominant source of P in both systems illustrating the sensitivity of these lakes to mink farms in their subcatchments. Nowlans Lake and Placides Lake had the highest fitted export coefficients (36% and 22%) and had the largest relative contributions from mink farms. As previously discussed, they also have the highest number of mink farms in their watersheds. Although Placides has a high number of mink farms in the watershed and a large relative contribution of P from mink farms, it is possible that some of the P attributed to mink farms could be due to internal loading. Since bathymetry for Placides is not available, the P contributions from internal loading could not be calculated and may instead be represented in the model as loading from mink farms.

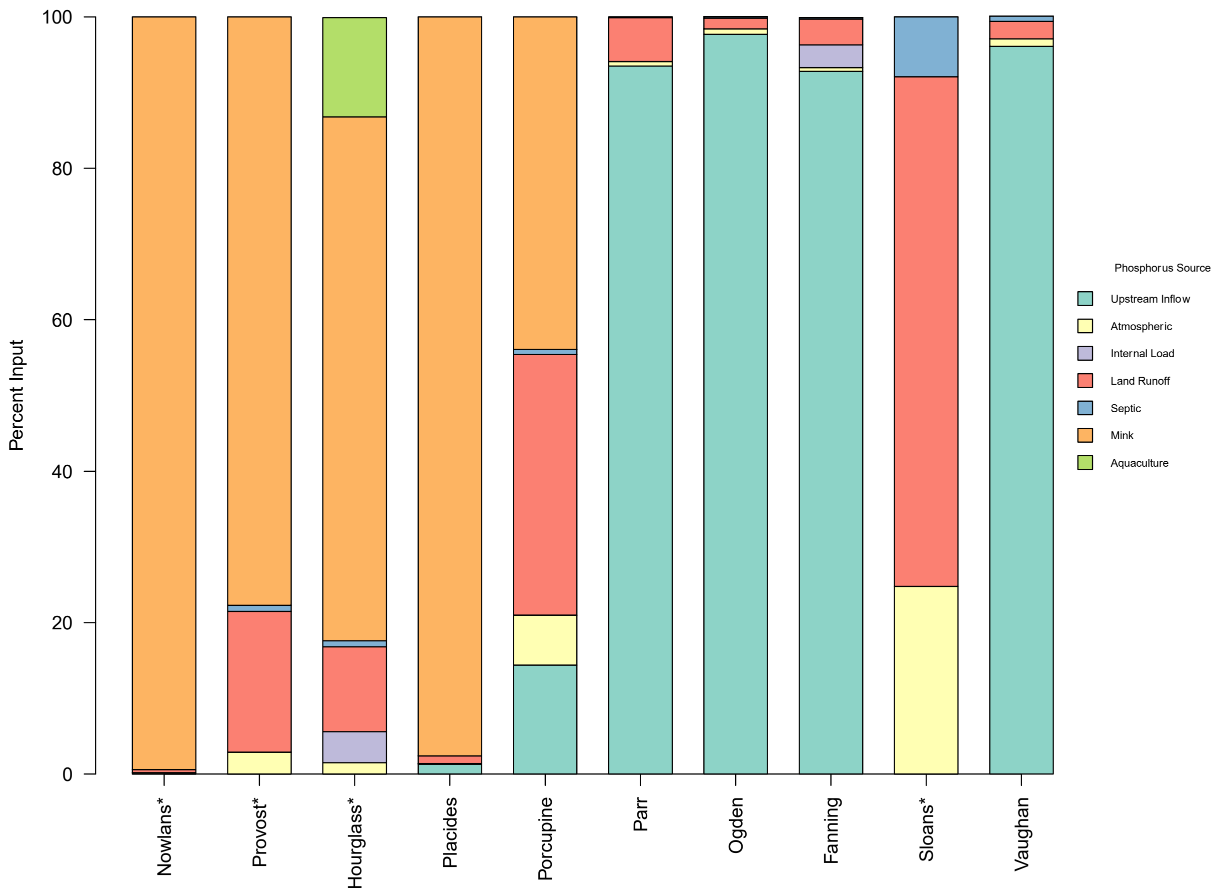

Figure 13: Percent input of P sources in the calibrated mink coefficient scenario in the 2017 model

The results of the various modeling scenarios confirmed that in watersheds that contain mink farms, the majority of the P load was from the mink farms. Other anthropogenic sources, such as septic systems and aquaculture, produced small P loads by comparison. This analysis also illustrates that the majority of P in downstream lakes does not originate from within their subcatchments, but instead is sourced from upstream inputs; mink farms in the headwater lakes are impacting the water quality of large downstream lakes. Table 19 shows the mass of P in the outflow of each lake. The difference in mass between the different scenarios highlights just how much P is added to the watershed from the mink farms.

Table 19: Total mass of P in lake outflows for various P loading scenarios (measured in kg P/yr) in the 2017 model

Lake	Total Outflow (kg/yr)		
	No mink	50% mink export	Calibrated mink export coefficient
Nowlans	9	1957	1297
Provost	45	832	203
Hourglass	53	785	198
Placides	111	17403	7726
Porcupine	60	2011	136
Parr	1483	17391	8223
Ogden	1506	15789	7558
Fanning	1745	15309	7625
Sloans	22	246	22
Vaughan	1690	14992	5599

4.1.3 Additional Septic Modeling

In addition to modeling the impacts of increased mink P export, the impacts of increased septic P export were also modeled. In this scenario, complete septic failure was modeled. POWSIM was not used to predict the concentration of P in septic outflow, instead the annual P supply contributed per capita (0.8 kg/capita/yr (Paterson et al, 2006)) was multiplied by the number of residences within a watershed and this loading rate was input into the NSPM as a point source load.

Table 20 compares the measured lake TP to the predicted lake TP in this scenario. The cells of the table are colour coded to show the trophic status of each lake, with oligotrophic being the lightest shade of green and hyper-eutrophic the darkest shade of green. The results of this modeling scenario show that even with complete septic system failure, the trophic state of the study lakes, except for Hourglass Lake and Placides Lake would be remain oligotrophic. These results show that septic system failure, even catastrophic failure through the entire community, could not account for the levels of TP currently measured in the lakes.

Table 20: Measured P compared to total septic failure predicted P in 2017 model. Colour coded to indicate trophic status (oligotrophic, mesotrophic, meso-eutrophic, eutrophic, and hypereutrophic).

Lake	Measured P (mg/L)	Predicted P (mg/L)
Nowlans	0.623	0.006
Provost	0.029	0.009
Hourglass	0.073	0.029
Placides	0.63	0.010
Porcupine	0.013	0.007
Parr	0.049	0.007
Ogden	0.061	0.008
Fanning	0.025	0.009
Sloans	0.004	0.008
Vaughan	0.017	0.008

4.2 2008 Modeling Scenario

4.2.1 Predicted Total Phosphorus Concentrations

Similar to the 2017 model, the 2008 model scenarios, and water quality monitoring results, demonstrate that Nowlans Lake and Placides Lake had the highest measured and predicted TP concentrations (Figure 14). As previously discussed, this is due to the high density of mink farms within the watersheds of these lakes.

In the baseline model scenario, no anthropogenic sources of P were included, and all lakes were predicted to possess TP concentrations in the oligotrophic range. In the no mink farm scenario, all lakes, except for Hourglass Lake due to the aquaculture facility, had a predicted TP concentration in the oligotrophic range.

The mink farm loading scenarios also yielded similar results to the 2017 model. Downstream lakes such as Parr, Ogden, Fanning, and Vaughan remained below a hyper-eutrophic level. Nowlans Lake and Placides Lake possessed the highest measured and predicted lake TP due to the high density of mink farms in their watersheds.

For all model scenarios, Sloans Lake was predicted to remain at an oligotrophic level. Sloans Lake did not have any mink farms in its watershed in 2008 and it is a headwater lake. The percent difference between measured and predicted TP in Sloans was 5.6%, providing further validation of land runoff export coefficients used.

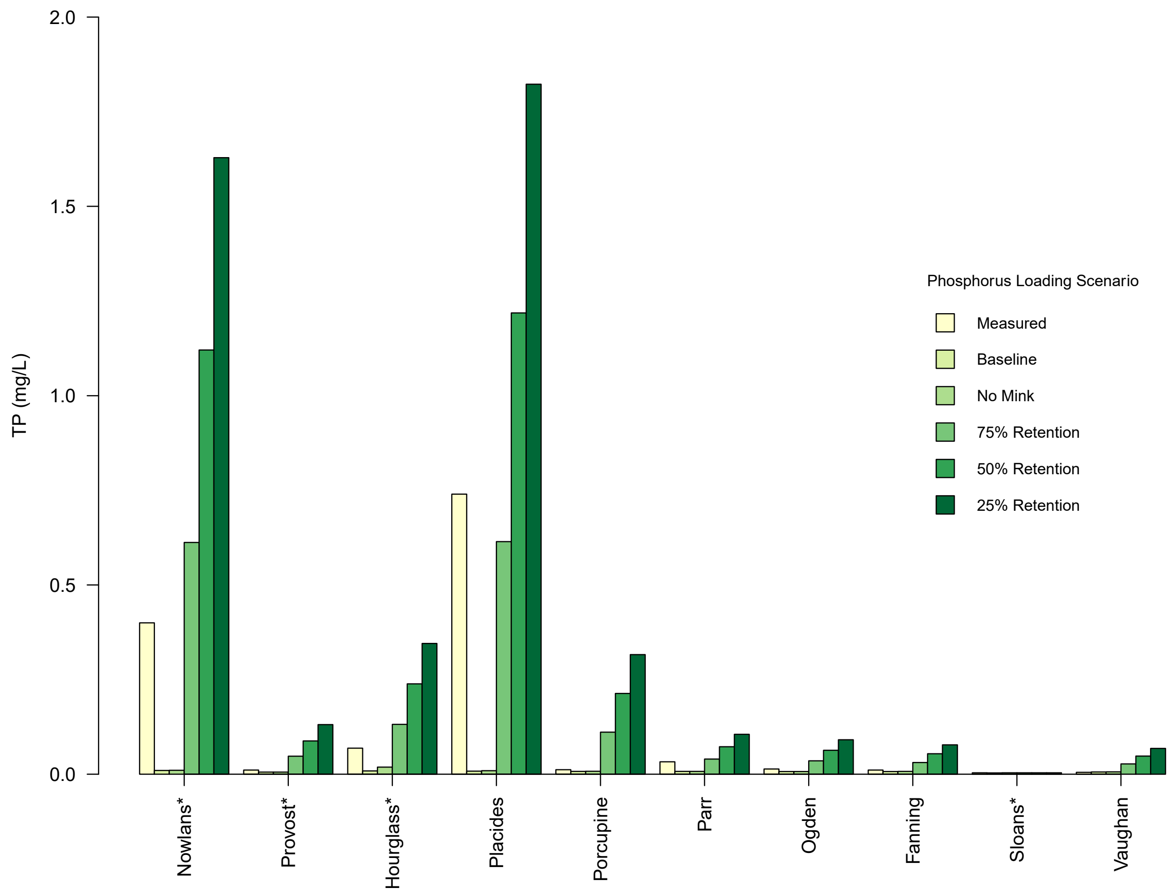

Figure 14: Results of the 2008 model with various P loading scenarios

4.2.2 Phosphorus Sources

The relative contribution of P sources within each study lake for the no mink farm scenario were similar to those estimated for the 2017 model scenario (Figure 15). Small upstream lakes were dominated by land runoff loading, and large downstream lakes were dominated by loading from upstream inputs.

The major difference between the 2008 and 2017 no mink farm scenarios is the impact of internal loading in the 2008 model, especially in Nowlans Lake. In 2017, only three lakes had dissolved oxygen profiles indicating hypolimnetic anoxia, and the surface area of sediments exposed to anoxia was small. The predicted internal P loading from sediment was therefore lower in 2017, especially in comparison to the other P sources. In 2008, seven lakes possessed dissolved oxygen profiles indicating hypolimnetic anoxia, and a much larger sediment area was anoxic in each lake. The predicted internal P loading was therefore much larger and had a greater impact on lake TP concentrations. The factors influencing the extent of sediment anoxia will be further discussed in section 4.5.

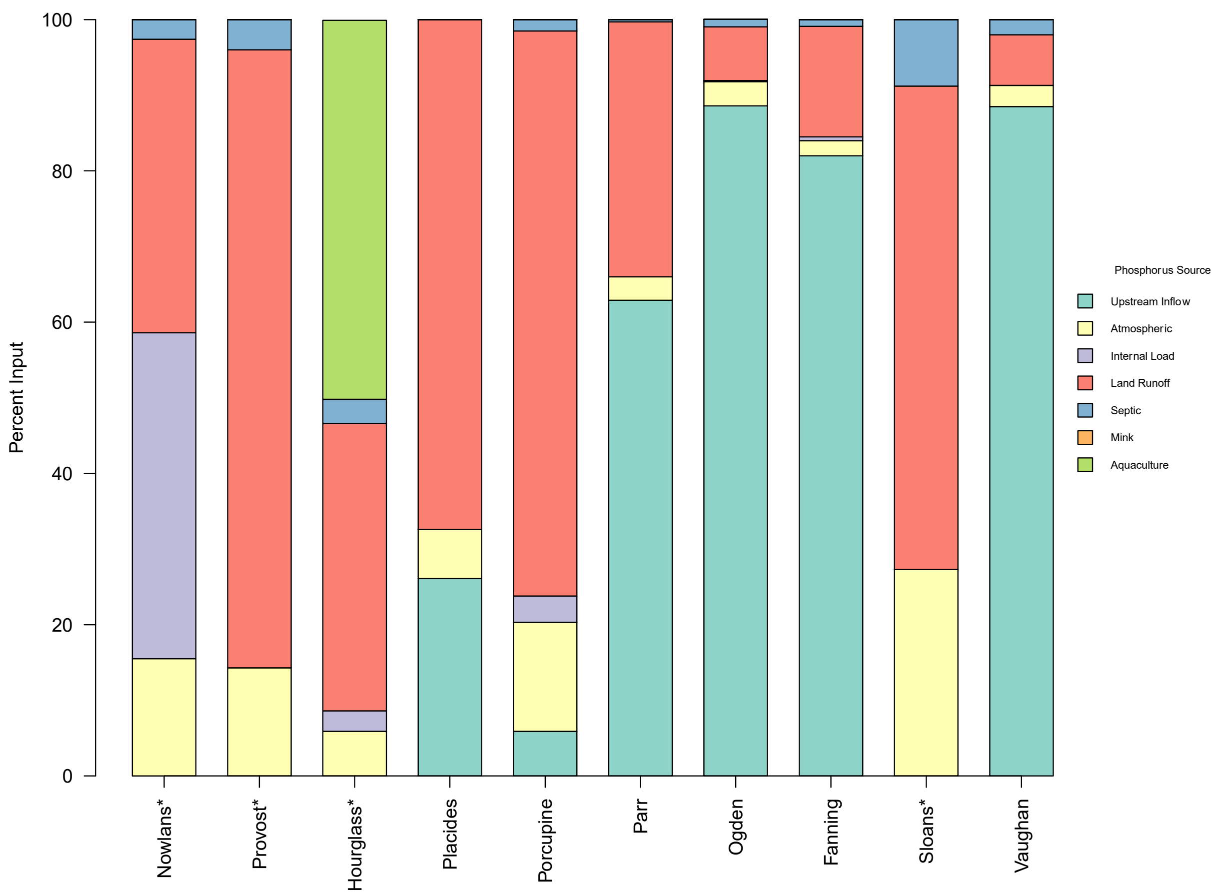

Figure 15: Percent input of P sources in the no mink scenario in the 2008 model

The relative contributions from different P sources for the 50% mink farm export scenario are provided in Figure 16. Similar to the 2017 model, it is evident that in watersheds containing mink farms, most of the P is sourced from mink farms. Large downstream lakes see increased contributions of upstream inflow loading when compared to the no farm mink scenario. The loading of P into Sloans Lake remains unchanged since there were no mink farms in the watershed.

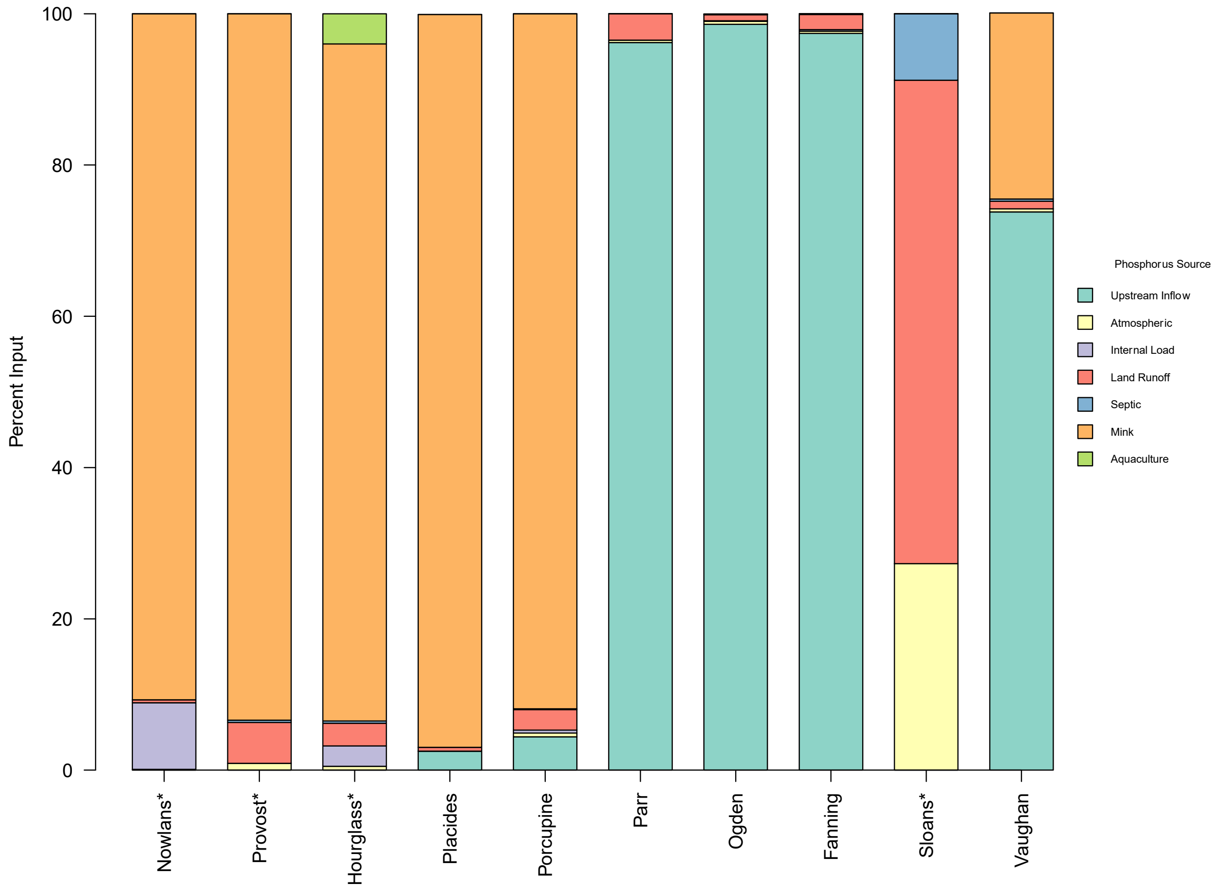

Figure 16: Percent input of P sources in the 50% mink scenario in the 2008 model

The P loading profiles generated from model results using fitted mink farm P export coefficients are shown in Figure 17 with the fitted coefficients provided in Table 21. Similar to the 2017 model, Nowlans Lake and Placides Lake have the highest mink farm P export coefficients and the highest measured P concentrations. Concentrations in some downstream lakes with no mink farms in their watersheds such as Ogden, Fanning, and Vaughan, were overpredicted which may suggest more P sedimentation than predicted; however, the measured concentrations only represent a single measurement during the summer.

Table 21: Fitted mink farm export coefficients and the percent difference between predicted and measured P for the 2008 model

Lake	Export Coefficient	Predicted P (mg/L)	Measured P (mg/L)	Percent Difference
Nowlans	0.15	0.4	0.4	0.00
Provost	0.05	0.014	0.014	0.00
Hourglass	0.10	0.069	0.069	0.00
Placides	0.31	0.74	0.74	0.00
Porcupine	0.004	0.012	0.012	0.00
Parr	0	0.035	0.033	6.46
Ogden	0	0.031	0.014	121.37
Fanning	0	0.027	0.011	148.66
Sloans	0	0.004	0.0037	5.64
Vaughan	0	0.019	0.005	284.17

Placides Lake possessed the highest P loading from mink farms (Figure 17) and the highest mink P export coefficient (Table 21). Porcupine Lake had the lowest P loading from mink farms and has the smallest export coefficient. In this scenario, internal P loading was also predicted to be a larger contributor of P loading in several lakes. When compared to the 2017 fitted coefficient model, mink farms contributed less P in the 2008 model.

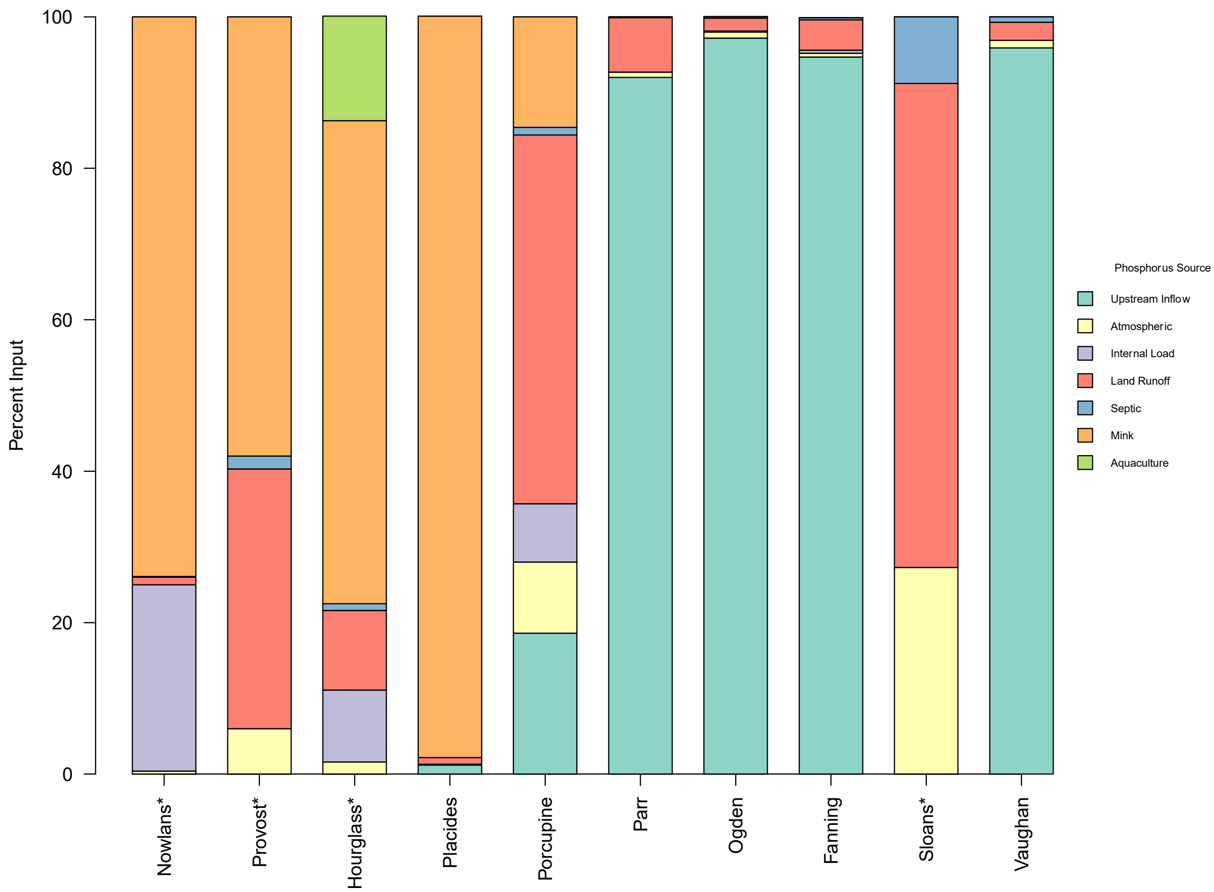

Figure 17: Percent input of P sources in the fitted coefficient scenario in the 2008 model

4.3 1983 Modeling Scenario

4.3.1 Predicted Total Phosphorus Concentrations

The year 1983 was selected to represent a scenario year prior to the dramatic increase in mink farming in the area. It was also the first year where water quality data was available for most lakes in the study domain. Unfortunately, data for Placides Lake and Porcupine Lake were not available for this time period. Table 22 summarizes the available water quality data and the sampling date.

Table 22: Summary of measured water quality data before the increase of mink farm activity

Lake	TP (mg/L)	Sampling Year
Nowlans	0.0155	1983
Provost	0.003	1983

Hourglass	0.012	1983
Placides	Not sampled	N/A
Porcupine	Not sampled	N/A
Parr	0.006	1986
Ogden	0.004	1986
Fanning	0.004	1986
Sloans	0.003	1986
Vaughan	0	1979

The 1983 model (Figure 18) shows that even with 75% export of mink P, most lakes would be mesotrophic or oligotrophic. Only Nowlans and Placides have predicted P concentrations higher than the mesotrophic range. This is because Nowlans and Placides had the highest number of mink farms in 1983 and are probably home to some of the first mink farms built in the area.

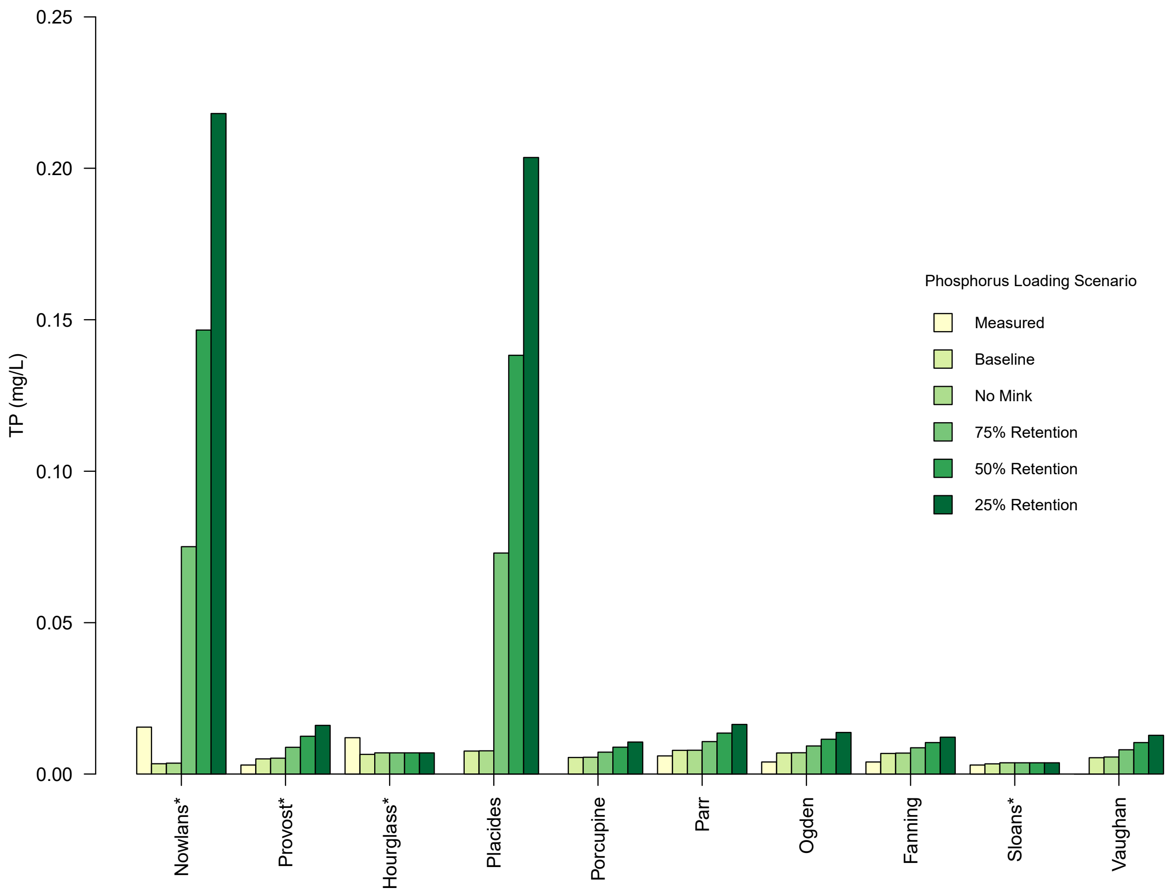

Figure 18: Results of the 1983 model with various P loading scenarios

4.3.2 PHOSPHORUS SOURCES

Results of the P loading analysis for the no mink scenario are provided in Figure 16. One major difference as compared to the 2008 and 2017 models is that there are no aquaculture inputs into Hourglass Lake; the aquaculture facility did not begin operating until 1988. Also, measured dissolved oxygen profiles were not available for this time period, so it was not possible to predict the P inputs from internal loading.

Similar to the previous models, small headwater lakes receive most of their P load from land runoff and large downstream lakes receive most of their P load from upstream inputs (Figure 19).

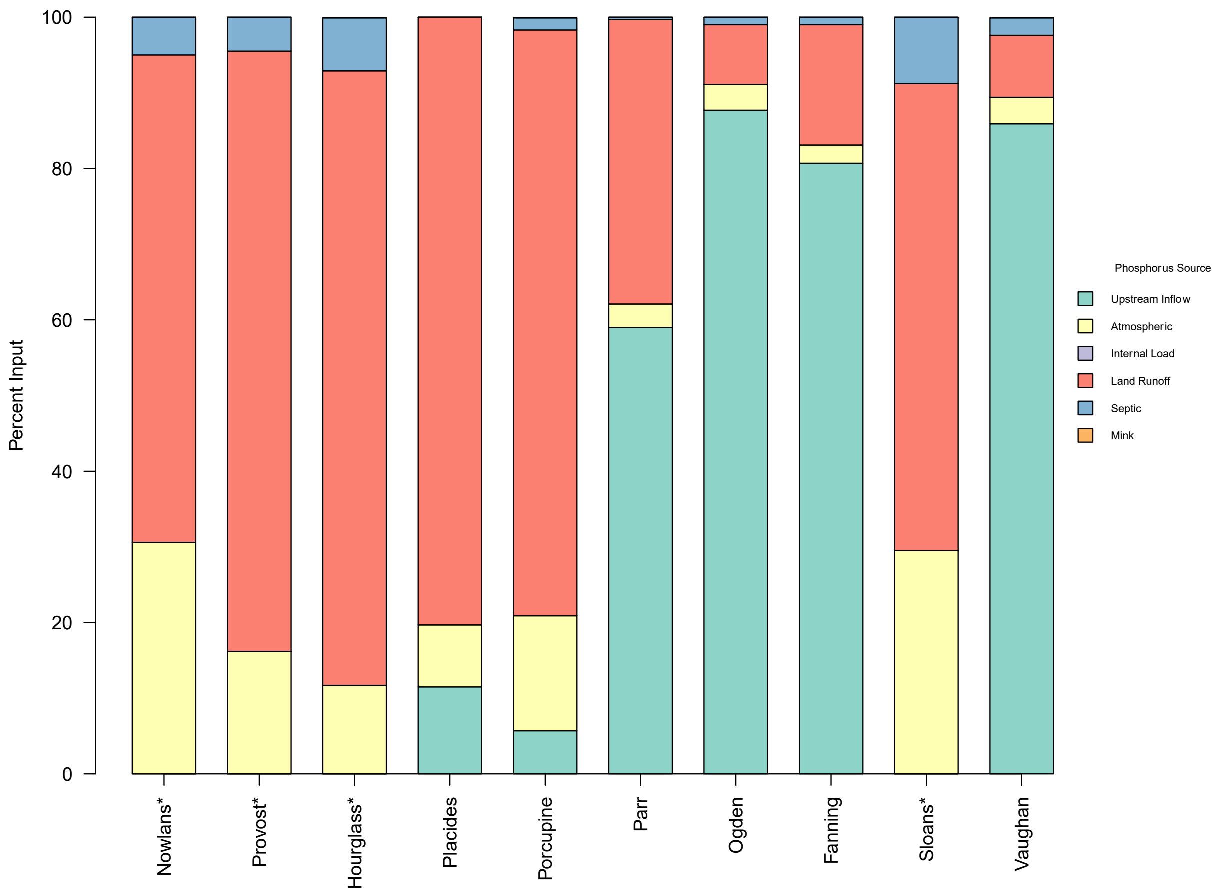

Figure 19: Percent input of P sources in the no mink scenario in the 1983 model

Results for the 50% mink farm P retention scenario are provided in Figure 20 for 1983. In this year, there were no mink farms in the Hourglass Lake or Sloans Lake watersheds. Similar to the 2008 and 2017 model scenarios, Nowlans Lake and Placides Lake have the largest P contribution from mink farms. The mink farms in these two watersheds were some of the first to be established in the region.

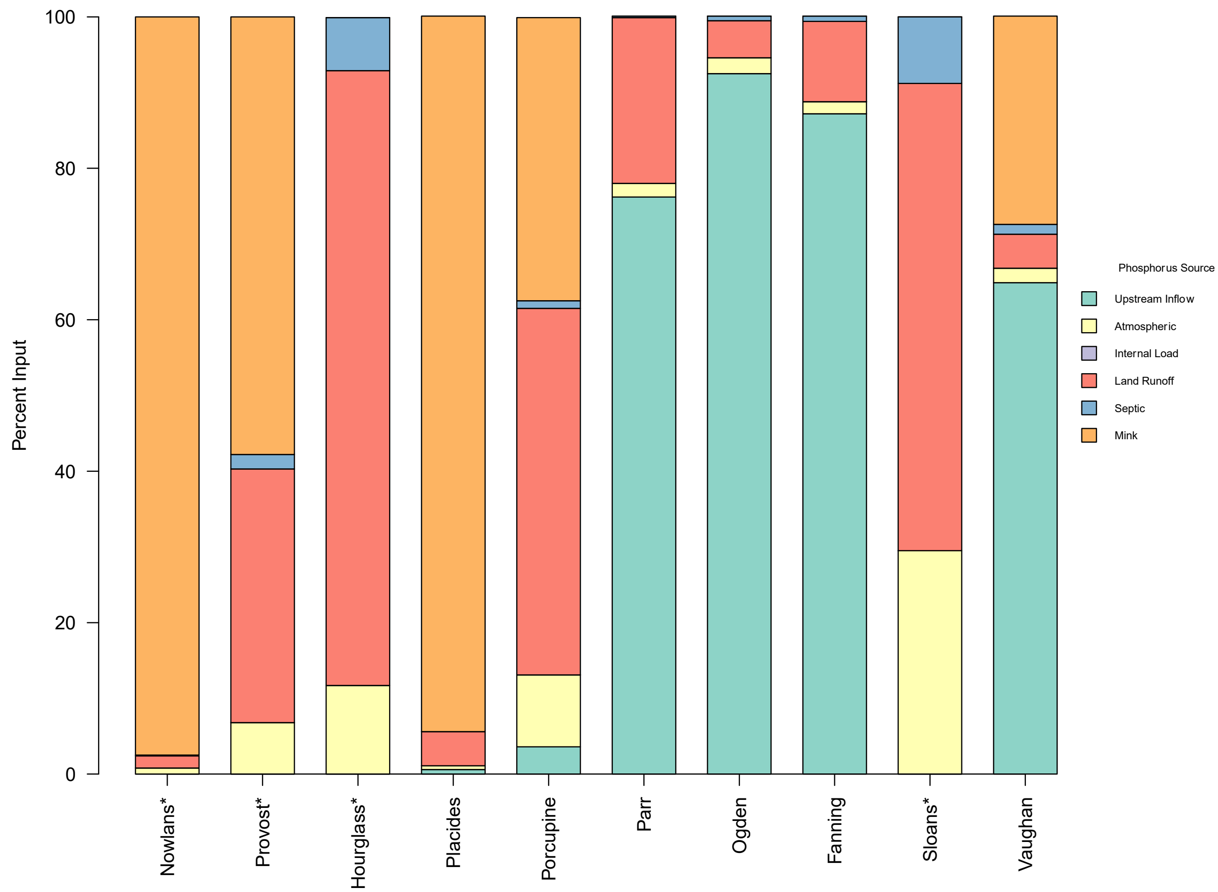

Figure 20: Percent input of P sources in the 50% mink scenario in the 1983 model

The predicted P loading profiles using model results where mink farm P export coefficients were optimized are shown in Figure 21, with the fitted coefficients provided in Table 23. Unfortunately for this modeling year, only the coefficient for Nowlans Lake could be optimized. Data was not available for either Placides Lake or Porcupine Lake, so a default export coefficient of 0.1 was assigned to both lakes. Provost and Vaughan both contained mink farms at this time, however the TP concentration in both lakes was overpredicted, so they were assigned a mink farm export coefficient of zero.

Table 23: Fitted mink farm export coefficients and the percent difference between predicted and measured P for the 1983 model

Lake	Export Coefficient	Predicted P (mg/L)	Measured P (mg/L)	Percent Difference
Nowlans	0.04	0.016	0.016	0.00
Provost	0	0.005	0.003	76.67
Hourglass	0	0.007	0.012	-41.67
Placides	0.1	0.034	N/A	N/A
Porcupine	0.1	0.006	N/A	N/A
Parr	0	0.009	0.006	50.00
Ogden	0	0.008	0.004	97.50
Fanning	0	0.008	0.004	90.00
Sloans	0	0.004	0.003	23.33
Vaughan	0	0.006	0	

With respect to P sources, Nowlans Lake and Placides Lake have the largest input from mink farms (Figure 21). However, since Placides Lake did not have water quality measurements for this sampling year, the mink P export coefficient could not be validated, therefore mink farm contributions to Placides Lake may be lower than predicted. The results of this model are similar to results of previous models; small headwater lakes receive the majority of P from mink farms in they are present in the watershed, and large downstream lakes are primarily impacted by upstream inputs.

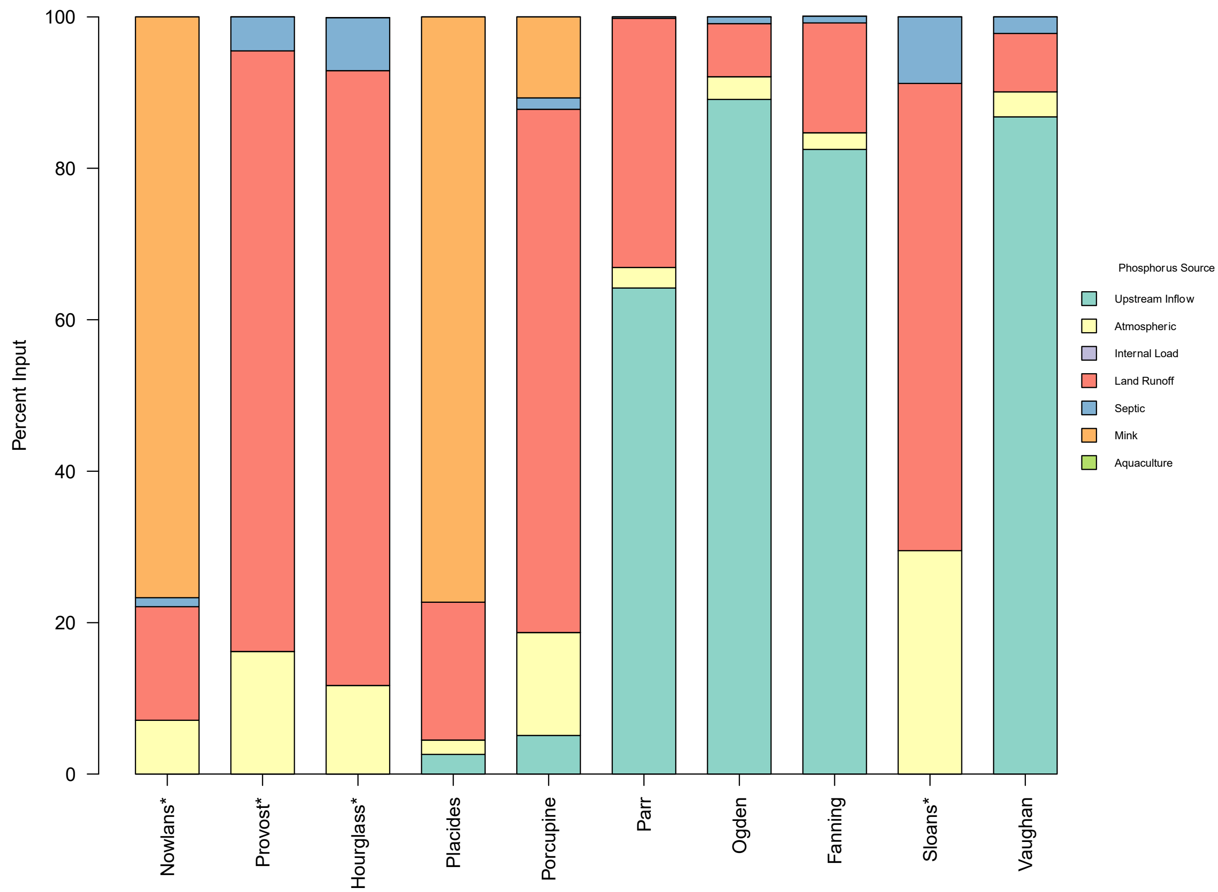

Figure 21: Percent input of P sources in the fitted coefficient scenario in the 1983 model

4.4 TEMPORAL CHANGES IN PHOSPHORUS DYNAMICS IN STUDY LAKES

This analysis has demonstrated clear temporal changes in the P dynamics of these lakes over the past four decades. Throughout the study area, measured lake TP concentrations have increased through time, and this is corroborated by the model predictions. An increase in TP concentration would be expected as development has increased, an aquaculture facility began operation, and the mink industry expanded in the area.

In general, the study lakes have transitioned from an oligotrophic state to a mesotrophic to hyper-eutrophic state, and this change is primarily attributed to the growth of the mink farming industry. This modeling approach has also provided insight on the amount of P that is generated on mink farms that is retained vs transported to receiving lakes, and how this may change with time. The fitted mink farm export coefficients for

Nowlans Lake indicate that the fraction of P retained on farms is decreasing with time (Figure 22). The decreasing retention could be attributed to saturation of the available P sorption sites within soils and sediments along drainage pathways between the mink farms and the lake (Sinclair, 2014). In early years of operation, the majority of P would have been sorbed by soil particles and it would not have entered the lake. Goyette et al (2018) discuss the concept of P buffering capacity, which is the ability of a watershed to modulate P export downstream by retaining P in different landscape compartments such as riparian areas, wetlands, and sediment. The results show that in most lakes the P buffering capacity of the watershed is decreasing, and more P is being transported to the lakes.

Results for Sloans Lake and Lake Vaughan also demonstrate the effects of mink farm age on P transport to receiving lakes. In both these lakes, the fitted mink farm P coefficient was zero, in order to best represent measured TP concentrations. This suggests that in these watersheds, natural P buffering capacity has not been exceeded. The mink farms in the watersheds of these two lakes are some of the newest with the mink farm on Sloans Lake initiating operation in 2009. Additionally, newer farms were constructed with improved waste management systems than the ones originally implemented in the 1960s (Personal Communication; Jim Mullen, 2019). In general, these results suggest that there is a correlation between mink farm age and the amount of mink P exported to receiving water bodies.

However, Hourglass Lake and Placides Lake produced a contrasting temporal trend, with the higher mink farm P export coefficients generated for the 2008 modeling year (Figure 22). This could be attributed to the recent decline in the mink industry in Nova Scotia (Statistics Canada, 2017; Puddicome, 2016), and uncertainty with respect to the actual number of mink being produced in each of these watersheds. One limitation of this study was the assumption that all mink farms that were delineated using satellite imagery were still fully operational and the mink population is distributed uniformly according to farm size. It is plausible that the mink farms in the Nowlans Lake watershed are still fully operational, explaining the increased export coefficient in 2017, but that farms in the Placides Lake watershed may have decreased production between 2008 and 2017. It also must be reiterated that the available water quality data was quite limited, consisting of a single measurement of TP in each year.

Porcupine Lake results follow a similar trend to those generated for Nowlans Lake and Provost Lake when comparing 2008 to 2017. The export coefficient for 1983 is larger as an export coefficient of 0.10 was assigned to any lake that did not have measured TP values, which included Porcupine Lake, and all additional lakes. A coefficient value of 0.10 seemed reasonable for the 2017 and 2008 models, however it may be too high for the 1983 model scenario.

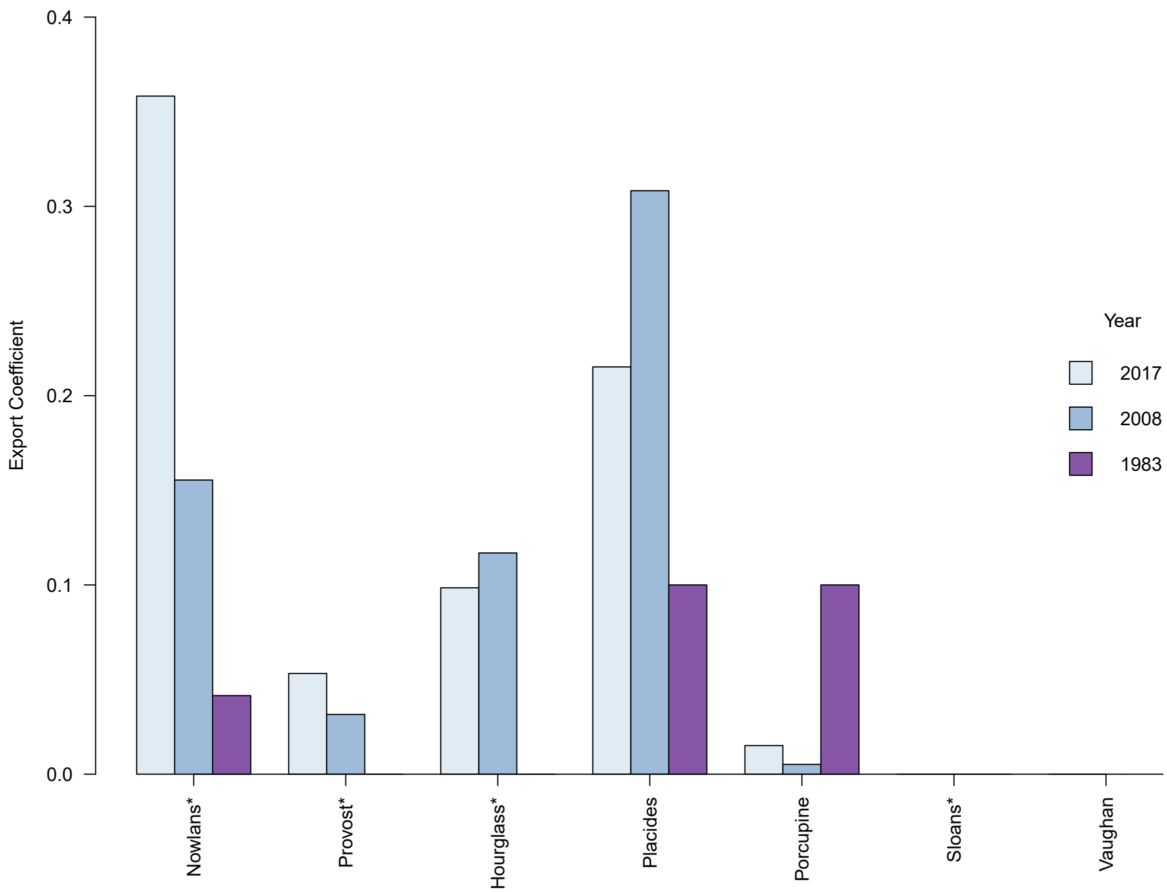

Figure 22: Calibrated mink export coefficients through time

4.5 Implications for Lake Restoration

The majority of the study lakes have experienced cultural eutrophication, and there are a number of approaches that could be employed to restore trophic state and reduce the risk of algal blooms. Restoration efforts should first focus on controlling external watershed sources of P, but water quality monitoring and modeling results indicate that internal P loading will also be an ongoing concern in several lakes.

The modeling study has demonstrated that mink farms are the largest contributors of P within the majority of the study lake watersheds. The results also indicate that downstream lakes in the Carleton River Watershed are also receiving large loads of P from mink farming activities in headwater lakes. Therefore, efforts should be focused on enhanced control measures to reduce P loads from mink farms. There has already been implementation of control measures on mink farms through Nova Scotia's Fur Industry Act (2015). The regulations under this act prescribe set back distances, mandatory surface water and groundwater monitoring, and allowable concentration limits of certain contaminants in surface water and groundwater. These regulations, along with the downturn in the industry, should result in reduced P loading from mink farms. However, the model results indicate that even if greater than 90% of the P generated on mink farms had been retained, changes in trophic state in receiving lakes would still be expected. This finding would suggest that if mink farming is to occur in this region, especially in the watersheds of headwater lakes, that they should be operated as zero discharge systems with complete containment and removal/management of waste at facilities located outside of the watershed. It should also be recognized that even if mink waste was fully contained and managed moving forward that there are likely still large amounts of legacy P that have accumulated within these watersheds, and it may take decades to millennia for P loading to return to baseline conditions (Goyette, 2018). Downstream lakes with no mink farms in their watersheds most likely do not have large amounts of P retained in their watersheds. However, model results show that the downstream lakes receive most of their P load from upstream lakes. Restoration efforts for downstream lakes will need to focus on reducing P contributions from upstream lakes. This also highlights the connectivity of environmental systems that may not be initially evident to municipal planners. Land use planning should examine implications on the entire watershed, and not just one lake. Additionally, land use planning should also take into consideration any future development in the area such as residential, agricultural, and forestry, and ensure that any future development focuses on minimizing their contributions towards cultural eutrophication. A holistic, watershed-scale approach that includes all stakeholders is required to restore these lakes and ensure they are healthy for future generations.

Another potential long-term issue is the storage and release of P from lake sediments. As P stored in the watershed can slowly be released into watercourses, the same is true of P stored in the lake sediment. This P can slowly be released, and it may take decades to millennia (Goyette, 2018) for this pool of P to be depleted. As outlined in Section 2.5.5 the release rate of P from lake sediment is dependent on the concentration and forms of P within the lake sediments, trophic state, timing and extent of stratification, and oxygen levels at the sediment-water interface. As shown in this study there can be large inter-annual variability in lake thermal regimes and levels of anoxia. Climate change is also expected to exasperate the process of internal loading. Recent studies have shown that climate change, specifically increasing air temperature and decreased wind speed have contributed to increased internal P loading (Favot et al, 2019; Magee and Wu, 2017). The combination of increased air temperature and decreased wind speed leads to a warmer epilimnion, a cooler hypolimnion, and longer and stronger periods of stratification. Longer periods of stratification lead to greater deoxygenation of the hypolimnion and anoxia at the sediment surface which are ideal conditions for internal P loading. It is possible that even if all external loads of P are controlled, that the effects of climate change will increase internal P loading, leading to continued cyanobacteria blooms in the future.

Moving forward, water quality monitoring should be focused on stratification dynamics and oxygen levels to better understand internal P loading. In the future, if internal P loading is deemed to be a cause of cyanobacteria blooms, there are various restoration methods that could be employed. In general, they fall under two categories: aeration/destratification systems and chemically immobilizing the sediment P. Aeration and destratification systems aim to increase vertical mixing in the lake to reduce the stratification and hypoxia at the sediment surface, thus reducing the amount of internal loading. However, aeration and destratification systems can exacerbate blooms as they transport P from the hypolimnion to the epilimnion for uptake by cyanobacteria (James et al, 2015). Chemical amendments work by immobilizing P in the sediment or flocculation leading to increasing P sedimentation. Common chemical amendments include aluminum sulfate (alum), iron, calcite, and Lanthanum in bentonite clay (Phoslock). Any chemical amendment must be cautiously added, as some can be toxic to aquatic life if applied too liberally (Nurnberg, 2017). If future monitoring shows that internal loading is the leading cause of algal blooms, then in-lake treatment methods should be considered.

5 Conclusions and Recommendations for Further Research

5.1 Conclusions

Through the use of watershed-scale spatial analysis and the NSP model, the objectives of this research were achieved. The various P sources in the watersheds were identified and their P loads were quantified. The model allowed for quantification of the relative P loads from each source entering each lake, which helped to identify which P source contributed the most to TP concentration.

Phosphorus sources that were identified and quantified included atmospheric deposition, land runoff, septic systems, aquaculture farms, mink farms, and internal loading. The quantified P loads were then input into the NSPM to predict the concentration of P in each study lake. The process of quantifying P loads was repeated for multiple study years in order to gain an understanding of current conditions (2017) and conditions before the peak in mink farming occurred (2008 and 1983). Additional lakes within the watershed systems were also modelled to better predict P transport through the watershed. The final aspect of the modeling process was to predict the amount of P from mink farms that actually reaches the watercourse. This was achieved by fitting predicted P concentrations to measured P concentrations by changing the mink export coefficient.

Results for the 2017 model scenario show that in headwater lakes, most of the P entering the lake can be sourced to mink farms in the watersheds. Nowlans and Placides had the highest measured TP concentration, and the model showed that over 95% of their total P input was sourced from mink farms. Downstream lakes with no mink farms in their watersheds received most of their P from headwater lakes. The results indicate that the water quality in the upstream lakes strongly influences the water quality in the downstream lakes. In addition to the fitted coefficient scenario, several other scenarios were run, including a baseline and a no mink scenario. In the baseline scenario (no anthropogenic sources of P), all lakes were predicted to be in the oligotrophic range. In the no mink farm scenario (all anthropogenic sources of P except for mink), all lakes were in the oligotrophic range, with the exception of Hourglass lake which was mesotrophic. An additional scenario of complete septic system failure was also run. In this scenario, all lakes were oligotrophic, except for Hourglass and Placides which were meso-eutrophic and eutrophic, respectively. All of these modeling scenarios indicate that additions of residential P sources do not dramatically change the trophic status of the lakes, only when P from mink farms are included does the trophic status change dramatically.

Results from the 2008 model resembled the findings of the 2017 model, with all lakes predicted to be oligotrophic except for Hourglass Lake in the no mink farming scenario. In this model scenario, the calibrated mink export coefficients were lower than in the 2017 model, suggesting that over time the soils and sediments have become saturated with P and less retention in the subsurface is possible.

The 1983 model results show a similar pattern, with all lakes in the baseline and no mink farming scenarios predicted to be oligotrophic. Nowlans Lake and Placides Lake were the two lakes most impacted by the addition of P from mink farms at this time. The calibrated coefficients for this scenario are lower than past model scenarios, supporting the theory that the surrounding environment has been saturated with P over time.

The 2017 model results show that internal loading was not a large contributor to overall P load, however internal loading in the 2008 model was much larger. This suggests that depending on climate and specific weather conditions that impact the strength and duration of lake stratification, internal loading may or may not have a large impact on P concentrations. Climate change is expected to exacerbate conditions that contribute to an increase in internal P load. Internal loading may become the main source of P in future years, as regulations and changes in mink production reduce P loads from mink farms to these lakes.

5.2 Recommendations for Further Research

The focus of further research should be on better understanding internal loading dynamics and the effects of climate change. Currently, it is unknown how much P is trapped in the lake sediments. The first mink farms in the area were founded in the 1960s and 1970s, and the industry was not specifically regulated until the introduction of the Fur Industry Act in 2013. During those 40 years, it is unknown how much P has been trapped in the sediment, or how long it will take to be released from the sediment. Internal loading could be a persistent issue in these lakes for decades to millennia (Goyette, 2018) and better understanding the P dynamics in internal loading could assist in remediation efforts.

Lake water quality monitoring should focus on stratification dynamics and oxygen levels. Understanding the relationships between air temperature, wind speed, stratification, and oxygen levels can help to predict when large internal loads will occur and when to expect cyanobacteria blooms. Understanding these relationships can also inform managers on how and when to possibly apply additional strategies to help in remediation efforts.

Future modeling of the system should focus on a transient approach at a smaller time scale. This model only examined a steady state approach on a yearly time scale and was unable to capture possible seasonal changes. This study also only used one data point for each model scenario, a late summer TP measurement. This was done so all model scenarios were consistent, as there were gaps in available data in past sampling years. Future models should use multiple measurements throughout the year to better show how TP concentrations change depending on stratification and other seasonal changes, especially the effects of seasonal internal loading.

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Appendix A: NSPM Spreadsheets

Showing results for the 2017 fitted coefficient scenario.

Table 24: Sample NSPM spreadsheet for Nowlans Lake

Nowlans Lake						
Input Parameters	**Symbol**	**Value**	**Units**	**Budgets**		
Morphology				**Hydraulic Budget (m3)**		
Drainage Basin Area (Excl. of Lake Area)	Ad	199.31	ha			**% Total**
Area Land Use Category 1 (Developed)	Ad1	36.75	ha	Upstream Inflow	0	0
Area Land Use Category 2 (Clearcut)	Ad2	35.2	ha	Precipitation	954712.48	34.7
Area Land Use Category 3 (Forest)	Ad3	113.63	ha	Surface Runoff	1793790	65.3
Area Land Use Category 4 (Wetlands)	Ad4	13.73	ha	Evaporation	-453185.32	-16.5
Lake Surface Area (Waterbodies)	Ao	77.72	ha	Point Sources		0
Lake Volume	V	925834	m3	Total Outflow	2295317.16	83.5
Hydrology Inputs				Check		100
Upstream Hydraulic Inputs	Qi	0	m3/yr	**Phosphorus Budget (gm/yr)**		
Annual Unit Precipitation	Pr	1.2284	m/yr			**% Total**
Annual Unit Lake Evaporation	Ev	0.5831	m/yr	Upstream Inflow	0.0	0.0
Annual Unit Hydraulic Runoff	Ru	0.9	m/yr	Atmospheric	13445.6	0.3
Phosphorus Inputs				Internal Load	0.0	0.0
Upstream P Input	Ju	0	gm P/yr	Watershed Inputs	5097359.8	99.7
Annual Unit Atmospheric Phosphorus Deposition	Da	0.0173	gm P/m2/yr	Land Runoff	32063.7	0.6
Land Use Category 1 P Export Coefficient	E1	0.03	gm P/m2/yr	Development	2010.0	0.0
Land Use Category 2 P Export Coefficient	E2	0.0174	gm P/m2/yr	Mink	5063286.1	99.1
Land Use Category 3 P Export Coefficient	E3	0.0095	gm P/m2/yr	Sedimentation	-4127706.8	-80.8
Land Use Category 4 P Export Coefficient	E4	0.03	gm P/m2/yr	Total Outflow	983098.6	19.2
Point Source Input 1 (POWSIM)	PS1	2010	gm P/yr	Check		100.0

				Model Validation	
Point Source Input 2 (Internal Load)	PS2	0	gm P/yr		
Point Source Input 3 (Mink)	PS3	7390068.6	gm P/yr	Predicted P	0.62
Point Source Input 4 (Aquaculture)	PS4	0	gm P/yr	Measured P	0.6233
Lake Phosphorus Retention Coefficient	v	12.4	n/a	% Difference	-1.8E-14

Model Outputs				Export Coefficients	
Total Precipitation Hydraulic Input	Ppti	954712.48	m3/yr	25%	0.25
Total Evaporation Hydraulic Loss	Eo	453185.32	m3/yr	50%	0.5
Total Hydraulic Surface Runoff	Ql	1793790.00	m3/yr	75%	0.75
Total Hydraulic Input	Qt	2748502.48	m3/yr	Matched	0.364885
Areal Hydraulic Input	*qs*	2.95	m/yr		
Total Hydraulic Outflow	Qo	2295317.16	m3/yr		
Total Atmospheric P Input	Jd	13445.56	gm/yr		
Total Surface Runoff P Input	Je	32063.65	gm/yr		
Total Development P Input	Jr	7392078.60	gm/yr		
Total P Input	Jt	7437587.81	gm/yr		
Lake P Retention Factor	Rp	0.81	n/a		
Lake P Retention	Ps	6006916.62	gm/yr		
Predicted Lake P Concentration	[P]	0.62	mg/L		
Lake P Outflow	Jo	1430671.19	gm/yr		
Lake Mean Depth	z	3.30	m		
Lake Flushing Rate	FR	2.48	1/yr		
Lake Turnover Time	TT	0.40	yr		
Lake Response Time	RT(1/2)	0.13	yr		

Table 25: Sample NSPM spreadsheet for Provost Lake

Provost Lake						
Input Parameters	**Symbol**	**Value**	**Units**	**Budgets**		
Morphology				**Hydraulic Budget (m3)**		
Drainage Basin Area (Excl. of Lake Area)	Ad	713.85	ha			**% Total**
Area Land Use Category 1 (Developed)	Ad1	61.32	ha	Upstream Inflow	0	0
Area Land Use Category 2 (Clearcut)	Ad2	142.11	ha	Precipitation	1069445.04	14.2705
Area Land Use Category 3 (Forest)	Ad3	488.98	ha	Surface Runoff	6424650	85.7295
Area Land Use Category 4 (Wetlands)	Ad4	21.44	ha	Evaporation	-507646.86	-6.77396
Lake Surface Area (Waterbodies)	Ao	87.06	ha	Point Sources		0
Lake Volume	V	1057810	m3	Total Outflow	6986448.18	93.22604
Hydrology Inputs				Check		100
Upstream Hydraulic Inputs	Qi	0	m3/yr	**Phosphorus Budget (gm/yr)**		
Annual Unit Precipitation	Pr	1.2284	m/yr			**% Total**
Annual Unit Lake Evaporation	Ev	0.5831	m/yr	Upstream Inflow	0.0	0.0
Annual Unit Hydraulic Runoff	Ru	0.9	m/yr	Atmospheric	15061.4	2.9
Phosphorus Inputs				Internal Load	0.0	0.0
Upstream P Input	Ju	0	gm P/yr	Watershed Inputs	500613.4	97.1
Annual Unit Atmospheric Phosphorus Deposition	Da	0.0173	gm P/m2/yr	Land Runoff	96008.2	18.6
Land Use Category 1 P Export Coefficient	E1	0.03	gm P/m2/yr	Development	4140.0	0.8
Land Use Category 2 P Export Coefficient	E2	0.0174	gm P/m2/yr	Mink	400465.1	77.7
Land Use Category 3 P Export Coefficient	E3	0.0095	gm P/m2/yr	Sedimentation	-313067.8	-60.7
Land Use Category 4 P Export Coefficient	E4	0.03	gm P/m2/yr	Total Outflow	202607.0	39.3
Point Source Input 1 (POWSIM)	PS1	4140	gm P/yr	Check		100.0

Point Source Input 2 (Internal Load)	PS2	0	gm P/yr	**Model Validation**	
Point Source Input 3 (Mink)	PS3	400465.1372	gm P/yr	Predicted P	0.029
Point Source Input 4 (Aquaculture)	PS4	0	gm P/yr	Measured P	0.029
Lake Phosphorus Retention Coefficient	v	12.4	n/a	% Difference	4.79E-14
Model Outputs				**Export Coefficients**	
Total Precipitation Hydraulic Input	Ppti	1069445.04	m3/yr	25%	0.25
Total Evaporation Hydraulic Loss	Eo	507646.86	m3/yr	50%	0.5
Total Hydraulic Surface Runoff	Ql	6424650.00	m3/yr	75%	0.75
Total Hydraulic Input	Qt	7494095.04	m3/yr	Matched	0.099996
Areal Hydraulic Input	*qs*	8.02	m/yr		
Total Hydraulic Outflow	Qo	6986448.18	m3/yr		
Total Atmospheric P Input	Jd	15061.38	gm/yr		
Total Surface Runoff P Input	Je	96008.24	gm/yr		
Total Development P Input	Jr	404605.14	gm/yr		
Total P Input	Jt	515674.76	gm/yr		
Lake P Retention Factor	Rp	0.61	n/a		
Lake P Retention	Ps	313067.76	gm/yr		
Predicted Lake P Concentration	[P]	0.03	mg/L		
Lake P Outflow	Jo	202607.00	gm/yr		
Lake Mean Depth	z	3.1	m		
Lake Flushing Rate	FR	6.60	1/yr		
Lake Turnover Time	TT	0.15	yr		
Lake Response Time	RT(1/2)	0.07	yr		

Table 26: Sample NSPM spreadsheet for Brights Lake

Brights Lake						
Input Parameters	**Symbol**	**Value**	**Units**	**Budgets**		
Morphology				**Hydraulic Budget (m3)**		
Drainage Basin Area (Excl. of Lake Area)	Ad	52.45	ha			**% Total**
Area Land Use Category 1 (Developed)	Ad1	2.91	ha	Upstream Inflow	0	0
Area Land Use Category 2 (Clearcut)	Ad2	0.96	ha	Precipitation	224797.2	32.25918
Area Land Use Category 3 (Forest)	Ad3	44.7	ha	Surface Runoff	472050	67.74082
Area Land Use Category 4 (Wetlands)	Ad4	3.88	ha	Evaporation	-106707.3	-15.31287
Lake Surface Area (Waterbodies)	Ao	18.3	ha	Point Sources		0
Lake Volume	V	795516	m3	Total Outflow	590139.9	84.68713
Hydrology Inputs				Check		100
Upstream Hydraulic Inputs	Qi	0	m3/yr	**Phosphorus Budget (gm/yr)**		
Annual Unit Precipitation	Pr	1.2284	m/yr			**% Total**
Annual Unit Lake Evaporation	Ev	0.5831	m/yr	Upstream Inflow	0.0	0.0
Annual Unit Hydraulic Runoff	Ru	0.9	m/yr	Atmospheric	3165.9	4.4
Phosphorus Inputs				Internal Load	0.0	0.0
Upstream P Input	Ju	0	gm P/yr	Watershed Inputs	68454.3	95.6
Annual Unit Atmospheric Phosphorus Deposition	Da	0.0173	gm P/m2/yr	Land Runoff	6450.5	9.0
Land Use Category 1 P Export Coefficient	E1	0.03	gm P/m2/yr	Development	0.0	0.0
Land Use Category 2 P Export Coefficient	E2	0.0174	gm P/m2/yr	Mink	62003.8	86.6
Land Use Category 3 P Export Coefficient	E3	0.0095	gm P/m2/yr	Sedimentation	-56838.5	-79.4
Land Use Category 4 P Export Coefficient	E4	0.03	gm P/m2/yr	Total Outflow	14781.7	20.6
Point Source Input 1 (POWSIM)	PS1	0	gm P/yr	Check		100.0
Point Source Input 2 (Internal Load)	PS2	0	gm P/yr	**Model Validation**		

Point Source Input 3 (Mink)	PS3	62003.8	gm P/yr	Predicted P	0.03
Point Source Input 4 (Aquaculture)	PS4	0	gm P/yr	Measured P	0
Lake Phosphorus Retention Coefficient	v	12.4	n/a	% Difference	N/A
Model Outputs				**Export Coefficients**	
Total Precipitation Hydraulic Input	Ppti	224797.20	m3/yr	25%	0.25
Total Evaporation Hydraulic Loss	Eo	106707.30	m3/yr	50%	0.5
Total Hydraulic Surface Runoff	Ql	472050.00	m3/yr	75%	0.75
Total Hydraulic Input	Qt	696847.20	m3/yr	Matched	0.1
Areal Hydraulic Input	*qs*	3.22	m/yr		
Total Hydraulic Outflow	Qo	590139.90	m3/yr		
Total Atmospheric P Input	Jd	3165.90	gm/yr		
Total Surface Runoff P Input	Je	6450.54	gm/yr		
Total Development P Input	Jr	62003.80	gm/yr		
Total P Input	Jt	71620.24	gm/yr		
Lake P Retention Factor	Rp	0.79	n/a		
Lake P Retention	Ps	56838.52	gm/yr		
Predicted Lake P Concentration	[P]	0.03	mg/L		
Lake P Outflow	Jo	14781.72	gm/yr		
Lake Mean Depth	z	4.70	m		
Lake Flushing Rate	FR	0.74	1/yr		
Lake Turnover Time	TT	1.35	yr		
Lake Response Time	RT(1/2)	0.24	yr		

Table 27: Sample NSPM spreadsheet for Bill Lake

Bill Lake						
Input Parameters	**Symbol**	**Value**	**Units**	**Budgets**		
Morphology				**Hydraulic Budget (m3)**		
Drainage Basin Area (Excl. of Lake Area)	Ad	587.5	ha			**% Total**
Area Land Use Category 1 (Developed)	Ad1	72.83	ha	Upstream Inflow	590139.9	9.695934
Area Land Use Category 2 (Clearcut)	Ad2	43.55	ha	Precipitation	208828	3.431021
Area Land Use Category 3 (Forest)	Ad3	456.49	ha	Surface Runoff	5287500	86.87305
Area Land Use Category 4 (Wetlands)	Ad4	14.63	ha	Evaporation	-99127	-1.62865
Lake Surface Area (Waterbodies)	Ao	17	ha	Point Sources		0
Lake Volume	V	351003	m3	Total Outflow	5987340.9	98.37135
Hydrology Inputs				Check		100
Upstream Hydraulic Inputs	Qi	590139.90	m3/yr	**Phosphorus Budget (gm/yr)**		
Annual Unit Precipitation	Pr	1.2284	m/yr			**% Total**
Annual Unit Lake Evaporation	Ev	0.5831	m/yr	Upstream Inflow	14781.7	0.6
Annual Unit Hydraulic Runoff	Ru	0.9	m/yr	Atmospheric	2941.0	0.1
Phosphorus Inputs				Internal Load	0.0	0.0
Upstream P Input	Ju	14781.72	gm P/yr	Watershed Inputs	2568997.6	99.3
Annual Unit Atmospheric Phosphorus Deposition	Da	0.0173	gm P/m2/yr	Land Runoff	77182.3	3.0
Land Use Category 1 P Export Coefficient	E1	0.03	gm P/m2/yr	Development	0.0	0.0
Land Use Category 2 P Export Coefficient	E2	0.0174	gm P/m2/yr	Mink	2491815.3	96.3
Land Use Category 3 P Export Coefficient	E3	0.0095	gm P/m2/yr	Sedimentation	-673573.4	-26.0
Land Use Category 4 P Export Coefficient	E4	0.03	gm P/m2/yr	Total Outflow	1913146.9	74.0
Point Source Input 1 (POWSIM)	PS1	0	gm P/yr	Check		100.0

Point Source Input 2 (Internal Load)	PS2	0	gm P/yr	**Model Validation**	
Point Source Input 3 (Mink)	PS3	2491815.3	gm P/yr	Predicted P	0.319532
Point Source Input 4 (Aquaculture)	PS4	0	gm P/yr	Measured P	0
Lake Phosphorus Retention Coefficient	v	12.4	n/a	% Difference	N/A
Model Outputs				**Export Coefficients**	
Total Precipitation Hydraulic Input	Ppti	208828.00	m3/yr	25%	0.25
Total Evaporation Hydraulic Loss	Eo	99127.00	m3/yr	50%	0.5
Total Hydraulic Surface Runoff	Ql	5287500.00	m3/yr	75%	0.75
Total Hydraulic Input	Qt	6086467.90	m3/yr	Matched	0.1
Areal Hydraulic Input	*qs*	35.22	m/yr		
Total Hydraulic Outflow	Qo	5987340.90	m3/yr		
Total Atmospheric P Input	Jd	2941.00	gm/yr		
Total Surface Runoff P Input	Je	77182.25	gm/yr		
Total Development P Input	Jr	2491815.32	gm/yr		
Total P Input	Jt	2586720.28	gm/yr		
Lake P Retention Factor	Rp	0.26	n/a		
Lake P Retention	Ps	673573.41	gm/yr		
Predicted Lake P Concentration	[P]	0.32	mg/L		
Lake P Outflow	Jo	1913146.88	gm/yr		
Lake Mean Depth	z	2.20	m		
Lake Flushing Rate	FR	17.06	1/yr		
Lake Turnover Time	TT	0.06	yr		
Lake Response Time	RT(1/2)	0.03	yr		

Table 28: Sample NSPM spreadsheet for Simmonds Lake

Simmonds Lake						
Input Parameters	**Symbol**	**Value**	**Units**	**Budgets**		
Morphology				**Hydraulic Budget (m3)**		
Drainage Basin Area (Excl. of Lake Area)	Ad	415.56	ha			**% Total**
Area Land Use Category 1 (Developed)	Ad1	48.99	ha	Upstream Inflow	5987340.9	59.74739
Area Land Use Category 2 (Clearcut)	Ad2	16.74	ha	Precipitation	293710.44	2.930923
Area Land Use Category 3 (Forest)	Ad3	326.76	ha	Surface Runoff	3740040	37.32168
Area Land Use Category 4 (Wetlands)	Ad4	23.07	ha	Evaporation	-139419.21	-1.39126
Lake Surface Area (Waterbodies)	Ao	23.91	ha	Point Sources		0
Lake Volume	V		m3	Total Outflow	9881672.13	98.60874
Hydrology Inputs				Check		100
Upstream Hydraulic Inputs	Qi	5987340.90	m3/yr	**Phosphorus Budget (gm/yr)**		
Annual Unit Precipitation	Pr	1.2284	m/yr			**% Total**
Annual Unit Lake Evaporation	Ev	0.5831	m/yr	Upstream Inflow	1913146.9	65.2
Annual Unit Hydraulic Runoff	Ru	0.9	m/yr	Atmospheric	4136.4	0.1
Phosphorus Inputs				Internal Load	0.0	0.0
Upstream P Input	Ju	1913146.88	gm P/yr	Watershed Inputs	1018012.3	34.7
Annual Unit Atmospheric Phosphorus Deposition	Da	0.0173	gm P/m2/yr	Land Runoff	55573.0	1.9
Land Use Category 1 P Export Coefficient	E1	0.03	gm P/m2/yr	Development	0.0	0.0
Land Use Category 2 P Export Coefficient	E2	0.0174	gm P/m2/yr	Mink	962439.4	32.8
Land Use Category 3 P Export Coefficient	E3	0.0095	gm P/m2/yr	Sedimentation	-677435.4	-23.1
Land Use Category 4 P Export Coefficient	E4	0.03	gm P/m2/yr	Total Outflow	2257860.3	76.9
Point Source Input 1 (POWSIM)	PS1	0	gm P/yr	Check		100.0

Point Source Input 2 (Internal Load)	PS2	0	gm P/yr	**Model Validation**	
Point Source Input 3 (Mink)	PS3	962439.3792	gm P/yr	Predicted P	0.22849
Point Source Input 4 (Aquaculture)	PS4	0	gm P/yr	Measured P	0
Lake Phosphorus Retention Coefficient	v	12.4	n/a	% Difference	N/A
Model Outputs				**Export Coefficients**	
Total Precipitation Hydraulic Input	Ppti	293710.44	m3/yr	25%	0.25
Total Evaporation Hydraulic Loss	Eo	139419.21	m3/yr	50%	0.5
Total Hydraulic Surface Runoff	Ql	3740040.00	m3/yr	75%	0.75
Total Hydraulic Input	Qt	10021091.34	m3/yr	Matched	0.1
Areal Hydraulic Input	*qs*	41.33	m/yr		
Total Hydraulic Outflow	Qo	9881672.13	m3/yr		
Total Atmospheric P Input	Jd	4136.43	gm/yr		
Total Surface Runoff P Input	Je	55572.96	gm/yr		
Total Development P Input	Jr	962439.38	gm/yr		
Total P Input	Jt	2935295.65	gm/yr		
Lake P Retention Factor	Rp	0.23	n/a		
Lake P Retention	Ps	677435.39	gm/yr		
Predicted Lake P Concentration	[P]	0.23	mg/L		
Lake P Outflow	Jo	2257860.26	gm/yr		
Lake Mean Depth	z	3.30	m		
Lake Flushing Rate	FR	0	1/yr		
Lake Turnover Time	TT	0	yr		
Lake Response Time	RT(1/2)	0	yr		

Table 29: Sample NSPM spreadsheet for Hourglass Lake

Hourglass Lake						
Input Parameters	**Symbol**	**Value**	**Units**	**Budgets**		
Morphology				**Hydraulic Budget (m3)**		
Drainage Basin Area (Excl. of Lake Area)	Ad	277.49	ha			**% Total**
Area Land Use Category 1 (Developed)	Ad1	53.11	ha	Upstream Inflow	0	0
Area Land Use Category 2 (Clearcut)	Ad2	16.04	ha	Precipitation	410408.44	14.11396
Area Land Use Category 3 (Forest)	Ad3	191.83	ha	Surface Runoff	2497410	85.88604
Area Land Use Category 4 (Wetlands)	Ad4	16.51	ha	Evaporation	-194813.71	-6.69965
Lake Surface Area (Waterbodies)	Ao	33.41	ha	Point Sources		0
Lake Volume	V	666581	m3	Total Outflow	2713004.73	93.30035
Hydrology Inputs				Check		100
Upstream Hydraulic Inputs	Qi	0	m3/yr	**Phosphorus Budget (gm/yr)**		
Annual Unit Precipitation	Pr	1.2284	m/yr			**% Total**
Annual Unit Lake Evaporation	Ev	0.5831	m/yr	Upstream Inflow	0.0	0.0
Annual Unit Hydraulic Runoff	Ru	0.9	m/yr	Atmospheric	5779.9	1.5
Phosphorus Inputs				Internal Load	0.0	0.0
Upstream P Input	Ju	0	gm P/yr	Watershed Inputs	352367.9	94.3
Annual Unit Atmospheric Phosphorus Deposition	Da	0.0173	gm P/m2/yr	Land Runoff	41900.8	11.2
Land Use Category 1 P Export Coefficient	E1	0.03	gm P/m2/yr	Development	3160.0	0.8
Land Use Category 2 P Export Coefficient	E2	0.0174	gm P/m2/yr	Mink	258455.5	69.2
Land Use Category 3 P Export Coefficient	E3	0.0095	gm P/m2/yr	Aquaculture	48851.6	13.1
Land Use Category 4 P Export Coefficient	E4	0.03	gm P/m2/yr	Sedimentation	-175603.0	-47.0
Point Source Input 1 (POWSIM)	PS1	3160	gm P/yr	Total Outflow	198049.3	53.0

Point Source Input 2 (Internal Load)	PS2	15504.4769	gm P/yr
Point Source Input 3 (Mink)	PS3	258455.488	gm P/yr
Point Source Input 4 (Aquaculture)	PS4	48851.6	gm P/yr
Lake Phosphorus Retention Coefficient	v	7.2	n/a

Model Validation	
Predicted P	0.073
Measured P	0.073
% Difference	-3.8E-14

Model Outputs			
Total Precipitation Hydraulic Input	Ppti	410408.44	m3/yr
Total Evaporation Hydraulic Loss	Eo	194813.71	m3/yr
Total Hydraulic Surface Runoff	Ql	2497410.00	m3/yr
Total Hydraulic Input	Qt	2907818.44	m3/yr
Areal Hydraulic Input	*qs*	8.12	m/yr
Total Hydraulic Outflow	Qo	2713004.73	m3/yr
Total Atmospheric P Input	Jd	5779.93	gm/yr
Total Surface Runoff P Input	Je	41900.81	gm/yr
Total Development P Input	Jr	325971.57	gm/yr
Total P Input	Jt	373652.31	gm/yr
Lake P Retention Factor	Rp	0.47	n/a
Lake P Retention	Ps	175602.96	gm/yr
Predicted Lake P Concentration	[P]	0.07	mg/L
Lake P Outflow	Jo	198049.35	gm/yr
Lake Mean Depth	z	2.1	m
Lake Flushing Rate	FR	4.07	1/yr
Lake Turnover Time	TT	0.25	yr
Lake Response Time	RT(1/2)	0.08	yr

Export Coefficients	
25%	0.25
50%	0.5
75%	0.75
Matched	0.094568

Table 30: Sample NSPM spreadsheet for Placides Lake

Placides Lake						
Input Parameters	**Symbol**	**Value**	**Units**	**Budgets**		
Morphology				**Hydraulic Budget (m3)**		
Drainage Basin Area (Excl. of Lake Area)	Ad	995.07	ha			**% Total**
Area Land Use Category 1 (Developed)	Ad1	167.06	ha	Upstream Inflow	0	0
Area Land Use Category 2 (Clearcut)	Ad2	105.22	ha	Precipitation	954712.48	34.7
Area Land Use Category 3 (Forest)	Ad3	683.75	ha	Surface Runoff	1793790	65.3
Area Land Use Category 4 (Wetlands)	Ad4	39.04	ha	Evaporation	-453185.32	-16.5
Lake Surface Area (Waterbodies)	Ao	92.23	ha	Point Sources		0
Lake Volume	V	0	m3	Total Outflow	2295317.16	83.5
Hydrology Inputs				Check		100
Upstream Hydraulic Inputs	Qi	2713004.73	m3/yr	**Phosphorus Budget (gm/yr)**		
Annual Unit Precipitation	Pr	1.2284	m/yr			**% Total**
Annual Unit Lake Evaporation	Ev	0.5831	m/yr	Upstream Inflow	198049.3	1.3
Annual Unit Hydraulic Runoff	Ru	0.9	m/yr	Atmospheric	15955.8	0.1
Phosphorus Inputs				Internal Load	0.0	0.0
Upstream P Input	Ju	198049.35	gm P/yr	Watershed Inputs	14717193.3	98.6
Annual Unit Atmospheric Phosphorus Deposition	Da	0.0173	gm P/m2/yr	Land Runoff	145094.5	1.0
Land Use Category 1 P Export Coefficient	E1	0.03	gm P/m2/yr	Development	0.0	0.0
Land Use Category 2 P Export Coefficient	E2	0.0174	gm P/m2/yr	Mink	14572098.7	97.6
Land Use Category 3 P Export Coefficient	E3	0.0095	gm P/m2/yr	Sedimentation	-7205007.6	-48.3
Land Use Category 4 P Export Coefficient	E4	0.03	gm P/m2/yr	Total Outflow	7726190.8	51.7
Point Source Input 1 (POWSIM)	PS1	0	gm P/yr	Check		100.0

Point Source Input 2 (Internal Load)	PS2	0	gm P/yr	**Model Validation**	
Point Source Input 3 (Mink)	PS3	14572098.73	gm P/yr	Predicted P	0.63
Point Source Input 4 (Aquaculture)	PS4	0	gm P/yr	Measured P	0.63
Lake Phosphorus Retention Coefficient	v	12.4	n/a	% Difference	0
Model Outputs				**Export Coefficients**	
Total Precipitation Hydraulic Input	Ppti	1132953.32	m3/yr	25%	0.25
Total Evaporation Hydraulic Loss	Eo	537793.13	m3/yr	50%	0.5
Total Hydraulic Surface Runoff	Ql	8955630.00	m3/yr	75%	0.75
Total Hydraulic Input	Qt	12801588.05	m3/yr	Matched	0.222907
Areal Hydraulic Input	*qs*	13.30	m/yr		
Total Hydraulic Outflow	Qo	12263794.92	m3/yr		
Total Atmospheric P Input	Jd	15955.79	gm/yr		
Total Surface Runoff P Input	Je	145094.53	gm/yr		
Total Development P Input	Jr	14572098.73	gm/yr		
Total P Input	Jt	14931198.40	gm/yr		
Lake P Retention Factor	Rp	0.48	n/a		
Lake P Retention	Ps	7205007.60	gm/yr		
Predicted Lake P Concentration	[P]	0.63	mg/L		
Lake P Outflow	Jo	7726190.80	gm/yr		
Lake Mean Depth	z	3.30	m		
Lake Flushing Rate	FR	0	1/yr		
Lake Turnover Time	TT	0	yr		
Lake Response Time	RT(1/2)	0	yr		

Table 31: Sample NSPM spreadsheet for Clearwater Lake

Clearwater Lake						
Input Parameters	**Symbol**	**Value**	**Units**	**Budgets**		
Morphology				**Hydraulic Budget (m3)**		
Drainage Basin Area (Excl. of Lake Area)	Ad	30.57	ha			**% Total**
Area Land Use Category 1 (Developed)	Ad1	0	ha	Upstream Inflow	0	0
Area Land Use Category 2 (Clearcut)	Ad2	0.26	ha	Precipitation	173818.6	38.71682
Area Land Use Category 3 (Forest)	Ad3	30.22	ha	Surface Runoff	275130	61.28318
Area Land Use Category 4 (Wetlands)	Ad4	0.09	ha	Evaporation	-82508.7	-18.3782
Lake Surface Area (Waterbodies)	Ao	14.15	ha	Point Sources		0
Lake Volume	V	436878	m3	Total Outflow	366440	81.6218
Hydrology Inputs				Check		100
Upstream Hydraulic Inputs	Qi	0	m3/yr	**Phosphorus Budget (gm/yr)**		
Annual Unit Precipitation	Pr	1.2284	m/yr			**% Total**
Annual Unit Lake Evaporation	Ev	0.5831	m/yr	Upstream Inflow	0.0	0.0
Annual Unit Hydraulic Runoff	Ru	0.9	m/yr	Atmospheric	2448.0	45.4
Phosphorus Inputs				Internal Load	0.0	0.0
Upstream P Input	Ju	0	gm P/yr	Watershed Inputs	2943.1	54.6
Annual Unit Atmospheric Phosphorus Deposition	Da	0.0173	gm P/m2/yr	Land Runoff	2943.1	54.6
Land Use Category 1 P Export Coefficient	E1	0.03	gm P/m2/yr	Development	0.0	0.0
Land Use Category 2 P Export Coefficient	E2	0.0174	gm P/m2/yr	Mink	0.0	0.0
Land Use Category 3 P Export Coefficient	E3	0.0095	gm P/m2/yr	Sedimentation	-3965.0	-73.5
Land Use Category 4 P Export Coefficient	E4	0.03	gm P/m2/yr	Total Outflow	1426.1	26.5
Point Source Input 1 (POWSIM)	PS1	0	gm P/yr	Check		100.0
Point Source Input 2 (Internal Load)	PS2	0	gm P/yr	**Model Validation**		

Point Source Input 3 (Mink)	PS3	0	gm P/yr	Predicted P	0.003892
Point Source Input 4 (Aquaculture)	PS4	0	gm P/yr	Measured P	0.004
Lake Phosphorus Retention Coefficient	v	12.4	n/a	% Difference	-2.70476
Model Outputs				**Export Coefficients**	
Total Precipitation Hydraulic Input	Ppti	173818.60	m3/yr	25%	0.25
Total Evaporation Hydraulic Loss	Eo	82508.65	m3/yr	50%	0.5
Total Hydraulic Surface Runoff	Ql	275130.00	m3/yr	75%	0.75
Total Hydraulic Input	Qt	448948.60	m3/yr	Matched	0
Areal Hydraulic Input	*qs*	2.59	m/yr		
Total Hydraulic Outflow	Qo	366439.95	m3/yr		
Total Atmospheric P Input	Jd	2447.95	gm/yr		
Total Surface Runoff P Input	Je	2943.14	gm/yr		
Total Development P Input	Jr	0.00	gm/yr		
Total P Input	Jt	5391.09	gm/yr		
Lake P Retention Factor	Rp	0.74	n/a		
Lake P Retention	Ps	3964.98	gm/yr		
Predicted Lake P Concentration	[P]	0.00	mg/L		
Lake P Outflow	Jo	1426.11	gm/yr		
Lake Mean Depth	z	3.50	m		
Lake Flushing Rate	FR	0.84	1/yr		
Lake Turnover Time	TT	1.19	yr		
Lake Response Time	RT(1/2)	0.19	yr		

Table 32: Sample NSPM spreadsheet for Oliver Lake

Oliver Lake						
Input Parameters	**Symbol**	**Value**	**Units**	**Budgets**		
Morphology				**Hydraulic Budget (m3)**		
Drainage Basin Area (Excl. of Lake Area)	Ad	104.54	ha			**% Total**
Area Land Use Category 1 (Developed)	Ad1	8.63	ha	Upstream Inflow	0	0
Area Land Use Category 2 (Clearcut)	Ad2	6.23	ha	Precipitation	231062	19.7165
Area Land Use Category 3 (Forest)	Ad3	79.8	ha	Surface Runoff	940860	80.2835
Area Land Use Category 4 (Wetlands)	Ad4	9.88	ha	Evaporation	-109681	-9.35908
Lake Surface Area (Waterbodies)	Ao	18.81	ha	Point Sources		0
Lake Volume	V	367303	m3	Total Outflow	1062241	90.64092
Hydrology Inputs				Check		100
Upstream Hydraulic Inputs	Qi	0	m3/yr	**Phosphorus Budget (gm/yr)**		
Annual Unit Precipitation	Pr	1.2284	m/yr			**% Total**
Annual Unit Lake Evaporation	Ev	0.5831	m/yr	Upstream Inflow	0.0	0.0
Annual Unit Hydraulic Runoff	Ru	0.9	m/yr	Atmospheric	3254.1	18.6
Phosphorus Inputs				Internal Load	0.0	0.0
Upstream P Input	Ju	0	gm P/yr	Watershed Inputs	14218.0	81.4
Annual Unit Atmospheric Phosphorus Deposition	Da	0.0173	gm P/m2/yr	Land Runoff	14218.0	81.4
Land Use Category 1 P Export Coefficient	E1	0.03	gm P/m2/yr	Development	0.0	0.0
Land Use Category 2 P Export Coefficient	E2	0.0174	gm P/m2/yr	Mink	0.0	0.0
Land Use Category 3 P Export Coefficient	E3	0.0095	gm P/m2/yr	Sedimentation	-12004.9	-68.7
Land Use Category 4 P Export Coefficient	E4	0.03	gm P/m2/yr	Total Outflow	5467.3	31.3
Point Source Input 1 (POWSIM)	PS1	0	gm P/yr	Check		100.0
Point Source Input 2 (Internal Load)	PS2	0	gm P/yr	**Model Validation**		

Point Source Input 3 (Mink)	PS3	0	gm P/yr	Predicted P	0.005147
Point Source Input 4 (Aquaculture)	PS4	0	gm P/yr	Measured P	N/A
Lake Phosphorus Retention Coefficient	v	12.4	n/a	% Difference	N/A
Model Outputs				**Export Coefficients**	
Total Precipitation Hydraulic Input	Ppti	231062.04	m3/yr	25%	0.25
Total Evaporation Hydraulic Loss	Eo	109681.11	m3/yr	50%	0.5
Total Hydraulic Surface Runoff	Ql	940860.00	m3/yr	75%	0.75
Total Hydraulic Input	Qt	1171922.04	m3/yr	Matched	0
Areal Hydraulic Input	*qs*	5.65	m/yr		
Total Hydraulic Outflow	Qo	1062240.93	m3/yr		
Total Atmospheric P Input	Jd	3254.13	gm/yr		
Total Surface Runoff P Input	Je	14218.02	gm/yr		
Total Development P Input	Jr	0.00	gm/yr		
Total P Input	Jt	17472.15	gm/yr		
Lake P Retention Factor	Rp	0.69	n/a		
Lake P Retention	Ps	12004.88	gm/yr		
Predicted Lake P Concentration	[P]	0.01	mg/L		
Lake P Outflow	Jo	5467.27	gm/yr		
Lake Mean Depth	z	2.00	m		
Lake Flushing Rate	FR	2.89	1/yr		
Lake Turnover Time	TT	0.35	yr		
Lake Response Time	RT(1/2)	0.09	yr		

Table 33: Sample NSPM spreadsheet for Paul Lake

Paul Lake						
Input Parameters	**Symbol**	**Value**	**Units**	**Budgets**		
Morphology				**Hydraulic Budget (m3)**		
Drainage Basin Area (Excl. of Lake Area)	Ad	97.5	ha			**% Total**
Area Land Use Category 1 (Developed)	Ad1	1.11	ha	Upstream Inflow	1062241	49.67234
Area Land Use Category 2 (Clearcut)	Ad2	0.29	ha	Precipitation	198755.1	9.294154
Area Land Use Category 3 (Forest)	Ad3	94.09	ha	Surface Runoff	877500	41.03351
Area Land Use Category 4 (Wetlands)	Ad4	2.01	ha	Evaporation	-94345.6	-4.41177
Lake Surface Area (Waterbodies)	Ao	16.18	ha	Point Sources		0
Lake Volume	V	337210	m3	Total Outflow	2044150	95.58823
Hydrology Inputs				Check		100
Upstream Hydraulic Inputs	Qi	1062240.93	m3/yr	**Phosphorus Budget (gm/yr)**		
Annual Unit Precipitation	Pr	1.2284	m/yr			**% Total**
Annual Unit Lake Evaporation	Ev	0.5831	m/yr	Upstream Inflow	5467.3	5.4
Annual Unit Hydraulic Runoff	Ru	0.9	m/yr	Atmospheric	2799.1	2.7
Phosphorus Inputs				Internal Load	0.0	0.0
Upstream P Input	Ju	5467.27	gm P/yr	Watershed Inputs	93840.9	91.9
Annual Unit Atmospheric Phosphorus Deposition	Da	0.0173	gm P/m2/yr	Land Runoff	9925.0	9.7
Land Use Category 1 P Export Coefficient	E1	0.03	gm P/m2/yr	Development	0.0	0.0
Land Use Category 2 P Export Coefficient	E2	0.0174	gm P/m2/yr	Mink	83915.9	82.2
Land Use Category 3 P Export Coefficient	E3	0.0095	gm P/m2/yr	Sedimentation	-50576.8	-49.5
Land Use Category 4 P Export Coefficient	E4	0.03	gm P/m2/yr	Total Outflow	51530.5	50.5
Point Source Input 1 (POWSIM)	PS1	0	gm P/yr	Check		100.0
Point Source Input 2 (Internal Load)	PS2	0	gm P/yr	**Model Validation**		

Point Source Input 3 (Mink)	PS3	83915.87	gm P/yr	Predicted P	0.025209
Point Source Input 4 (Aquaculture)	PS4	0	gm P/yr	Measured P	N/A
Lake Phosphorus Retention Coefficient	v	12.4	n/a	% Difference	N/A
Model Outputs				**Export Coefficients**	
Total Precipitation Hydraulic Input	Ppti	198755.12	m3/yr	25%	0.25
Total Evaporation Hydraulic Loss	Eo	94345.58	m3/yr	50%	0.5
Total Hydraulic Surface Runoff	Ql	877500.00	m3/yr	75%	0.75
Total Hydraulic Input	Qt	2138496.05	m3/yr	Matched	0.1
Areal Hydraulic Input	*qs*	12.63	m/yr		
Total Hydraulic Outflow	Qo	2044150.47	m3/yr		
Total Atmospheric P Input	Jd	2799.14	gm/yr		
Total Surface Runoff P Input	Je	9925.01	gm/yr		
Total Development P Input	Jr	83915.87	gm/yr		
Total P Input	Jt	102107.29	gm/yr		
Lake P Retention Factor	Rp	0.50	n/a		
Lake P Retention	Ps	50576.81	gm/yr		
Predicted Lake P Concentration	[P]	0.03	mg/L		
Lake P Outflow	Jo	51530.47	gm/yr		
Lake Mean Depth	z	20841.16	m		
Lake Flushing Rate	FR	6.06	1/yr		
Lake Turnover Time	TT	0.16	yr		
Lake Response Time	RT(1/2)	0.11	yr		

Table 34: Sample NSPM spreadsheet for Porcupine Lake

Porcupine Lake						
Input Parameters	**Symbol**	**Value**	**Units**	**Budgets**		
Morphology				**Hydraulic Budget (m3)**		
Drainage Basin Area (Excl. of Lake Area)	Ad	840.35	ha			**% Total**
Area Land Use Category 1 (Developed)	Ad1	124.58	ha	Upstream Inflow	2044150.47	18.1002
Area Land Use Category 2 (Clearcut)	Ad2	103.78	ha	Precipitation	1686224.68	14.9309
Area Land Use Category 3 (Forest)	Ad3	565.35	ha	Surface Runoff	7563150	66.9689
Area Land Use Category 4 (Wetlands)	Ad4	46.64	ha	Evaporation	-800421.37	-7.08744
Lake Surface Area (Waterbodies)	Ao	137.27	ha	Point Sources		0
Lake Volume	V	1410041	m3	Total Outflow	10493103.8	92.91256
Hydrology Inputs				Check		100
Upstream Hydraulic Inputs	Qi	2044150.47	m3/yr	**Phosphorus Budget (gm/yr)**		
Annual Unit Precipitation	Pr	1.2284	m/yr			**% Total**
Annual Unit Lake Evaporation	Ev	0.5831	m/yr	Upstream Inflow	51530.5	14.4
Annual Unit Hydraulic Runoff	Ru	0.9	m/yr	Atmospheric	23747.7	6.6
Phosphorus Inputs				Internal Load	0.0	0.0
Upstream P Input	Ju	51530.47	gm P/yr	Watershed Inputs	282411.4	79.0
Annual Unit Atmospheric Phosphorus Deposition	Da	0.0173	gm P/m2/yr	Land Runoff	123132.0	34.4
Land Use Category 1 P Export Coefficient	E1	0.03	gm P/m2/yr	Development	2370.0	0.7
Land Use Category 2 P Export Coefficient	E2	0.0174	gm P/m2/yr	Mink	156909.4	43.9
Land Use Category 3 P Export Coefficient	E3	0.0095	gm P/m2/yr	Sedimentation	-221279.2	-61.9
Land Use Category 4 P Export Coefficient	E4	0.03	gm P/m2/yr	Total Outflow	136410.3	38.1
Point Source Input 1 (POWSIM)	PS1	2370	gm P/yr	Check		100.0

				Model Validation	
Point Source Input 2 (Internal Load)	PS2	0	gm P/yr		
Point Source Input 3 (Mink)	PS3	156909.4354	gm P/yr	Predicted P	0.013
Point Source Input 4 (Aquaculture)	PS4	0	gm P/yr	Measured P	0.013
Lake Phosphorus Retention Coefficient	v	12.4	n/a	% Difference	1.33E-14
Model Outputs				**Export Coefficients**	
Total Precipitation Hydraulic Input	Ppti	1686224.68	m3/yr	25%	0.25
Total Evaporation Hydraulic Loss	Eo	800421.37	m3/yr	50%	0.5
Total Hydraulic Surface Runoff	Ql	7563150.00	m3/yr	75%	0.75
Total Hydraulic Input	Qt	11293525.15	m3/yr	Matched	0.016001
Areal Hydraulic Input	*qs*	7.64	m/yr		
Total Hydraulic Outflow	Qo	10493103.78	m3/yr		
Total Atmospheric P Input	Jd	23747.71	gm/yr		
Total Surface Runoff P Input	Je	123131.97	gm/yr		
Total Development P Input	Jr	159279.44	gm/yr		
Total P Input	Jt	357689.59	gm/yr		
Lake P Retention Factor	Rp	0.62	n/a		
Lake P Retention	Ps	221279.24	gm/yr		
Predicted Lake P Concentration	[P]	0.01	mg/L		
Lake P Outflow	Jo	136410.35	gm/yr		
Lake Mean Depth	z	1.00	m		
Lake Flushing Rate	FR	7.44	1/yr		
Lake Turnover Time	TT	0.13	yr		
Lake Response Time	RT(1/2)	0.04	yr		

Table 35: Sample NSPM spreadsheet for Doyles Lake

Doyles Lake						
Input Parameters	**Symbol**	**Value**	**Units**	**Budgets**		
Morphology				**Hydraulic Budget (m3)**		
Drainage Basin Area (Excl. of Lake Area)	Ad	646.62	ha			**% Total**
Area Land Use Category 1 (Developed)	Ad1	28.01	ha	Upstream Inflow	0	0
Area Land Use Category 2 (Clearcut)	Ad2	64.44	ha	Precipitation	1574932	21.29866
Area Land Use Category 3 (Forest)	Ad3	472.9	ha	Surface Runoff	5819580	78.70134
Area Land Use Category 4 (Wetlands)	Ad4	81.27	ha	Evaporation	-747593	-10.1101
Lake Surface Area (Waterbodies)	Ao	128.21	ha	Point Sources		0
Lake Volume	V	1406694	m3	Total Outflow	6646919	89.8899
Hydrology Inputs				Check		100
Upstream Hydraulic Inputs	Qi	0	m3/yr	**Phosphorus Budget (gm/yr)**		
Annual Unit Precipitation	Pr	1.2284	m/yr			**% Total**
Annual Unit Lake Evaporation	Ev	0.5831	m/yr	Upstream Inflow	0.0	0.0
Annual Unit Hydraulic Runoff	Ru	0.9	m/yr	Atmospheric	22180.3	20.0
Phosphorus Inputs				Internal Load	0.0	0.0
Upstream P Input	Ju	0	gm P/yr	Watershed Inputs	88922.1	80.0
Annual Unit Atmospheric Phosphorus Deposition	Da	0.0173	gm P/m2/yr	Land Runoff	88922.1	80.0
Land Use Category 1 P Export Coefficient	E1	0.03	gm P/m2/yr	Development	0.0	0.0
Land Use Category 2 P Export Coefficient	E2	0.0174	gm P/m2/yr	Mink	0.0	0.0
Land Use Category 3 P Export Coefficient	E3	0.0095	gm P/m2/yr	Sedimentation	-78346.1	-70.5
Land Use Category 4 P Export Coefficient	E4	0.03	gm P/m2/yr	Total Outflow	32756.3	29.5
Point Source Input 1 (POWSIM)	PS1	0	gm P/yr	Check		100.0
Point Source Input 2 (Internal Load)	PS2	0	gm P/yr	**Model Validation**		

Point Source Input 3 (Mink)	PS3	0	gm P/yr	Predicted P	0.004928
Point Source Input 4 (Aquaculture)	PS4	0	gm P/yr	Measured P	N/A
Lake Phosphorus Retention Coefficient	v	12.4	n/a	% Difference	N/A
Model Outputs				**Export Coefficients**	
Total Precipitation Hydraulic Input	Ppti	1574931.64	m3/yr	25%	0.25
Total Evaporation Hydraulic Loss	Eo	747592.51	m3/yr	50%	0.5
Total Hydraulic Surface Runoff	Ql	5819580.00	m3/yr	75%	0.75
Total Hydraulic Input	Qt	7394511.64	m3/yr	Matched	0
Areal Hydraulic Input	*qs*	5.18	m/yr		
Total Hydraulic Outflow	Qo	6646919.13	m3/yr		
Total Atmospheric P Input	Jd	22180.33	gm/yr		
Total Surface Runoff P Input	Je	88922.06	gm/yr		
Total Development P Input	Jr	0.00	gm/yr		
Total P Input	Jt	111102.39	gm/yr		
Lake P Retention Factor	Rp	0.71	n/a		
Lake P Retention	Ps	78346.13	gm/yr		
Predicted Lake P Concentration	[P]	0.00	mg/L		
Lake P Outflow	Jo	32756.26	gm/yr		
Lake Mean Depth	z	1.50	m		
Lake Flushing Rate	FR	4.73	1/yr		
Lake Turnover Time	TT	0.21	yr		
Lake Response Time	RT(1/2)	0.06	yr		

Table 36: Sample NSPM spreadsheet for Bear Lake

Bear Lake						
Input Parameters	**Symbol**	**Value**	**Units**	**Budgets**		
Morphology				**Hydraulic Budget (m3)**		
Drainage Basin Area (Excl. of Lake Area)	Ad	277.82	ha			**% Total**
Area Land Use Category 1 (Developed)	Ad1	1.35	ha	Upstream Inflow	0	0
Area Land Use Category 2 (Clearcut)	Ad2	4.92	ha	Precipitation	660142.2	20.88712
Area Land Use Category 3 (Forest)	Ad3	269.54	ha	Surface Runoff	2500380	79.11288
Area Land Use Category 4 (Wetlands)	Ad4	2.01	ha	Evaporation	-313358	-9.91475
Lake Surface Area (Waterbodies)	Ao	53.74	ha	Point Sources		0
Lake Volume	V		m3	Total Outflow	2847164	90.08525
Hydrology Inputs				Check		100
Upstream Hydraulic Inputs	Qi	0	m3/yr	**Phosphorus Budget (gm/yr)**		
Annual Unit Precipitation	Pr	1.2284	m/yr			**% Total**
Annual Unit Lake Evaporation	Ev	0.5831	m/yr	Upstream Inflow	0.0	0.0
Annual Unit Hydraulic Runoff	Ru	0.9	m/yr	Atmospheric	9297.0	25.3
Phosphorus Inputs				Internal Load	0.0	0.0
Upstream P Input	Ju	0	gm P/yr	Watershed Inputs	27470.4	74.7
Annual Unit Atmospheric Phosphorus Deposition	Da	0.0173	gm P/m2/yr	Land Runoff	27470.4	74.7
Land Use Category 1 P Export Coefficient	E1	0.03	gm P/m2/yr	Development	0.0	0.0
Land Use Category 2 P Export Coefficient	E2	0.0174	gm P/m2/yr	Mink	0.0	0.0
Land Use Category 3 P Export Coefficient	E3	0.0095	gm P/m2/yr	Sedimentation	-25760.8	-70.1
Land Use Category 4 P Export Coefficient	E4	0.03	gm P/m2/yr	Total Outflow	11006.6	29.9
Point Source Input 1 (POWSIM)	PS1	0	gm P/yr	Check		100.0
Point Source Input 2 (Internal Load)	PS2	0	gm P/yr	**Model Validation**		

Point Source Input 3 (Mink)	PS3	0	gm P/yr	Predicted P	0.003866
Point Source Input 4 (Aquaculture)	PS4	0	gm P/yr	Measured P	N/A
Lake Phosphorus Retention Coefficient	v	12.4	n/a	% Difference	N/A
Model Outputs				**Export Coefficients**	
Total Precipitation Hydraulic Input	Ppti	660142.16	m3/yr	25%	0.25
Total Evaporation Hydraulic Loss	Eo	313357.94	m3/yr	50%	0.5
Total Hydraulic Surface Runoff	Ql	2500380.00	m3/yr	75%	0.75
Total Hydraulic Input	Qt	3160522.16	m3/yr	Matched	0
Areal Hydraulic Input	*qs*	5.30	m/yr		
Total Hydraulic Outflow	Qo	2847164.22	m3/yr		
Total Atmospheric P Input	Jd	9297.02	gm/yr		
Total Surface Runoff P Input	Je	27470.38	gm/yr		
Total Development P Input	Jr	0.00	gm/yr		
Total P Input	Jt	36767.40	gm/yr		
Lake P Retention Factor	Rp	0.70	n/a		
Lake P Retention	Ps	25760.81	gm/yr		
Predicted Lake P Concentration	[P]	0.00	mg/L		
Lake P Outflow	Jo	11006.59	gm/yr		
Lake Mean Depth	z	0	m		
Lake Flushing Rate	FR	0	1/yr		
Lake Turnover Time	TT	0	yr		
Lake Response Time	RT(1/2)	0	yr		

Table 37: Sample NSPM spreadsheet for Sullivans Lake

Sullivans Lake						
Input Parameters	**Symbol**	**Value**	**Units**	**Budgets**		
Morphology				**Hydraulic Budget (m3)**		
Drainage Basin Area (Excl. of Lake Area)	Ad	721.22	ha			**% Total**
Area Land Use Category 1 (Developed)	Ad1	50.85	ha	Upstream Inflow	2847164.22	27.67411
Area Land Use Category 2 (Clearcut)	Ad2	59.84	ha	Precipitation	950044.56	9.234323
Area Land Use Category 3 (Forest)	Ad3	580.53	ha	Surface Runoff	6490980	63.09157
Area Land Use Category 4 (Wetlands)	Ad4	30	ha	Evaporation	-450969.54	-4.38337
Lake Surface Area (Waterbodies)	Ao	77.34	ha	Point Sources		0
Lake Volume	V	939930	m3	Total Outflow	9837219.24	95.61663
Hydrology Inputs				Check		100
Upstream Hydraulic Inputs	Qi	2847164.22	m3/yr	**Phosphorus Budget (gm/yr)**		
Annual Unit Precipitation	Pr	1.2284	m/yr			**% Total**
Annual Unit Lake Evaporation	Ev	0.5831	m/yr	Upstream Inflow	11006.6	1.3
Annual Unit Hydraulic Runoff	Ru	0.9	m/yr	Atmospheric	13379.8	1.6
Phosphorus Inputs				Internal Load	0.0	0.0
Upstream P Input	Ju	11006.59	gm P/yr	Watershed Inputs	824560.6	97.1
Annual Unit Atmospheric Phosphorus Deposition	Da	0.0173	gm P/m2/yr	Land Runoff	89817.5	10.6
Land Use Category 1 P Export Coefficient	E1	0.03	gm P/m2/yr	Development	0.0	0.0
Land Use Category 2 P Export Coefficient	E2	0.0174	gm P/m2/yr	Mink	734743.1	86.5
Land Use Category 3 P Export Coefficient	E3	0.0095	gm P/m2/yr	Sedimentation	-419075.5	-49.4
Land Use Category 4 P Export Coefficient	E4	0.03	gm P/m2/yr	Total Outflow	429871.6	50.6
Point Source Input 1 (POWSIM)	PS1	0	gm P/yr	Check		100.0

Point Source Input 2 (Internal Load)	PS2	0	gm P/yr	**Model Validation**	
Point Source Input 3 (Mink)	PS3	734743.1025	gm P/yr	Predicted P	0.043698
Point Source Input 4 (Aquaculture)	PS4	0	gm P/yr	Measured P	N/A
Lake Phosphorus Retention Coefficient	v	12.4	n/a	% Difference	N/A
Model Outputs				**Export Coefficients**	
Total Precipitation Hydraulic Input	Ppti	950044.56	m3/yr	25%	0.25
Total Evaporation Hydraulic Loss	Eo	450969.54	m3/yr	50%	0.5
Total Hydraulic Surface Runoff	Ql	6490980.00	m3/yr	75%	0.75
Total Hydraulic Input	Qt	10288188.78	m3/yr	Matched	0.1
Areal Hydraulic Input	*qs*	12.72	m/yr		
Total Hydraulic Outflow	Qo	9837219.24	m3/yr		
Total Atmospheric P Input	Jd	13379.82	gm/yr		
Total Surface Runoff P Input	Je	89817.51	gm/yr		
Total Development P Input	Jr	734743.10	gm/yr		
Total P Input	Jt	848947.02	gm/yr		
Lake P Retention Factor	Rp	0.49	n/a		
Lake P Retention	Ps	419075.45	gm/yr		
Predicted Lake P Concentration	[P]	0.04	mg/L		
Lake P Outflow	Jo	429871.57	gm/yr		
Lake Mean Depth	z	1.80	m		
Lake Flushing Rate	FR	10.47	1/yr		
Lake Turnover Time	TT	0.10	yr		
Lake Response Time	RT(1/2)	0.04	yr		

Table 38: Sample NSPM spreadsheet for Wentworth Lake

Wentworth Lake						
Input Parameters	**Symbol**	**Value**	**Units**	**Budgets**		
	Morphology			**Hydraulic Budget (m3)**		
Drainage Basin Area (Excl. of Lake Area)	Ad	8717.37	ha			**% Total**
Area Land Use Category 1 (Developed)	Ad1	489.06	ha	Upstream Inflow	39241037.07	31.95003
Area Land Use Category 2 (Clearcut)	Ad2	874.07	ha	Precipitation	5122673.68	4.170878
Area Land Use Category 3 (Forest)	Ad3	6931.12	ha	Surface Runoff	78456330	63.87909
Area Land Use Category 4 (Wetlands)	Ad4	423.12	ha	Evaporation	-2431643.62	-1.97984
Lake Surface Area (Waterbodies)	Ao	417.02	ha	Point Sources		0
Lake Volume	V	7217099	m3	Total Outflow	120388397.1	98.02016
	Hydrology Inputs			Check		100
Upstream Hydraulic Inputs	Qi	39241037.07	m3/yr	**Phosphorus Budget (gm/yr)**		
Annual Unit Precipitation	Pr	1.2284	m/yr			**% Total**
Annual Unit Lake Evaporation	Ev	0.5831	m/yr	Upstream Inflow	8325229.0	60.5
Annual Unit Hydraulic Runoff	Ru	0.9	m/yr	Atmospheric	72144.5	0.5
	Phosphorus Inputs			Internal Load	0.0	0.0
Upstream P Input	Ju	8325228.98	gm P/yr	Watershed Inputs	5370536.7	39.0
Annual Unit Atmospheric Phosphorus Deposition	Da	0.0173	gm P/m2/yr	Land Runoff	1084198.6	7.9
Land Use Category 1 P Export Coefficient	E1	0.03	gm P/m2/yr	Development	0.0	0.0
Land Use Category 2 P Export Coefficient	E2	0.0174	gm P/m2/yr	Mink	4286338.2	31.1
Land Use Category 3 P Export Coefficient	E3	0.0095	gm P/m2/yr	Sedimentation	-4136838.4	-30.0
Land Use Category 4 P Export Coefficient	E4	0.03	gm P/m2/yr	Total Outflow	9631071.8	70.0
Point Source Input 1 (POWSIM)	PS1	0	gm P/yr	Check		100.0

Point Source Input 2 (Internal Load)	PS2	0	gm P/yr
Point Source Input 3 (Mink)	PS3	4286338.152	gm P/yr
Point Source Input 4 (Aquaculture)	PS4	0	gm P/yr
Lake Phosphorus Retention Coefficient	v	12.4	n/a
Model Outputs			
Total Precipitation Hydraulic Input	Ppti	5122673.68	m3/yr
Total Evaporation Hydraulic Loss	Eo	2431643.62	m3/yr
Total Hydraulic Surface Runoff	Ql	78456330.00	m3/yr
Total Hydraulic Input	Qt	122820040.75	m3/yr
Areal Hydraulic Input	*qs*	28.87	m/yr
Total Hydraulic Outflow	Qo	120388397.13	m3/yr
Total Atmospheric P Input	Jd	72144.46	gm/yr
Total Surface Runoff P Input	Je	1084198.58	gm/yr
Total Development P Input	Jr	4286338.15	gm/yr
Total P Input	Jt	13767910.17	gm/yr
Lake P Retention Factor	Rp	0.30	n/a
Lake P Retention	Ps	4136838.40	gm/yr
Predicted Lake P Concentration	[P]	0.08	mg/L
Lake P Outflow	Jo	9631071.77	gm/yr
Lake Mean Depth	z	2.30	m
Lake Flushing Rate	FR	16.68	1/yr
Lake Turnover Time	TT	0.06	yr
Lake Response Time	RT(1/2)	0.03	yr

Model Validation	
Predicted P	0.08
Measured P	0.08
% Difference	3.47E-14

Export Coefficients	
25%	0.25
50%	0.5
75%	0.75
Matched	0.266363

Table 39: Sample NSPM spreadsheet for Little Wentworth Lake

Little Wentworth Lake						
Input Parameters	**Symbol**	**Value**	**Units**	**Budgets**		
Morphology				**Hydraulic Budget (m3)**		
Drainage Basin Area (Excl. of Lake Area)	Ad	165.12	ha			**% Total**
Area Land Use Category 1 (Developed)	Ad1	1.13	ha	Upstream Inflow	120388397.1	98.51493
Area Land Use Category 2 (Clearcut)	Ad2	12.57	ha	Precipitation	328719.84	0.268994
Area Land Use Category 3 (Forest)	Ad3	151.25	ha	Surface Runoff	1486080	1.216073
Area Land Use Category 4 (Wetlands)	Ad4	0.17	ha	Evaporation	-156037.56	-0.12769
Lake Surface Area (Waterbodies)	Ao	26.76	ha	Point Sources		0
Lake Volume	V		m3	Total Outflow	122047159.4	99.87231
Hydrology Inputs				Check		100
Upstream Hydraulic Inputs	Qi	120388397.13	m3/yr	**Phosphorus Budget (gm/yr)**		
Annual Unit Precipitation	Pr	1.2284	m/yr			**% Total**
Annual Unit Lake Evaporation	Ev	0.5831	m/yr	Upstream Inflow	9631071.8	99.8
Annual Unit Hydraulic Runoff	Ru	0.9	m/yr	Atmospheric	4629.5	0.0
Phosphorus Inputs				Internal Load	0.0	0.0
Upstream P Input	Ju	9631071.77	gm P/yr	Watershed Inputs	16945.9	0.2
Annual Unit Atmospheric Phosphorus Deposition	Da	0.0173	gm P/m2/yr	Land Runoff	16945.9	0.2
Land Use Category 1 P Export Coefficient	E1	0.03	gm P/m2/yr	Development	0.0	0.0
Land Use Category 2 P Export Coefficient	E2	0.0174	gm P/m2/yr	Mink	0.0	0.0
Land Use Category 3 P Export Coefficient	E3	0.0095	gm P/m2/yr	Sedimentation	-255491.5	-2.6
Land Use Category 4 P Export Coefficient	E4	0.03	gm P/m2/yr	Total Outflow	9397155.6	97.4
Point Source Input 1 (POWSIM)	PS1	0	gm P/yr	Check		100.0
Point Source Input 2 (Internal Load)	PS2	0	gm P/yr	**Model Validation**		

Point Source Input 3 (Mink)	PS3	0	gm P/yr	Predicted P	0.076996
Point Source Input 4 (Aquaculture)	PS4	0	gm P/yr	Measured P	N/A
Lake Phosphorus Retention Coefficient	v	12.4	n/a	% Difference	N/A
Model Outputs				**Export Coefficients**	
Total Precipitation Hydraulic Input	Ppti	328719.84	m3/yr	25%	0.25
Total Evaporation Hydraulic Loss	Eo	156037.56	m3/yr	50%	0.5
Total Hydraulic Surface Runoff	Ql	1486080.00	m3/yr	75%	0.75
Total Hydraulic Input	Qt	122203196.97	m3/yr	Matched	0
Areal Hydraulic Input	*qs*	456.08	m/yr		
Total Hydraulic Outflow	Qo	122047159.41	m3/yr		
Total Atmospheric P Input	Jd	4629.48	gm/yr		
Total Surface Runoff P Input	Je	16945.93	gm/yr		
Total Development P Input	Jr	0.00	gm/yr		
Total P Input	Jt	9652647.18	gm/yr		
Lake P Retention Factor	Rp	0.03	n/a		
Lake P Retention	Ps	255491.55	gm/yr		
Predicted Lake P Concentration	[P]	0.08	mg/L		
Lake P Outflow	Jo	9397155.63	gm/yr		
Lake Mean Depth	z	3.30	m		
Lake Flushing Rate	FR	0	1/yr		
Lake Turnover Time	TT	0	yr		
Lake Response Time	RT(1/2)	0	yr		

Table 40: Sample NSPM spreadsheet for Privilege Lake

Privilege Lake						
Input Parameters	**Symbol**	**Value**	**Units**	**Budgets**		
Morphology				**Hydraulic Budget (m3)**		
Drainage Basin Area (Excl. of Lake Area)	Ad	115.5	ha			**% Total**
Area Land Use Category 1 (Developed)	Ad1	0.64	ha	Upstream Inflow	122047159.4	98.9282
Area Land Use Category 2 (Clearcut)	Ad2	2.7	ha	Precipitation	282777.68	0.229212
Area Land Use Category 3 (Forest)	Ad3	111.8	ha	Surface Runoff	1039500	0.842591
Area Land Use Category 4 (Wetlands)	Ad4	0.36	ha	Evaporation	-134229.62	-0.1088
Lake Surface Area (Waterbodies)	Ao	23.02	ha	Point Sources		0
Lake Volume	V		m3	Total Outflow	123235207.5	99.8912
Hydrology Inputs				Check		100
Upstream Hydraulic Inputs	Qi	122047159.41	m3/yr	**Phosphorus Budget (gm/yr)**		
Annual Unit Precipitation	Pr	1.2284	m/yr			**% Total**
Annual Unit Lake Evaporation	Ev	0.5831	m/yr	Upstream Inflow	9397155.6	99.8
Annual Unit Hydraulic Runoff	Ru	0.9	m/yr	Atmospheric	3982.5	0.0
Phosphorus Inputs				Internal Load	0.0	0.0
Upstream P Input	Ju	9397155.63	gm P/yr	Watershed Inputs	11390.8	0.1
Annual Unit Atmospheric Phosphorus Deposition	Da	0.0173	gm P/m2/yr	Land Runoff	11390.8	0.1
Land Use Category 1 P Export Coefficient	E1	0.03	gm P/m2/yr	Development	0.0	0.0
Land Use Category 2 P Export Coefficient	E2	0.0174	gm P/m2/yr	Mink	0.0	0.0
Land Use Category 3 P Export Coefficient	E3	0.0095	gm P/m2/yr	Sedimentation	-213085.4	-2.3
Land Use Category 4 P Export Coefficient	E4	0.03	gm P/m2/yr	Total Outflow	9199443.5	97.7
Point Source Input 1 (POWSIM)	PS1	0	gm P/yr	Check		100.0

Point Source Input 2 (Internal Load)	PS2	0	gm P/yr
Point Source Input 3 (Mink)	PS3	0	gm P/yr
Point Source Input 4 (Aquaculture)	PS4	0	gm P/yr
Lake Phosphorus Retention Coefficient	v	12.4	n/a
Model Outputs			
Total Precipitation Hydraulic Input	Ppti	282777.68	m3/yr
Total Evaporation Hydraulic Loss	Eo	134229.62	m3/yr
Total Hydraulic Surface Runoff	Ql	1039500.00	m3/yr
Total Hydraulic Input	Qt	123369437.09	m3/yr
Areal Hydraulic Input	*qs*	535.34	m/yr
Total Hydraulic Outflow	Qo	123235207.47	m3/yr
Total Atmospheric P Input	Jd	3982.46	gm/yr
Total Surface Runoff P Input	Je	11390.80	gm/yr
Total Development P Input	Jr	0.00	gm/yr
Total P Input	Jt	9412528.89	gm/yr
Lake P Retention Factor	Rp	0.02	n/a
Lake P Retention	Ps	213085.43	gm/yr
Predicted Lake P Concentration	[P]	0.07	mg/L
Lake P Outflow	Jo	9199443.46	gm/yr
Lake Mean Depth	z	0.00	m
Lake Flushing Rate	FR	0	1/yr
Lake Turnover Time	TT	0	yr
Lake Response Time	RT(1/2)	0	yr

Model Validation	
Predicted P	0.074649
Measured P	N/A
% Difference	N/A
Export Coefficients	
25%	0.25
50%	0.5
75%	0.75
Matched	0.364885

Table 41: Sample NSPM spreadsheet for Big Bear Lake

Big Bear Lake						
Input Parameters	**Symbol**	**Value**	**Units**	**Budgets**		
Morphology				**Hydraulic Budget (m3)**		
Drainage Basin Area (Excl. of Lake Area)	Ad	353.61	ha			**% Total**
Area Land Use Category 1 (Developed)	Ad1	2.62	ha	Upstream Inflow	0	0
Area Land Use Category 2 (Clearcut)	Ad2	37.74	ha	Precipitation	603267.2	15.93518
Area Land Use Category 3 (Forest)	Ad3	304.22	ha	Surface Runoff	3182490	84.06482
Area Land Use Category 4 (Wetlands)	Ad4	9.03	ha	Evaporation	-286360	-7.56415
Lake Surface Area (Waterbodies)	Ao	49.11	ha	Point Sources		0
Lake Volume	V		m3	Total Outflow	3499397	92.43585
Hydrology Inputs				Check		100
Upstream Hydraulic Inputs	Qi	0	m3/yr	**Phosphorus Budget (gm/yr)**		
Annual Unit Precipitation	Pr	1.2284	m/yr			**% Total**
Annual Unit Lake Evaporation	Ev	0.5831	m/yr	Upstream Inflow	0.0	0.0
Annual Unit Hydraulic Runoff	Ru	0.9	m/yr	Atmospheric	8496.0	17.9
Phosphorus Inputs				Internal Load	0.0	0.0
Upstream P Input	Ju	0	gm P/yr	Watershed Inputs	38962.7	82.1
Annual Unit Atmospheric Phosphorus Deposition	Da	0.0173	gm P/m2/yr	Land Runoff	38962.7	82.1
Land Use Category 1 P Export Coefficient	E1	0.03	gm P/m2/yr	Development	0.0	0.0
Land Use Category 2 P Export Coefficient	E2	0.0174	gm P/m2/yr	Mink	0.0	0.0
Land Use Category 3 P Export Coefficient	E3	0.0095	gm P/m2/yr	Sedimentation	-30139.2	-63.5
Land Use Category 4 P Export Coefficient	E4	0.03	gm P/m2/yr	Total Outflow	17319.4	36.5
Point Source Input 1 (POWSIM)	PS1	0	gm P/yr	Check		100.0
Point Source Input 2 (Internal Load)	PS2	0	gm P/yr	**Model Validation**		

Point Source Input 3 (Mink)	PS3	0	gm P/yr	Predicted P	0.004949
Point Source Input 4 (Aquaculture)	PS4	0	gm P/yr	Measured P	N/A
Lake Phosphorus Retention Coefficient	v	12.4	n/a	% Difference	N/A
Model Outputs				**Export Coefficients**	
Total Precipitation Hydraulic Input	Ppti	603267.24	m3/yr	25%	0.25
Total Evaporation Hydraulic Loss	Eo	286360.41	m3/yr	50%	0.5
Total Hydraulic Surface Runoff	Ql	3182490.00	m3/yr	75%	0.75
Total Hydraulic Input	Qt	3785757.24	m3/yr	Matched	0
Areal Hydraulic Input	*qs*	7.13	m/yr		
Total Hydraulic Outflow	Qo	3499396.83	m3/yr		
Total Atmospheric P Input	Jd	8496.03	gm/yr		
Total Surface Runoff P Input	Je	38962.66	gm/yr		
Total Development P Input	Jr	0.00	gm/yr		
Total P Input	Jt	47458.69	gm/yr		
Lake P Retention Factor	Rp	0.64	n/a		
Lake P Retention	Ps	30139.25	gm/yr		
Predicted Lake P Concentration	[P]	0.00	mg/L		
Lake P Outflow	Jo	17319.44	gm/yr		
Lake Mean Depth	z		m		
Lake Flushing Rate	FR		1/yr		
Lake Turnover Time	TT		yr		
Lake Response Time	RT(1/2)		yr		

Table 42: Sample NSPM spreadsheet for Salmon Lake

Salmon Lake						
Input Parameters	**Symbol**	**Value**	**Units**	**Budgets**		
Morphology				**Hydraulic Budget (m3)**		
Drainage Basin Area (Excl. of Lake Area)	Ad	145.36	ha			**% Total**
Area Land Use Category 1 (Developed)	Ad1	0.31	ha	Upstream Inflow	0	0
Area Land Use Category 2 (Clearcut)	Ad2	0.64	ha	Precipitation	622553.1	32.24339
Area Land Use Category 3 (Forest)	Ad3	143.31	ha	Surface Runoff	1308240	67.75661
Area Land Use Category 4 (Wetlands)	Ad4	1.1	ha	Evaporation	-295515	-15.3054
Lake Surface Area (Waterbodies)	Ao	50.68	ha	Point Sources		0
Lake Volume	V		m3	Total Outflow	1635278	84.69463
Hydrology Inputs				Check		100
Upstream Hydraulic Inputs	Qi	0	m3/yr	**Phosphorus Budget (gm/yr)**		
Annual Unit Precipitation	Pr	1.2284	m/yr			**% Total**
Annual Unit Lake Evaporation	Ev	0.5831	m/yr	Upstream Inflow	0.0	0.0
Annual Unit Hydraulic Runoff	Ru	0.9	m/yr	Atmospheric	8767.6	38.3
Phosphorus Inputs				Internal Load	0.0	0.0
Upstream P Input	Ju	0	gm P/yr	Watershed Inputs	14148.8	61.7
Annual Unit Atmospheric Phosphorus Deposition	Da	0.0173	gm P/m2/yr	Land Runoff	14148.8	61.7
Land Use Category 1 P Export Coefficient	E1	0.03	gm P/m2/yr	Development	0.0	0.0
Land Use Category 2 P Export Coefficient	E2	0.0174	gm P/m2/yr	Mink	0.0	0.0
Land Use Category 3 P Export Coefficient	E3	0.0095	gm P/m2/yr	Sedimentation	-18184.5	-79.4
Land Use Category 4 P Export Coefficient	E4	0.03	gm P/m2/yr	Total Outflow	4731.9	20.6
Point Source Input 1 (POWSIM)	PS1	0	gm P/yr	Check		100.0
Point Source Input 2 (Internal Load)	PS2	0	gm P/yr	**Model Validation**		

Point Source Input 3 (Mink)	PS3	0	gm P/yr	Predicted P	0.002894
Point Source Input 4 (Aquaculture)	PS4	0	gm P/yr	Measured P	N/A
Lake Phosphorus Retention Coefficient	v	12.4	n/a	% Difference	N/A
Model Outputs				**Export Coefficients**	
Total Precipitation Hydraulic Input	Ppti	622553.12	m3/yr	25%	0.25
Total Evaporation Hydraulic Loss	Eo	295515.08	m3/yr	50%	0.5
Total Hydraulic Surface Runoff	Ql	1308240.00	m3/yr	75%	0.75
Total Hydraulic Input	Qt	1930793.12	m3/yr	Matched	0
Areal Hydraulic Input	*qs*	3.23	m/yr		
Total Hydraulic Outflow	Qo	1635278.04	m3/yr		
Total Atmospheric P Input	Jd	8767.64	gm/yr		
Total Surface Runoff P Input	Je	14148.81	gm/yr		
Total Development P Input	Jr	0.00	gm/yr		
Total P Input	Jt	22916.45	gm/yr		
Lake P Retention Factor	Rp	0.79	n/a		
Lake P Retention	Ps	18184.55	gm/yr		
Predicted Lake P Concentration	[P]	0.00	mg/L		
Lake P Outflow	Jo	4731.90	gm/yr		
Lake Mean Depth	z		m		
Lake Flushing Rate	FR		1/yr		
Lake Turnover Time	TT		yr		
Lake Response Time	RT(1/2)		yr		

Table 43: Sample NSPM spreadsheet for Kempt Back Lake

Kempt Back Lake						
Input Parameters	**Symbol**	**Value**	**Units**	**Budgets**		
Morphology				**Hydraulic Budget (m3)**		
Drainage Basin Area (Excl. of Lake Area)	Ad	1456.05	ha			**% Total**
Area Land Use Category 1 (Developed)	Ad1	51.3	ha	Upstream Inflow	0	0
Area Land Use Category 2 (Clearcut)	Ad2	133.47	ha	Precipitation	4199040	24.26701
Area Land Use Category 3 (Forest)	Ad3	1231.37	ha	Surface Runoff	13104450	75.73299
Area Land Use Category 4 (Wetlands)	Ad4	39.91	ha	Evaporation	-1993211	-11.5191
Lake Surface Area (Waterbodies)	Ao	341.83	ha	Point Sources		0
Lake Volume	V	14281680	m3	Total Outflow	15310279	88.48087
Hydrology Inputs				Check		100
Upstream Hydraulic Inputs	Qi	0	m3/yr	**Phosphorus Budget (gm/yr)**		
Annual Unit Precipitation	Pr	1.2284	m/yr			**% Total**
Annual Unit Lake Evaporation	Ev	0.5831	m/yr	Upstream Inflow	0.0	0.0
Annual Unit Hydraulic Runoff	Ru	0.9	m/yr	Atmospheric	59136.6	26.1
Phosphorus Inputs				Internal Load	0.0	0.0
Upstream P Input	Ju	0	gm P/yr	Watershed Inputs	167566.9	73.9
Annual Unit Atmospheric Phosphorus Deposition	Da	0.0173	gm P/m2/yr	Land Runoff	167566.9	73.9
Land Use Category 1 P Export Coefficient	E1	0.03	gm P/m2/yr	Development	0.0	0.0
Land Use Category 2 P Export Coefficient	E2	0.0174	gm P/m2/yr	Mink	0.0	0.0
Land Use Category 3 P Export Coefficient	E3	0.0095	gm P/m2/yr	Sedimentation	-166546.5	-73.5
Land Use Category 4 P Export Coefficient	E4	0.03	gm P/m2/yr	Total Outflow	60157.1	26.5
Point Source Input 1 (POWSIM)	PS1	0	gm P/yr	Check		100.0

Point Source Input 2 (Internal Load)	PS2	0	gm P/yr
Point Source Input 3 (Mink)	PS3	0	gm P/yr
Point Source Input 4 (Aquaculture)	PS4	0	gm P/yr
Lake Phosphorus Retention Coefficient	v	12.4	n/a

Model Validation	
Predicted P	0.003929
Measured P	N/A
% Difference	N/A

Model Outputs			
Total Precipitation Hydraulic Input	Ppti	4199039.72	m3/yr
Total Evaporation Hydraulic Loss	Eo	1993210.73	m3/yr
Total Hydraulic Surface Runoff	Ql	13104450.00	m3/yr
Total Hydraulic Input	Qt	17303489.72	m3/yr
Areal Hydraulic Input	*qs*	4.48	m/yr
Total Hydraulic Outflow	Qo	15310278.99	m3/yr
Total Atmospheric P Input	Jd	59136.59	gm/yr
Total Surface Runoff P Input	Je	167566.93	gm/yr
Total Development P Input	Jr	0.00	gm/yr
Total P Input	Jt	226703.52	gm/yr
Lake P Retention Factor	Rp	0.73	n/a
Lake P Retention	Ps	166546.46	gm/yr
Predicted Lake P Concentration	[P]	0.00	mg/L
Lake P Outflow	Jo	60157.06	gm/yr
Lake Mean Depth	z	2.30	m
Lake Flushing Rate	FR	1.07	1/yr
Lake Turnover Time	TT	0.93	yr
Lake Response Time	RT(1/2)	0.13	yr

Export Coefficients	
25%	0.25
50%	0.5
75%	0.75
Matched	0

Table 44: Sample NSPM spreadsheet for Hunter Lake

Hunter Lake						
Input Parameters	**Symbol**	**Value**	**Units**	**Budgets**		
Morphology				**Hydraulic Budget (m3)**		
Drainage Basin Area (Excl. of Lake Area)	Ad	709.13	ha			**% Total**
Area Land Use Category 1 (Developed)	Ad1	56.23	ha	Upstream Inflow	0	0
Area Land Use Category 2 (Clearcut)	Ad2	110.22	ha	Precipitation	813692.2	11.30778
Area Land Use Category 3 (Forest)	Ad3	538.39	ha	Surface Runoff	6382170	88.69222
Area Land Use Category 4 (Wetlands)	Ad4	4.29	ha	Evaporation	-386245	-5.3676
Lake Surface Area (Waterbodies)	Ao	66.24	ha	Point Sources		0
Lake Volume	V	509565	m3	Total Outflow	6809617	94.6324
Hydrology Inputs				Check		100
Upstream Hydraulic Inputs	Qi	0	m3/yr	**Phosphorus Budget (gm/yr)**		
Annual Unit Precipitation	Pr	1.2284	m/yr			**% Total**
Annual Unit Lake Evaporation	Ev	0.5831	m/yr	Upstream Inflow	0.0	0.0
Annual Unit Hydraulic Runoff	Ru	0.9	m/yr	Atmospheric	11459.5	11.5
Phosphorus Inputs				Internal Load	0.0	0.0
Upstream P Input	Ju	0	gm P/yr	Watershed Inputs	88481.3	88.5
Annual Unit Atmospheric Phosphorus Deposition	Da	0.0173	gm P/m2/yr	Land Runoff	88481.3	88.5
Land Use Category 1 P Export Coefficient	E1	0.03	gm P/m2/yr	Development	0.0	0.0
Land Use Category 2 P Export Coefficient	E2	0.0174	gm P/m2/yr	Mink	0.0	0.0
Land Use Category 3 P Export Coefficient	E3	0.0095	gm P/m2/yr	Sedimentation	-54640.9	-54.7
Land Use Category 4 P Export Coefficient	E4	0.03	gm P/m2/yr	Total Outflow	45300.0	45.3
Point Source Input 1 (POWSIM)	PS1	0	gm P/yr	Check		100.0
Point Source Input 2 (Internal Load)	PS2	0	gm P/yr	**Model Validation**		

Point Source Input 3 (Mink)	PS3	0	gm P/yr	Predicted P	0.006652
Point Source Input 4 (Aquaculture)	PS4	0	gm P/yr	Measured P	N/A
Lake Phosphorus Retention Coefficient	v	12.4	n/a	% Difference	N/A
Model Outputs				**Export Coefficients**	
Total Precipitation Hydraulic Input	Ppti	813692.16	m3/yr	25%	0.25
Total Evaporation Hydraulic Loss	Eo	386245.44	m3/yr	50%	0.5
Total Hydraulic Surface Runoff	Ql	6382170.00	m3/yr	75%	0.75
Total Hydraulic Input	Qt	7195862.16	m3/yr	Matched	0
Areal Hydraulic Input	*qs*	10.28	m/yr		
Total Hydraulic Outflow	Qo	6809616.72	m3/yr		
Total Atmospheric P Input	Jd	11459.52	gm/yr		
Total Surface Runoff P Input	Je	88481.33	gm/yr		
Total Development P Input	Jr	0.00	gm/yr		
Total P Input	Jt	99940.85	gm/yr		
Lake P Retention Factor	Rp	0.55	n/a		
Lake P Retention	Ps	54640.86	gm/yr		
Predicted Lake P Concentration	[P]	0.01	mg/L		
Lake P Outflow	Jo	45299.99	gm/yr		
Lake Mean Depth	z	1.50	m		
Lake Flushing Rate	FR	13.36	1/yr		
Lake Turnover Time	TT	0.07	yr		
Lake Response Time	RT(1/2)	0.03	yr		

Table 45: Sample NSPM spreadsheet for Four Island Lake

Four Island Lake						
Input Parameters	**Symbol**	**Value**	**Units**	**Budgets**		
Morphology				**Hydraulic Budget (m3)**		
Drainage Basin Area (Excl. of Lake Area)	Ad	422.14	ha			**% Total**
Area Land Use Category 1 (Developed)	Ad1	50.53	ha	Upstream Inflow	6809617	57.21635
Area Land Use Category 2 (Clearcut)	Ad2	119.46	ha	Precipitation	1292645	10.86118
Area Land Use Category 3 (Forest)	Ad3	247.67	ha	Surface Runoff	3799260	31.92247
Area Land Use Category 4 (Wetlands)	Ad4	4.48	ha	Evaporation	-613596	-5.15561
Lake Surface Area (Waterbodies)	Ao	105.23	ha	Point Sources		0
Lake Volume	V		m3	Total Outflow	11287926	94.84439
Hydrology Inputs				Check		100
Upstream Hydraulic Inputs	Qi	6809616.72	m3/yr	**Phosphorus Budget (gm/yr)**		
Annual Unit Precipitation	Pr	1.2284	m/yr			**% Total**
Annual Unit Lake Evaporation	Ev	0.5831	m/yr	Upstream Inflow	45300.0	36.4
Annual Unit Hydraulic Runoff	Ru	0.9	m/yr	Atmospheric	18204.8	14.6
Phosphorus Inputs				Internal Load	0.0	0.0
Upstream P Input	Ju	45299.99	gm P/yr	Watershed Inputs	60817.7	48.9
Annual Unit Atmospheric Phosphorus Deposition	Da	0.0173	gm P/m2/yr	Land Runoff	60817.7	48.9
Land Use Category 1 P Export Coefficient	E1	0.03	gm P/m2/yr	Development	0.0	0.0
Land Use Category 2 P Export Coefficient	E2	0.0174	gm P/m2/yr	Mink	0.0	0.0
Land Use Category 3 P Export Coefficient	E3	0.0095	gm P/m2/yr	Sedimentation	-66658.2	-53.6
Land Use Category 4 P Export Coefficient	E4	0.03	gm P/m2/yr	Total Outflow	57664.2	46.4
Point Source Input 1 (POWSIM)	PS1	0	gm P/yr	Check		100.0

Point Source Input 2 (Internal Load)	PS2	0	gm P/yr	**Model Validation**	
Point Source Input 3 (Mink)	PS3	0	gm P/yr	Predicted P	0.005108
Point Source Input 4 (Aquaculture)	PS4	0	gm P/yr	Measured P	N/A
Lake Phosphorus Retention Coefficient	v	12.4	n/a	% Difference	N/A
Model Outputs				**Export Coefficients**	
Total Precipitation Hydraulic Input	Ppti	1292645.32	m3/yr	25%	0.25
Total Evaporation Hydraulic Loss	Eo	613596.13	m3/yr	50%	0.5
Total Hydraulic Surface Runoff	Ql	3799260.00	m3/yr	75%	0.75
Total Hydraulic Input	Qt	11901522.04	m3/yr	Matched	0
Areal Hydraulic Input	*qs*	10.73	m/yr		
Total Hydraulic Outflow	Qo	11287925.91	m3/yr		
Total Atmospheric P Input	Jd	18204.79	gm/yr		
Total Surface Runoff P Input	Je	60817.69	gm/yr		
Total Development P Input	Jr	0.00	gm/yr		
Total P Input	Jt	124322.47	gm/yr		
Lake P Retention Factor	Rp	0.54	n/a		
Lake P Retention	Ps	66658.23	gm/yr		
Predicted Lake P Concentration	[P]	0.01	mg/L		
Lake P Outflow	Jo	57664.25	gm/yr		
Lake Mean Depth	z	0	m		
Lake Flushing Rate	FR	0	1/yr		
Lake Turnover Time	TT	0	yr		
Lake Response Time	RT(1/2)	0	yr		

Table 46: Sample NSPM spreadsheet for Second Briar Lake

Second Briar Lake						
Input Parameters	**Symbol**	**Value**	**Units**	**Budgets**		
Morphology				**Hydraulic Budget (m3)**		
Drainage Basin Area (Excl. of Lake Area)	Ad	65.27	ha			**% Total**
Area Land Use Category 1 (Developed)	Ad1	5.88	ha	Upstream Inflow	11287926	91.19966
Area Land Use Category 2 (Clearcut)	Ad2	20.9	ha	Precipitation	501801.4	4.054254
Area Land Use Category 3 (Forest)	Ad3	37.79	ha	Surface Runoff	587430	4.746082
Area Land Use Category 4 (Wetlands)	Ad4	0.7	ha	Evaporation	-238196	-1.92448
Lake Surface Area (Waterbodies)	Ao	40.85	ha	Point Sources		0
Lake Volume	V		m3	Total Outflow	12138961	98.07552
Hydrology Inputs				Check		100
Upstream Hydraulic Inputs	Qi	11287925.91	m3/yr	**Phosphorus Budget (gm/yr)**		
Annual Unit Precipitation	Pr	1.2284	m/yr			**% Total**
Annual Unit Lake Evaporation	Ev	0.5831	m/yr	Upstream Inflow	57664.2	78.0
Annual Unit Hydraulic Runoff	Ru	0.9	m/yr	Atmospheric	7067.1	9.6
Phosphorus Inputs				Internal Load	0.0	0.0
Upstream P Input	Ju	57664.25	gm P/yr	Watershed Inputs	9200.7	12.4
Annual Unit Atmospheric Phosphorus Deposition	Da	0.0173	gm P/m2/yr	Land Runoff	9200.7	12.4
Land Use Category 1 P Export Coefficient	E1	0.03	gm P/m2/yr	Development	0.0	0.0
Land Use Category 2 P Export Coefficient	E2	0.0174	gm P/m2/yr	Mink	0.0	0.0
Land Use Category 3 P Export Coefficient	E3	0.0095	gm P/m2/yr	Sedimentation	-21767.4	-29.4
Land Use Category 4 P Export Coefficient	E4	0.03	gm P/m2/yr	Total Outflow	52164.5	70.6
Point Source Input 1 (POWSIM)	PS1	0	gm P/yr	Check		100.0

Point Source Input 2 (Internal Load)	PS2	0	gm P/yr
Point Source Input 3 (Mink)	PS3	0	gm P/yr
Point Source Input 4 (Aquaculture)	PS4	0	gm P/yr
Lake Phosphorus Retention Coefficient	v	12.4	n/a

Model Validation	
Predicted P	0.004297
Measured P	N/A
% Difference	N/A

Model Outputs			
Total Precipitation Hydraulic Input	Ppti	501801.40	m3/yr
Total Evaporation Hydraulic Loss	Eo	238196.35	m3/yr
Total Hydraulic Surface Runoff	Ql	587430.00	m3/yr
Total Hydraulic Input	Qt	12377157.31	m3/yr
Areal Hydraulic Input	*qs*	29.72	m/yr
Total Hydraulic Outflow	Qo	12138960.96	m3/yr
Total Atmospheric P Input	Jd	7067.05	gm/yr
Total Surface Runoff P Input	Je	9200.65	gm/yr
Total Development P Input	Jr	0.00	gm/yr
Total P Input	Jt	73931.95	gm/yr
Lake P Retention Factor	Rp	0.29	n/a
Lake P Retention	Ps	21767.44	gm/yr
Predicted Lake P Concentration	[P]	0.00	mg/L
Lake P Outflow	Jo	52164.51	gm/yr
Lake Mean Depth	z	0	m
Lake Flushing Rate	FR	0	1/yr
Lake Turnover Time	TT	0	yr
Lake Response Time	RT(1/2)	0	yr

Export Coefficients	
25%	0.25
50%	0.5
75%	0.75
Matched	0

Table 47: Sample NSPM spreadsheet for First Briar Lake

First Briar Lake						
Input Parameters	**Symbol**	**Value**	**Units**	**Budgets**		
Morphology				**Hydraulic Budget (m3)**		
Drainage Basin Area (Excl. of Lake Area)	Ad	442.31	ha			**% Total**
Area Land Use Category 1 (Developed)	Ad1	10.45	ha	Upstream Inflow	12138961	74.15047
Area Land Use Category 2 (Clearcut)	Ad2	119.36	ha	Precipitation	250962.1	1.532994
Area Land Use Category 3 (Forest)	Ad3	307.98	ha	Surface Runoff	3980790	24.31653
Area Land Use Category 4 (Wetlands)	Ad4	4.52	ha	Evaporation	-119127	-0.72769
Lake Surface Area (Waterbodies)	Ao	20.43	ha	Point Sources		0
Lake Volume	V		m3	Total Outflow	16251586	99.27231
Hydrology Inputs				Check		100
Upstream Hydraulic Inputs	Qi	12138960.96	m3/yr	**Phosphorus Budget (gm/yr)**		
Annual Unit Precipitation	Pr	1.2284	m/yr			**% Total**
Annual Unit Lake Evaporation	Ev	0.5831	m/yr	Upstream Inflow	52164.5	47.3
Annual Unit Hydraulic Runoff	Ru	0.9	m/yr	Atmospheric	3534.4	3.2
Phosphorus Inputs				Internal Load	0.0	0.0
Upstream P Input	Ju	52164.51	gm P/yr	Watershed Inputs	54517.7	49.5
Annual Unit Atmospheric Phosphorus Deposition	Da	0.0173	gm P/m2/yr	Land Runoff	54517.7	49.5
Land Use Category 1 P Export Coefficient	E1	0.03	gm P/m2/yr	Development	0.0	0.0
Land Use Category 2 P Export Coefficient	E2	0.0174	gm P/m2/yr	Mink	0.0	0.0
Land Use Category 3 P Export Coefficient	E3	0.0095	gm P/m2/yr	Sedimentation	-14863.7	-13.5
Land Use Category 4 P Export Coefficient	E4	0.03	gm P/m2/yr	Total Outflow	95352.9	86.5
Point Source Input 1 (POWSIM)	PS1	0	gm P/yr	Check		100.0

Point Source Input 2 (Internal Load)	PS2	0	gm P/yr	**Model Validation**	
Point Source Input 3 (Mink)	PS3	0	gm P/yr	Predicted P	0.005867
Point Source Input 4 (Aquaculture)	PS4	0	gm P/yr	Measured P	N/A
Lake Phosphorus Retention Coefficient	v	12.4	n/a	% Difference	N/A
Model Outputs				**Export Coefficients**	
Total Precipitation Hydraulic Input	Ppti	250962.12	m3/yr	25%	0.25
Total Evaporation Hydraulic Loss	Eo	119127.33	m3/yr	50%	0.5
Total Hydraulic Surface Runoff	Ql	3980790.00	m3/yr	75%	0.75
Total Hydraulic Input	Qt	16370713.08	m3/yr	Matched	0
Areal Hydraulic Input	*qs*	79.55	m/yr		
Total Hydraulic Outflow	Qo	16251585.75	m3/yr		
Total Atmospheric P Input	Jd	3534.39	gm/yr		
Total Surface Runoff P Input	Je	54517.74	gm/yr		
Total Development P Input	Jr	0.00	gm/yr		
Total P Input	Jt	110216.64	gm/yr		
Lake P Retention Factor	Rp	0.13	n/a		
Lake P Retention	Ps	14863.74	gm/yr		
Predicted Lake P Concentration	[P]	0.01	mg/L		
Lake P Outflow	Jo	95352.90	gm/yr		
Lake Mean Depth	z	0	m		
Lake Flushing Rate	FR	0	1/yr		
Lake Turnover Time	TT	0	yr		
Lake Response Time	RT(1/2)	0	yr		

Table 48: Sample NSPM spreadsheet for Parr Lake

Parr Lake						
Input Parameters	**Symbol**	**Value**	**Units**	**Budgets**		
Morphology				**Hydraulic Budget (m3)**		
Drainage Basin Area (Excl. of Lake Area)	Ad	5403.52	ha			**% Total**
Area Land Use Category 1 (Developed)	Ad1	151.04	ha	Upstream Inflow	159931747.1	75.03096
Area Land Use Category 2 (Clearcut)	Ad2	365.86	ha	Precipitation	4590899.32	2.153791
Area Land Use Category 3 (Forest)	Ad3	4843.5	ha	Surface Runoff	48631680	22.81524
Area Land Use Category 4 (Wetlands)	Ad4	43.12	ha	Evaporation	-2179219.63	-1.02237
Lake Surface Area (Waterbodies)	Ao	373.73	ha	Point Sources		0
Lake Volume	V	10529820	m3	Total Outflow	210975106.8	98.97763
Hydrology Inputs				Check		100
Upstream Hydraulic Inputs	Qi	159931747.08	m3/yr	**Phosphorus Budget (gm/yr)**		
Annual Unit Precipitation	Pr	1.2284	m/yr			**% Total**
Annual Unit Lake Evaporation	Ev	0.5831	m/yr	Upstream Inflow	9377004.8	93.5
Annual Unit Hydraulic Runoff	Ru	0.9	m/yr	Atmospheric	64655.3	0.6
Phosphorus Inputs				Internal Load	0.0	0.0
Upstream P Input	Ju	9377004.77	gm P/yr	Watershed Inputs	587070.1	5.9
Annual Unit Atmospheric Phosphorus Deposition	Da	0.0173	gm P/m2/yr	Land Runoff	582040.1	5.8
Land Use Category 1 P Export Coefficient	E1	0.03	gm P/m2/yr	Development	5030.0	0.1
Land Use Category 2 P Export Coefficient	E2	0.0174	gm P/m2/yr	Mink	0.0	0.0
Land Use Category 3 P Export Coefficient	E3	0.0095	gm P/m2/yr	Sedimentation	-1806159.3	-18.0
Land Use Category 4 P Export Coefficient	E4	0.03	gm P/m2/yr	Total Outflow	8222570.9	82.0
Point Source Input 1 (POWSIM)	PS1	5030	gm P/yr	Check		100.0

Point Source Input 2 (Internal Load)	PS2	0	gm P/yr	**Model Validation**	
Point Source Input 3 (Mink)	PS3	0	gm P/yr	Predicted P	0.038974
Point Source Input 4 (Aquaculture)	PS4	0	gm P/yr	Measured P	0.049
Lake Phosphorus Retention Coefficient	v	12.4	n/a	% Difference	-20.461
Model Outputs				**Export Coefficients**	
Total Precipitation Hydraulic Input	Ppti	4590899.32	m3/yr	25%	0.25
Total Evaporation Hydraulic Loss	Eo	2179219.63	m3/yr	50%	0.5
Total Hydraulic Surface Runoff	Ql	48631680.00	m3/yr	75%	0.75
Total Hydraulic Input	Qt	213154326.40	m3/yr	Matched	0
Areal Hydraulic Input	*qs*	56.45	m/yr		
Total Hydraulic Outflow	Qo	210975106.77	m3/yr		
Total Atmospheric P Input	Jd	64655.29	gm/yr		
Total Surface Runoff P Input	Je	582040.14	gm/yr		
Total Development P Input	Jr	5030.00	gm/yr		
Total P Input	Jt	10028730.20	gm/yr		
Lake P Retention Factor	Rp	0.18	n/a		
Lake P Retention	Ps	1806159.32	gm/yr		
Predicted Lake P Concentration	[P]	0.04	mg/L		
Lake P Outflow	Jo	8222570.88	gm/yr		
Lake Mean Depth	z	3.2	m		
Lake Flushing Rate	FR	20.04	1/yr		
Lake Turnover Time	TT	0.05	yr		
Lake Response Time	RT(1/2)	0.03	yr		

Table 49: Sample NSPM spreadsheet for Ogden Lake

Ogden Lake						
Input Parameters	**Symbol**	**Value**	**Units**	**Budgets**		
Morphology				**Hydraulic Budget (m3)**		
Drainage Basin Area (Excl. of Lake Area)	Ad	959.8	ha			**% Total**
Area Land Use Category 1 (Developed)	Ad1	49.25	ha	Upstream Inflow	210975106.8	94.21764
Area Land Use Category 2 (Clearcut)	Ad2	74.13	ha	Precipitation	4309841.4	1.924697
Area Land Use Category 3 (Forest)	Ad3	793.98	ha	Surface Runoff	8638200	3.857663
Area Land Use Category 4 (Wetlands)	Ad4	42.44	ha	Evaporation	-2045806.35	-0.91362
Lake Surface Area (Waterbodies)	Ao	350.85	ha	Point Sources		0
Lake Volume	V	11674510	m3	Total Outflow	221877341.8	99.08638
Hydrology Inputs				Check		100
Upstream Hydraulic Inputs	Qi	210975106.77	m3/yr	**Phosphorus Budget (gm/yr)**		
Annual Unit Precipitation	Pr	1.2284	m/yr			**% Total**
Annual Unit Lake Evaporation	Ev	0.5831	m/yr	Upstream Inflow	8222570.9	97.7
Annual Unit Hydraulic Runoff	Ru	0.9	m/yr	Atmospheric	60697.1	0.7
Phosphorus Inputs				Internal Load	0.0	0.0
Upstream P Input	Ju	8222570.88	gm P/yr	Watershed Inputs	133583.7	1.6
Annual Unit Atmospheric Phosphorus Deposition	Da	0.0173	gm P/m2/yr	Land Runoff	115833.7	1.4
Land Use Category 1 P Export Coefficient	E1	0.03	gm P/m2/yr	Development	17750.0	0.2
Land Use Category 2 P Export Coefficient	E2	0.0174	gm P/m2/yr	Mink	0.0	0.0
Land Use Category 3 P Export Coefficient	E3	0.0095	gm P/m2/yr	Sedimentation	-860504.3	-10.2
Land Use Category 4 P Export Coefficient	E4	0.03	gm P/m2/yr	Total Outflow	7558089.1	89.8
Point Source Input 1 (POWSIM)	PS1	17750	gm P/yr	Check		100.0

Point Source Input 2 (Internal Load)	PS2	1741.701377	gm P/yr	**Model Validation**	
Point Source Input 3 (Mink)	PS3	0	gm P/yr	Predicted P	0.034064
Point Source Input 4 (Aquaculture)	PS4	0	gm P/yr	Measured P	0.061
Lake Phosphorus Retention Coefficient	v	7.2	n/a	% Difference	-44.1569
Model Outputs				**Export Coefficients**	
Total Precipitation Hydraulic Input	Ppti	4309841.40	m3/yr	25%	0.25
Total Evaporation Hydraulic Loss	Eo	2045806.35	m3/yr	50%	0.5
Total Hydraulic Surface Runoff	Ql	8638200.00	m3/yr	75%	0.75
Total Hydraulic Input	Qt	223923148.17	m3/yr	Matched	0
Areal Hydraulic Input	*qs*	63.24	m/yr		
Total Hydraulic Outflow	Qo	221877341.82	m3/yr		
Total Atmospheric P Input	Jd	60697.05	gm/yr		
Total Surface Runoff P Input	Je	115833.72	gm/yr		
Total Development P Input	Jr	19491.70	gm/yr		
Total P Input	Jt	8418593.35	gm/yr		
Lake P Retention Factor	Rp	0.10	n/a		
Lake P Retention	Ps	860504.27	gm/yr		
Predicted Lake P Concentration	[P]	0.03	mg/L		
Lake P Outflow	Jo	7558089.08	gm/yr		
Lake Mean Depth	z	4.4	m		
Lake Flushing Rate	FR	19.01	1/yr		
Lake Turnover Time	TT	0.05	yr		
Lake Response Time	RT(1/2)	0.03	yr		

Table 50: Sample NSPM spreadsheet for Mink Lake

Mink Lake						
Input Parameters	**Symbol**	**Value**	**Units**	**Budgets**		
Morphology				**Hydraulic Budget (m3)**		
Drainage Basin Area (Excl. of Lake Area)	Ad	557.74	ha			**% Total**
Area Land Use Category 1 (Developed)	Ad1	33.45	ha	Upstream Inflow	0	0
Area Land Use Category 2 (Clearcut)	Ad2	24.34	ha	Precipitation	1780811	26.18659
Area Land Use Category 3 (Forest)	Ad3	481.48	ha	Surface Runoff	5019660	73.81341
Area Land Use Category 4 (Wetlands)	Ad4	18.47	ha	Evaporation	-845320	-12.4303
Lake Surface Area (Waterbodies)	Ao	144.97	ha	Point Sources		0
Lake Volume	V	9080796	m3	Total Outflow	5955151	87.56968
Hydrology Inputs				Check		100
Upstream Hydraulic Inputs	Qi	0	m3/yr	**Phosphorus Budget (gm/yr)**		
Annual Unit Precipitation	Pr	1.2284	m/yr			**% Total**
Annual Unit Lake Evaporation	Ev	0.5831	m/yr	Upstream Inflow	0.0	0.0
Annual Unit Hydraulic Runoff	Ru	0.9	m/yr	Atmospheric	13445.6	0.3
Phosphorus Inputs				Internal Load	0.0	0.0
Upstream P Input	Ju	0	gm P/yr	Watershed Inputs	5097359.8	99.7
Annual Unit Atmospheric Phosphorus Deposition	Da	0.0173	gm P/m2/yr	Land Runoff	32063.7	0.6
Land Use Category 1 P Export Coefficient	E1	0.03	gm P/m2/yr	Development	2010.0	0.0
Land Use Category 2 P Export Coefficient	E2	0.0174	gm P/m2/yr	Mink	5063286.1	99.1
Land Use Category 3 P Export Coefficient	E3	0.0095	gm P/m2/yr	Sedimentation	-4127706.8	-80.8
Land Use Category 4 P Export Coefficient	E4	0.03	gm P/m2/yr	Total Outflow	983098.6	19.2
Point Source Input 1 (POWSIM)	PS1	0	gm P/yr	Check		100.0

Point Source Input 2 (Internal Load)	PS2	0	gm P/yr	**Model Validation**	
Point Source Input 3 (Mink)	PS3	0	gm P/yr	Predicted P	0.003787
Point Source Input 4 (Aquaculture)	PS4	0	gm P/yr	Measured P	N/A
Lake Phosphorus Retention Coefficient	v	12.4	n/a	% Difference	N/A
Model Outputs				**Export Coefficients**	
Total Precipitation Hydraulic Input	Ppti	1780811.48	m3/yr	25%	0.25
Total Evaporation Hydraulic Loss	Eo	845320.07	m3/yr	50%	0.5
Total Hydraulic Surface Runoff	Ql	5019660.00	m3/yr	75%	0.75
Total Hydraulic Input	Qt	6800471.48	m3/yr	Matched	0
Areal Hydraulic Input	*qs*	4.11	m/yr		
Total Hydraulic Outflow	Qo	5955151.41	m3/yr		
Total Atmospheric P Input	Jd	25079.81	gm/yr		
Total Surface Runoff P Input	Je	65551.76	gm/yr		
Total Development P Input	Jr	0.00	gm/yr		
Total P Input	Jt	90631.57	gm/yr		
Lake P Retention Factor	Rp	0.75	n/a		
Lake P Retention	Ps	68078.61	gm/yr		
Predicted Lake P Concentration	[P]	0.00	mg/L		
Lake P Outflow	Jo	22552.96	gm/yr		
Lake Mean Depth	z	6.30	m		
Lake Flushing Rate	FR	0.66	1/yr		
Lake Turnover Time	TT	1.52	yr		
Lake Response Time	RT(1/2)	0.31	yr		

Table 51: Sample NSPM spreadsheet for Fanning Lake

Fanning Lake						
Input Parameters	**Symbol**	**Value**	**Units**	**Budgets**		
Morphology				**Hydraulic Budget (m3)**		
Drainage Basin Area (Excl. of Lake Area)	Ad	2245.4	ha			**% Total**
Area Land Use Category 1 (Developed)	Ad1	137.14	ha	Upstream Inflow	227832493.2	90.74414
Area Land Use Category 2 (Clearcut)	Ad2	234.53	ha	Precipitation	3030217.12	1.206915
Area Land Use Category 3 (Forest)	Ad3	1784.04	ha	Surface Runoff	20208600	8.048948
Area Land Use Category 4 (Wetlands)	Ad4	89.69	ha	Evaporation	-1438391.08	-0.5729
Lake Surface Area (Waterbodies)	Ao	246.68	ha	Point Sources		0
Lake Volume	V	5010224	m3	Total Outflow	249632919.3	99.4271
Hydrology Inputs				Check		100
Upstream Hydraulic Inputs	Qi	227832493.23	m3/yr	**Phosphorus Budget (gm/yr)**		
Annual Unit Precipitation	Pr	1.2284	m/yr			**% Total**
Annual Unit Lake Evaporation	Ev	0.5831	m/yr	Upstream Inflow	7580642.0	92.8
Annual Unit Hydraulic Runoff	Ru	0.9	m/yr	Atmospheric	42675.6	0.5
Phosphorus Inputs				Internal Load	0.0	0.0
Upstream P Input	Ju	7580642.04	gm P/yr	Watershed Inputs	296981.0	3.6
Annual Unit Atmospheric Phosphorus Deposition	Da	0.0173	gm P/m2/yr	Land Runoff	278341.0	3.4
Land Use Category 1 P Export Coefficient	E1	0.03	gm P/m2/yr	Development	18640.0	0.2
Land Use Category 2 P Export Coefficient	E2	0.0174	gm P/m2/yr	Mink	0.0	0.0
Land Use Category 3 P Export Coefficient	E3	0.0095	gm P/m2/yr	Sedimentation	-542485.7	-6.6
Land Use Category 4 P Export Coefficient	E4	0.03	gm P/m2/yr	Total Outflow	7624716.2	93.4
Point Source Input 1 (POWSIM)	PS1	18640	gm P/yr	Check		100.0

				Model Validation	
Point Source Input 2 (Internal Load)	PS2	246903.1343	gm P/yr		
Point Source Input 3 (Mink)	PS3	0	gm P/yr	Predicted P	0.030544
Point Source Input 4 (Aquaculture)	PS4	0	gm P/yr	Measured P	0.025
Lake Phosphorus Retention Coefficient	v	7.2	n/a	% Difference	22.17485
Model Outputs				**Export Coefficients**	
Total Precipitation Hydraulic Input	Ppti	3030217.12	m3/yr	25%	0.25
Total Evaporation Hydraulic Loss	Eo	1438391.08	m3/yr	50%	0.5
Total Hydraulic Surface Runoff	Ql	20208600.00	m3/yr	75%	0.75
Total Hydraulic Input	Qt	251071310.35	m3/yr	Matched	0
Areal Hydraulic Input	*qs*	101.20	m/yr		
Total Hydraulic Outflow	Qo	249632919.27	m3/yr		
Total Atmospheric P Input	Jd	42675.64	gm/yr		
Total Surface Runoff P Input	Je	278341.02	gm/yr		
Total Development P Input	Jr	265543.13	gm/yr		
Total P Input	Jt	8167201.84	gm/yr		
Lake P Retention Factor	Rp	0.07	n/a		
Lake P Retention	Ps	542485.66	gm/yr		
Predicted Lake P Concentration	[P]	0.03	mg/L		
Lake P Outflow	Jo	7624716.18	gm/yr		
Lake Mean Depth	z	4.2	m		
Lake Flushing Rate	FR	49.82	1/yr		
Lake Turnover Time	TT	0.02	yr		
Lake Response Time	RT(1/2)	0.01	yr		

Table 52: Sample NSPM spreadsheet for Sloans Lake

Sloans Lake						
Input Parameters	**Symbol**	**Value**	**Units**	**Budgets**		
Morphology				**Hydraulic Budget (m3)**		
Drainage Basin Area (Excl. of Lake Area)	Ad	466.69	ha			**% Total**
Area Land Use Category 1 (Developed)	Ad1	56.77	ha	Upstream Inflow	0	0
Area Land Use Category 2 (Clearcut)	Ad2	38.85	ha	Precipitation	1717180.36	29.01922
Area Land Use Category 3 (Forest)	Ad3	339.12	ha	Surface Runoff	4200210	70.98078
Area Land Use Category 4 (Wetlands)	Ad4	31.95	ha	Evaporation	-815115.49	-13.7749
Lake Surface Area (Waterbodies)	Ao	139.79	ha	Point Sources		0
Lake Volume	V	10469700	m3	Total Outflow	5102274.87	86.22509
Hydrology Inputs				Check		100
Upstream Hydraulic Inputs	Qi	0	m3/yr	**Phosphorus Budget (gm/yr)**		
Annual Unit Precipitation	Pr	1.2284	m/yr			**% Total**
Annual Unit Lake Evaporation	Ev	0.5831	m/yr	Upstream Inflow	0.0	0.0
Annual Unit Hydraulic Runoff	Ru	0.9	m/yr	Atmospheric	24183.7	24.8
Phosphorus Inputs				Internal Load	0.0	0.0
Upstream P Input	Ju	0	gm P/yr	Watershed Inputs	73282.3	75.2
Annual Unit Atmospheric Phosphorus Deposition	Da	0.0173	gm P/m2/yr	Land Runoff	65592.3	67.3
Land Use Category 1 P Export Coefficient	E1	0.03	gm P/m2/yr	Development	7690.0	7.9
Land Use Category 2 P Export Coefficient	E2	0.0174	gm P/m2/yr	Mink	0.0	0.0
Land Use Category 3 P Export Coefficient	E3	0.0095	gm P/m2/yr	Sedimentation	-75301.0	-77.3
Land Use Category 4 P Export Coefficient	E4	0.03	gm P/m2/yr	Total Outflow	22165.0	22.7
Point Source Input 1 (POWSIM)	PS1	7690	gm P/yr	Check		100.0

Point Source Input 2 (Internal Load)	PS2	0	gm P/yr	**Model Validation**	
Point Source Input 3 (Mink)	PS3	0	gm P/yr	Predicted P	0.004344
Point Source Input 4 (Aquaculture)	PS4	0	gm P/yr	Measured P	0.0037
Lake Phosphorus Retention Coefficient	v	12.4	n/a	% Difference	17.40898
Model Outputs				**Export Coefficients**	
Total Precipitation Hydraulic Input	Ppti	1717180.36	m3/yr	25%	0.25
Total Evaporation Hydraulic Loss	Eo	815115.49	m3/yr	50%	0.5
Total Hydraulic Surface Runoff	Ql	4200210.00	m3/yr	75%	0.75
Total Hydraulic Input	Qt	5917390.36	m3/yr	Matched	0
Areal Hydraulic Input	*qs*	3.65	m/yr		
Total Hydraulic Outflow	Qo	5102274.87	m3/yr		
Total Atmospheric P Input	Jd	24183.67	gm/yr		
Total Surface Runoff P Input	Je	65592.30	gm/yr		
Total Development P Input	Jr	7690.00	gm/yr		
Total P Input	Jt	97465.97	gm/yr		
Lake P Retention Factor	Rp	0.77	n/a		
Lake P Retention	Ps	75301.01	gm/yr		
Predicted Lake P Concentration	[P]	0.00	mg/L		
Lake P Outflow	Jo	22164.96	gm/yr		
Lake Mean Depth	z	6.7	m		
Lake Flushing Rate	FR	0.49	1/yr		
Lake Turnover Time	TT	2.05	yr		
Lake Response Time	RT(1/2)	0.35	yr		

Table 53: Sample NSPM spreadsheet for East Corning Lake

East Corning Lake						
Input Parameters	**Symbol**	**Value**	**Units**	**Budgets**		
Morphology				**Hydraulic Budget (m3)**		
Drainage Basin Area (Excl. of Lake Area)	Ad	144.92	ha			**% Total**
Area Land Use Category 1 (Developed)	Ad1	5.52	ha	Upstream Inflow	0	0
Area Land Use Category 2 (Clearcut)	Ad2	9.86	ha	Precipitation	575505.4	30.61548
Area Land Use Category 3 (Forest)	Ad3	122.21	ha	Surface Runoff	1304280	69.38452
Area Land Use Category 4 (Wetlands)	Ad4	7.33	ha	Evaporation	-273182	-14.5326
Lake Surface Area (Waterbodies)	Ao	46.85	ha	Point Sources		0
Lake Volume	V		m3	Total Outflow	1606603	85.46737
Hydrology Inputs				Check		100
Upstream Hydraulic Inputs	Qi	0	m3/yr	**Phosphorus Budget (gm/yr)**		
Annual Unit Precipitation	Pr	1.2284	m/yr			**% Total**
Annual Unit Lake Evaporation	Ev	0.5831	m/yr	Upstream Inflow	0.0	0.0
Annual Unit Hydraulic Runoff	Ru	0.9	m/yr	Atmospheric	8105.1	32.1
Phosphorus Inputs				Internal Load	0.0	0.0
Upstream P Input	Ju	0	gm P/yr	Watershed Inputs	17180.6	67.9
Annual Unit Atmospheric Phosphorus Deposition	Da	0.0173	gm P/m2/yr	Land Runoff	17180.6	67.9
Land Use Category 1 P Export Coefficient	E1	0.03	gm P/m2/yr	Development	0.0	0.0
Land Use Category 2 P Export Coefficient	E2	0.0174	gm P/m2/yr	Mink	0.0	0.0
Land Use Category 3 P Export Coefficient	E3	0.0095	gm P/m2/yr	Sedimentation	-19807.8	-78.3
Land Use Category 4 P Export Coefficient	E4	0.03	gm P/m2/yr	Total Outflow	5477.9	21.7
Point Source Input 1 (POWSIM)	PS1	0	gm P/yr	Check		100.0
Point Source Input 2 (Internal Load)	PS2	0	gm P/yr	**Model Validation**		

Point Source Input 3 (Mink)	PS3	0	gm P/yr	Predicted P	0.00341
Point Source Input 4 (Aquaculture)	PS4	0	gm P/yr	Measured P	N/A
Lake Phosphorus Retention Coefficient	v	12.4	n/a	% Difference	N/A
Model Outputs				**Export Coefficients**	
Total Precipitation Hydraulic Input	Ppti	575505.40	m3/yr	25%	0.25
Total Evaporation Hydraulic Loss	Eo	273182.35	m3/yr	50%	0.5
Total Hydraulic Surface Runoff	Ql	1304280.00	m3/yr	75%	0.75
Total Hydraulic Input	Qt	1879785.40	m3/yr	Matched	0
Areal Hydraulic Input	*qs*	3.43	m/yr		
Total Hydraulic Outflow	Qo	1606603.05	m3/yr		
Total Atmospheric P Input	Jd	8105.05	gm/yr		
Total Surface Runoff P Input	Je	17180.59	gm/yr		
Total Development P Input	Jr	0.00	gm/yr		
Total P Input	Jt	25285.64	gm/yr		
Lake P Retention Factor	Rp	0.78	n/a		
Lake P Retention	Ps	19807.76	gm/yr		
Predicted Lake P Concentration	[P]	0.00	mg/L		
Lake P Outflow	Jo	5477.88	gm/yr		
Lake Mean Depth	z	0	m		
Lake Flushing Rate	FR	0	1/yr		
Lake Turnover Time	TT	0	yr		
Lake Response Time	RT(1/2)	0	yr		

Table 54: Sample NSPM spreadsheet for Raynards Lake

Raynards Lake						
Input Parameters	**Symbol**	**Value**	**Units**	**Budgets**		
Morphology				**Hydraulic Budget (m3)**		
Drainage Basin Area (Excl. of Lake Area)	Ad	2461.88	ha			**% Total**
Area Land Use Category 1 (Developed)	Ad1	225.98	ha	Upstream Inflow	256341797.2	89.30024
Area Land Use Category 2 (Clearcut)	Ad2	121.15	ha	Precipitation	8557402.92	2.981091
Area Land Use Category 3 (Forest)	Ad3	1970.78	ha	Surface Runoff	22156920	7.718672
Area Land Use Category 4 (Wetlands)	Ad4	143.97	ha	Evaporation	-4062049.53	-1.41507
Lake Surface Area (Waterbodies)	Ao	696.63	ha	Point Sources		0
Lake Volume	V		m3	Total Outflow	282994070.6	98.58493
Hydrology Inputs				Check		100
Upstream Hydraulic Inputs	Qi	256341797.19	m3/yr	**Phosphorus Budget (gm/yr)**		
Annual Unit Precipitation	Pr	1.2284	m/yr			**% Total**
Annual Unit Lake Evaporation	Ev	0.5831	m/yr	Upstream Inflow	7652359.0	94.6
Annual Unit Hydraulic Runoff	Ru	0.9	m/yr	Atmospheric	120517.0	1.5
Phosphorus Inputs				Internal Load	0.0	0.0
Upstream P Input	Ju	7652359.02	gm P/yr	Watershed Inputs	319289.2	3.9
Annual Unit Atmospheric Phosphorus Deposition	Da	0.0173	gm P/m2/yr	Land Runoff	319289.2	3.9
Land Use Category 1 P Export Coefficient	E1	0.03	gm P/m2/yr	Development	0.0	0.0
Land Use Category 2 P Export Coefficient	E2	0.0174	gm P/m2/yr	Mink	0.0	0.0
Land Use Category 3 P Export Coefficient	E3	0.0095	gm P/m2/yr	Sedimentation	-1892429.5	-23.4
Land Use Category 4 P Export Coefficient	E4	0.03	gm P/m2/yr	Total Outflow	6199735.7	76.6
Point Source Input 1 (POWSIM)	PS1	0	gm P/yr	Check		100.0

Point Source Input 2 (Internal Load)	PS2	0	gm P/yr
Point Source Input 3 (Mink)	PS3	0	gm P/yr
Point Source Input 4 (Aquaculture)	PS4	0	gm P/yr
Lake Phosphorus Retention Coefficient	v	12.4	n/a

Model Validation	
Predicted P	0.021908
Measured P	0.0153
% Difference	43.18727

Model Outputs			
Total Precipitation Hydraulic Input	Ppti	8557402.92	m3/yr
Total Evaporation Hydraulic Loss	Eo	4062049.53	m3/yr
Total Hydraulic Surface Runoff	Ql	22156920.00	m3/yr
Total Hydraulic Input	Qt	287056120.11	m3/yr
Areal Hydraulic Input	*qs*	40.62	m/yr
Total Hydraulic Outflow	Qo	282994070.58	m3/yr
Total Atmospheric P Input	Jd	120516.99	gm/yr
Total Surface Runoff P Input	Je	319289.20	gm/yr
Total Development P Input	Jr	0.00	gm/yr
Total P Input	Jt	8092165.21	gm/yr
Lake P Retention Factor	Rp	0.23	n/a
Lake P Retention	Ps	1892429.46	gm/yr
Predicted Lake P Concentration	[P]	0.02	mg/L
Lake P Outflow	Jo	6199735.74	gm/yr
Lake Mean Depth	z	0	m
Lake Flushing Rate	FR	0	1/yr
Lake Turnover Time	TT	0	yr
Lake Response Time	RT(1/2)	0	yr

Export Coefficients	
25%	0.25
50%	0.5
75%	0.75
Matched	0

Table 55: Sample NSPM spreadsheet for Vaughan Lake

Vaughan Lake						
Input Parameters	**Symbol**	**Value**	**Units**	**Budgets**		
Morphology				**Hydraulic Budget (m3)**		
Drainage Basin Area (Excl. of Lake Area)	Ad	1084.9	ha			**% Total**
Area Land Use Category 1 (Developed)	Ad1	142.17	ha	Upstream Inflow	282994070.6	95.21596
Area Land Use Category 2 (Clearcut)	Ad2	42.41	ha	Precipitation	4454669.76	1.498815
Area Land Use Category 3 (Forest)	Ad3	850.89	ha	Surface Runoff	9764100	3.285221
Area Land Use Category 4 (Wetlands)	Ad4	49.43	ha	Evaporation	-2114553.84	-0.71146
Lake Surface Area (Waterbodies)	Ao	362.64	ha	Point Sources		0
Lake Volume	V	23696802	m3	Total Outflow	295098286.5	99.28854
Hydrology Inputs				Check		100
Upstream Hydraulic Inputs	Qi	282994070.58	m3/yr	**Phosphorus Budget (gm/yr)**		
Annual Unit Precipitation	Pr	1.2284	m/yr			**% Total**
Annual Unit Lake Evaporation	Ev	0.5831	m/yr	Upstream Inflow	6199735.7	96.1
Annual Unit Hydraulic Runoff	Ru	0.9	m/yr	Atmospheric	62736.7	1.0
Phosphorus Inputs				Internal Load	0.0	0.0
Upstream P Input	Ju	6199735.74	gm P/yr	Watershed Inputs	189483.9	2.9
Annual Unit Atmospheric Phosphorus Deposition	Da	0.0173	gm P/m2/yr	Land Runoff	145693.9	2.3
Land Use Category 1 P Export Coefficient	E1	0.03	gm P/m2/yr	Development	43790.0	0.7
Land Use Category 2 P Export Coefficient	E2	0.0174	gm P/m2/yr	Mink	0.0	0.0
Land Use Category 3 P Export Coefficient	E3	0.0095	gm P/m2/yr	Sedimentation	-853151.3	-13.2
Land Use Category 4 P Export Coefficient	E4	0.03	gm P/m2/yr	Total Outflow	5598805.1	86.8
Point Source Input 1 (POWSIM)	PS1	43790	gm P/yr	Check		100.0

				Model Validation	
Point Source Input 2 (Internal Load)	PS2	0	gm P/yr		
Point Source Input 3 (Mink)	PS3	0	gm P/yr	Predicted P	0.018973
Point Source Input 4 (Aquaculture)	PS4	0	gm P/yr	Measured P	0.0167
Lake Phosphorus Retention Coefficient	v	12.4	n/a	% Difference	13.60886
Model Outputs				**Export Coefficients**	
Total Precipitation Hydraulic Input	Ppti	4454669.76	m3/yr	25%	0.25
Total Evaporation Hydraulic Loss	Eo	2114553.84	m3/yr	50%	0.5
Total Hydraulic Surface Runoff	Ql	9764100.00	m3/yr	75%	0.75
Total Hydraulic Input	Qt	297212840.34	m3/yr	Matched	0
Areal Hydraulic Input	*qs*	81.37	m/yr		
Total Hydraulic Outflow	Qo	295098286.50	m3/yr		
Total Atmospheric P Input	Jd	62736.72	gm/yr		
Total Surface Runoff P Input	Je	145693.89	gm/yr		
Total Development P Input	Jr	43790.00	gm/yr		
Total P Input	Jt	6451956.35	gm/yr		
Lake P Retention Factor	Rp	0.13	n/a		
Lake P Retention	Ps	853151.29	gm/yr		
Predicted Lake P Concentration	[P]	0.02	mg/L		
Lake P Outflow	Jo	5598805.07	gm/yr		
Lake Mean Depth	z	5.1	m		
Lake Flushing Rate	FR	12.45	1/yr		
Lake Turnover Time	TT	0.08	yr		
Lake Response Time	RT(1/2)	0.05	yr		

APPENDIX B: SUMMARY OF WATER QUALITY RESULTS

Table 56: Temperature - DO profiles for all study lakes

Lake	Station	Date	Depth (m)	Temperature	DO (mg/L)	%DOSA
Nowlans	DS1	13-Aug-08	0.0	21.5	6.90	77.5
Nowlans	DS1	13-Aug-08	1.0	21.5	6.70	75.3
Nowlans	DS1	13-Aug-08	2.0	21.4	6.10	68.4
Nowlans	DS1	13-Aug-08	3.0	21.4	6.10	68.4
Nowlans	DS1	13-Aug-08	4.0	21.2	4.40	49.2
Nowlans	DS1	13-Aug-08	5.0	20.9	1.90	21.1
Nowlans	DS1	13-Aug-08	6.0	18.6	1.00	10.6
Nowlans	DS1	13-Aug-08	7.0	17.2	1.00	10.3
Nowlans	DS1	13-Aug-08	8.0	16.9	0.90	9.2
Nowlans	DS1	29-Aug-17	0.3	21.2	12.84	145.4
Nowlans	DS1	29-Aug-17	1.0	21.1	12.86	143.8
Nowlans	DS1	29-Aug-17	2.0	21.1	12.04	135.4
Nowlans	DS1	29-Aug-17	3.0	20.9	11.17	124.3
Nowlans	DS1	29-Aug-17	4.0	20.6	7.2	79.4
Nowlans	DS1	29-Aug-17	5.0	19.9	5.54	60.1
Nowlans	DS1	29-Aug-17	6.0	18.6	5.87	62.3
Nowlans	DS1	29-Aug-17	7.0	16.4	6.69	67.7
Provost	DS1	13-Aug-08	0.0	21.2	6.70	74.8
Provost	DS1	13-Aug-08	1.0	21.2	6.60	73.7
Provost	DS1	13-Aug-08	2.0	21.2	6.60	73.7
Provost	DS1	13-Aug-08	3.0	21.1	6.50	72.5
Provost	DS1	13-Aug-08	4.0	21.1	6.30	70.2
Provost	DS1	13-Aug-08	5.0	21.1	6.30	70.2
Provost	DS1	22-Aug-17	0.25	22.75	7.76	90.1
Provost	DS1	22-Aug-17	4.5	21.05	7.02	77.4
Provost	OL1	22-Aug-17	0.25	19.95	5.27	57.5
Provost	DS1	30-Aug-17	0.25	21.2	11.55	130.7
Provost	DS1	30-Aug-17	1	21.2	11.27	127.9
Provost	DS1	30-Aug-17	2	21.2	11.07	125.4
Provost	DS1	30-Aug-17	3	21.2	10.84	122.6
Provost	DS1	30-Aug-17	4	20.9	9.51	107.8
Provost	DS1	30-Aug-17	5	20.7	8.54	94.7
Provost	DS1	30-Aug-17	6	20.6	7.93	89
Provost	DS1	30-Aug-17	7	19.6	3.84	42.8
Provost	DS1	30-Aug-17	8	14.5	2.44	24

Lake	Station	Date	Depth (m)	Temperature	DO (mg/L)	%DOSA
Hourglass	DS3	13-Aug-08	0.0	21.1	6.40	71.4
Hourglass	DS3	13-Aug-08	1.0	21.1	6.20	69.1
Hourglass	DS3	13-Aug-08	2.0	21.1	6.20	69.1
Hourglass	DS3	13-Aug-08	3.0	20.9	5.50	61.1
Hourglass	DS3	13-Aug-08	4.0	17.3	1.30	13.4
Hourglass	DS3	13-Aug-08	5.0	13.5	1.40	13.3
Hourglass	DS3	13-Aug-08	6.0	12.5	1.50	14.0
Hourglass	DS1	Aug. 24/17	0.25	24.38	8.88	106.6
Hourglass	DS1	Aug. 24/17	2	20.87	4.87	56.8
Hourglass	DS1	Aug. 24/17	6.5	10.7	2.6	21.7
Hourglass	AQIN1	Aug. 24/17	0.25	21.64	8.00	90.9
Hourglass	AQIN2	Aug. 24/17	0.25	21.84	7.24	81.7
Hourglass	OL1	Aug. 24/17	0.25	23.31	8.89	104.1
Placides	DS1	13-Aug-08	1.0	21.5	6.90	77.5
Placides	DS1	13-Aug-08	2.0	21.2	6.10	68.1
Placides	DS1	13-Aug-08	3.0	20.9	5.00	55.5
Placides	DS1	13-Aug-08	4.0	20.6	4.00	44.2
Placides	DS1	13-Aug-08	5.0	17.2	1.10	11.3
Placides	DS1	13-Aug-08	6.0	13.5	1.10	10.5
Placides	DS1	13-Aug-08	7.0	12.7	1.00	9.3
Placides	DS1	29-Aug-17	0.25	23.6	10.87	127.1
Placides	DS1	29-Aug-17	1	22.6	11.14	128.1
Placides	DS1	29-Aug-17	2	21.8	10.38	117.6
Placides	DS1	29-Aug-17	3	20.5	9.18	101.5
Placides	DS1	29-Aug-17	4	19.6	8.59	93.8
Placides	DS1	29-Aug-17	5	17.6	3.58	36.4
Placides	DS1	29-Aug-17	6	14.9	2.55	25.1
Placides	IN-1	22-Aug-17	0.25	22.54	6.75	75.9
Placides	DS1	22-Aug-17	0.25	24.19	7.72	92.3
Placides	DS1	22-Aug-17	1.3	23.17	6.29	78.8
Placides	DS1	22-Aug-17	3.5	20.03	5.16	56.8
Placides	OL-1	22-Aug-17	0.25	22.5	8.3	94.4
Porcupine	DS1	13-Aug-08	1.0	23.0	7.10	82.1
Porcupine	DS1	13-Aug-08	2.0	21.8	6.90	78.0
Porcupine	DS1	13-Aug-08	3.0	21.5	6.70	75.3
Porcupine	DS1	13-Aug-08	4.0	21.4	6.50	72.9

Lake	Station	Date	Depth (m)	Temperature	DO (mg/L)	%DOSA
Porcupine	DS1	13-Aug-08	5.0	21.2	6.50	72.6
Porcupine	DS1	13-Aug-08	6.0	19.8	1.90	20.6
Porcupine	DS1	13-Aug-08	7.0	15.5	1.50	14.9
Porcupine	DS1	13-Aug-08	0.0	9.5	10.94	94.8
Porcupine	DS1	29-Aug-17	0.25	22.5	11.76	134.4
Porcupine	DS1	29-Aug-17	1.0	21.5	12.01	134.9
Porcupine	DS1	29-Aug-17	2.0	21.2	11.68	130.4
Porcupine	DS1	29-Aug-17	3.0	21.1	11.06	123.3
Porcupine	DS1	29-Aug-17	4.0	21	10.78	120
Porcupine	DS1	29-Aug-17	5.0	20.9	10.5	116.5
Porcupine	DS1	29-Aug-17	6.0	20.5	9.51	105.1
Porcupine	DS1	29-Aug-17	7.0	17.4	3.94	40.5
Porcupine	DS1	29-Aug-17	8.0	14.7	3.26	32.1
Porcupine	DS1	29-Aug-17	9.0	13.4	3.19	30.4
Porcupine	DS1	29-Aug-17	10.0	12.6	3.21	29.9
Porcupine	DS1	29-Aug-17	11.0	12	3.12	28.5
Porcupine	DS1	29-Aug-17	12.0	11.8	2.98	27.3
Porcupine	DS1	29-Aug-17	13.0	11.6	2.88	26.3
Parr	DS1	12-Aug-08	0.0	21.7	6.60	74.4
Parr	DS1	12-Aug-08	1.0	21.7	6.80	76.7
Parr	DS1	12-Aug-08	2.0	21.7	6.40	72.2
Parr	DS1	12-Aug-08	3.0	21.7	6.50	73.3
Parr	DS1	12-Aug-08	4.0	21.7	6.40	72.2
Parr	DS1	12-Aug-08	5.0	21.7	6.30	71.1
Parr	DS1	12-Aug-08	6.0	21.7	6.40	72.2
Parr	INA	20-Aug-17	0.25	17.48	6.23	65
Parr	INA	20-Aug-17	1.55	17.47	6.62	68.7
Parr	INB	20-Aug-17	0.25	16.44	7.05	72.1
Parr	INC	20-Aug-17	0.25	15.88	7.65	77.3
Parr	DS1	20-Aug-17	0.25	21.04	5.61	63
Parr	DS1	20-Aug-17	2	20.95	5.6	62.7
Parr	DS1	20-Aug-17	5.8	19.29	5.76	62.3
Parr	OL1	20-Aug-17	0.25	21.08	6.71	75.5
Parr	OL1	20-Aug-17	1.9	21.13	7.13	80.1
Ogden	DS1	14-Aug-08	0.0	21.3	6.50	72.8
Ogden	DS1	14-Aug-08	1.0	21.3	6.50	72.8

Lake	Station	Date	Depth (m)	Temperature	DO (mg/L)	%DOSA
Ogden	DS1	14-Aug-08	2.0	21.3	6.60	73.9
Ogden	DS1	14-Aug-08	3.0	21.3	6.60	73.9
Ogden	DS1	14-Aug-08	4.0	21.3	6.60	73.9
Ogden	DS1	14-Aug-08	5.0	21.3	6.60	73.9
Ogden	DS1	14-Aug-08	6.0	21.3	6.40	71.6
Ogden	DS1	14-Aug-08	7.0	20.7	4.50	49.8
Ogden	DS1	14-Aug-08	8.0	18.0	1.50	15.7
Ogden	DS1	14-Aug-08	9.0	15.2	2.90	28.6
Ogden	DS1	14-Aug-08	10.0	14.5	2.40	23.3
Ogden	DS1	14-Aug-08	11.0	14.0	2.80	26.9
Ogden	DS1	14-Aug-08	12.0	13.4	2.30	21.8
Ogden	DS1	14-Aug-08	13.0	13.0	1.30	12.2
Ogden	DS1	14-Aug-08	14.0	12.8	1.00	9.4
Ogden	DS1	14-Aug-08	15.0	12.7	0.80	7.5
Ogden	DS1	14-Aug-08	16.0	12.7	0.70	6.5
Ogden	DS1	14-Aug-08	17.0	12.6	0.70	6.5
Ogden	DS1	14-Aug-08	18.0	12.5	0.70	6.5
Ogden	IN1	20-Aug-17	0.25	21.2	6.35	71.5
Ogden	IN1	20-Aug-17	1.2	21.19	6.6	73.7
Ogden	DS1	20-Aug-17	0.25	21.97	5.14	59.3
Ogden	DS1	20-Aug-17	4	21.03	4.48	51
Ogden	DS1	20-Aug-17	19	8.34	0.67	5.9
Ogden	OL1	20-Aug-17	0.25	21.56	6.22	70.2
Ogden	OL1	20-Aug-17	1.2	21	6.58	73.2
Fanning	DS1	12-Aug-08	1.0	23.5	7.31	85.3
Fanning	DS1	12-Aug-08	2.0	22.8	7.51	86.5
Fanning	DS1	12-Aug-08	3.0	22.4	7.30	83.5
Fanning	DS1	12-Aug-08	4.0	22.3	7.17	81.8
Fanning	DS1	12-Aug-08	5.0	22.2	6.92	78.8
Fanning	DS1	12-Aug-08	6.0	22.1	6.60	75.0
Fanning	DS1	12-Aug-08	7.0	20.6	0.56	6.2
Fanning	DS1	12-Aug-08	8.0	18.1	0.13	1.4
Fanning	IN1	23-Aug-17	0.25	22.01	6.95	79.7
Fanning	IN2	23-Aug-17	0.25	21.21	7.04	78.9
Fanning	IN3	23-Aug-17	0.25	22.49	7.01	80.1
Fanning	DS3	23-Aug-17	0.25	22.01	6.41	73.3

Lake	Station	Date	Depth (m)	Temperature	DO (mg/L)	%DOSA
Fanning	DS3	23-Aug-17	3	21.98	5.27	62.8
Fanning	DS3	23-Aug-17	10	16.85	1.93	17.3
Fanning	OL1	23-Aug-17	0.25	21.31	6.42	71.9
Sloans	DS1	21-Aug-17	0.25	22.8	6.43	76.8
Sloans	DS1	21-Aug-17	9	11.12	4.94	44.9
Sloans	DS1	21-Aug-17	21	6.5	6.2	48.9
Sloans	DS2	21-Aug-17	0.25	23	6.34	75.4
Sloans	DS2	21-Aug-17	9.5	8.91	4.44	38.6
Sloans	DS2	21-Aug-17	15.5	7.06	4.81	39.1
Sloans	OL1	21-Aug-17	0.25	21.56	6.22	70.2
Vaughan	DS1	4-Aug-08	2.0	20.6	6.80	75.1
Vaughan	DS1	4-Aug-08	3.0	20.6	6.70	74.0
Vaughan	DS1	4-Aug-08	4.0	20.6	6.70	74.0
Vaughan	DS1	4-Aug-08	5.0	20.5	6.50	71.6
Vaughan	DS1	4-Aug-08	6.0	20.3	6.40	70.2
Vaughan	DS1	4-Aug-08	7.0	20.2	6.20	67.9
Vaughan	DS1	4-Aug-08	8.0	19.8	5.70	61.9
Vaughan	DS1	4-Aug-08	9.0	19.4	5.20	56.1
Vaughan	DS1	4-Aug-08	10.0	17.1	0.90	9.3
Vaughan	DS1	4-Aug-08	11.0	14.7	0.60	5.9
Vaughan	DS1	4-Aug-08	12.0	13.9	0.60	5.8
Vaughan	DS1	4-Aug-08	13.0	13.3	0.60	5.7
Vaughan	DS1	4-Aug-08	14.0	13.0	0.50	4.7
Vaughan	DS1	4-Aug-08	15.0	12.8	0.50	4.7
Vaughan	DS1	4-Aug-08	16.0	12.4	0.50	4.6
Vaughan	DS1	10-May-17	0.25	12.78	ND	ND
Vaughan	DS1	10-May-17	3.10	13.33	ND	ND
Vaughan	DS1	10-May-17	18.00	12.78	ND	ND
Vaughan	DS1	19-Oct-17	0.25	13.33	ND	ND
Vaughan	DS1	19-Oct-17	3.6	15.56	ND	ND
Vaughan	DS1	19-Oct-17	16.0	15.56	ND	ND

Table 57: Summary of TP measurements for all study lakes

Lake	Station	Date	Depth (m)	Total Phosphorus (mg/L)
Nowlans	DS1	2018-08-30	0	0.4640
Nowlans	DS1	2018-08-30	5	2.4050
Nowlans	DS1	2018-08-30	6.3	4.9420
Nowlans	DS1	2017-08-29	0.25	0.5420
Nowlans	DS1	2017-08-29	2	0.5640
Nowlans	DS1	2017-08-29	4.5	0.7640
Nowlans	DS1	2016-08-30	0.25	0.5480
Nowlans	DS1	2016-08-30	1.7	0.5640
Nowlans	DS1	2016-08-30	6.5	4.1800
Nowlans	DS1	2015-08-25	0.25	0.4970
Nowlans	DS1	2015-08-25	3.5	0.5420
Nowlans	DS1	2015-08-25	6	2.1600
Nowlans	DS1	2013-08-06	0	0.4460
Nowlans	DS1	2010-09-26	0	0.4200
Nowlans	DS1	2009-10-15	0	0.3800
Nowlans	DS1	2009-10-15	5.7	0.3800
Nowlans	DS1	2008-08-14	0	0.4000
Nowlans	DS1	1983-09-27	0	0.0060
Nowlans	DS1	1983-09-27	7.5	0.0250
Provost	DS1	2018-08-30	0	0.0090
Provost	DS1	2018-08-30	6.9	0.0170
Provost	DS1	2018-08-30	7	0.0170
Provost	DS1	2017-08-30	0.25	0.0120
Provost	DS1	2017-08-30	6	0.0450
Provost	DS1	2017-08-22	0.25	0.0080
Provost	DS1	2017-08-22	4.5	0.0140
Provost	DS1	2016-08-30	0.25	0.0160
Provost	DS1	2016-08-30	4.8	0.0180
Provost	DS1	2016-08-30	6.5	0.0220
Provost	DS1	2015-08-25	0.25	0.0160
Provost	DS1	2015-08-25	5	0.0420
Provost	DS1	2015-08-25	8	0.0910
Provost	DS1	2014-08-24	0	0.0160
Provost	DS1	2014-08-24	6.5	0.1430

Lake	Station	Date	Depth (m)	Total Phosphorus (mg/L)
Provost	DS1	2014-08-24	8	0.1660
Provost	DS1	2013-08-13	0.25	0.0160
Provost	DS1	2013-08-13	4	0.0140
Provost	DS1	2011-08-15	0	0.0110
Provost	DS1	2011-08-15	6	0.0160
Provost	DS1	2010-10-01	0	0.0160
Provost	DS1	2009-10-27	0	0.0200
Provost	DS1	2009-10-27	4.1	0.0200
Provost	DS1	1983-09-26	0	0.0030
Provost	DS1	1983-09-26	8	0.0030
Hourglass	DS1	2018-08-28	1.125	0.1180
Hourglass	DS1	2018-08-28	5.5	0.9750
Hourglass	DS1	2017-08-24	1.125	0.0730
Hourglass	DS1	2017-08-24	6.5	0.6510
Hourglass	DS1	2016-08-21	1.05	0.0800
Hourglass	DS1	2016-08-21	4.9	0.4420
Hourglass	DS1	2015-08-17	1	0.0650
Hourglass	DS1	2015-08-17	7	0.4290
Hourglass	DS1	2014-08-18	0.25	0.0670
Hourglass	DS1	2014-08-18	6.5	0.5640
Hourglass	DS1	2013-08-12	0.25	0.0560
Hourglass	DS1	2013-08-12	7	0.3740
Hourglass	DS1	2011-08-14	0	0.0450
Hourglass	DS1	2011-08-14	6	0.3900
Hourglass	DS1	2010-09-26	0	0.0500
Hourglass	DS1	2009-10-20	0	0.0780
Hourglass	DS1	2009-10-20	6.3	0.0790
Hourglass	DS1	1983-09-01	0	0.0120
Hourglass	DS1	1983-09-01	5	0.0110
Hourglass	DS1	1983-09-01	7	0.0450
Placides	DS1	2018-08-29	0	0.5830
Placides	DS1	2018-08-29	4.5	1.9720
Placides	DS1	2018-08-29	5.3	1.8960
Placides	DS1	2017-08-29	0.25	0.6090
Placides	DS1	2017-08-29	2	2.5700

Lake	Station	Date	Depth (m)	Total Phosphorus (mg/L)
Placides	DS1	2017-08-29	5	0.6150
Placides	DS1	2017-08-29	5	0.6150
Placides	DS1	2016-08-30	0.25	0.6210
Placides	DS1	2016-08-30	2.8	0.6270
Placides	DS1	2016-08-30	5.5	3.0200
Placides	DS1	2015-08-26	0.25	0.6980
Placides	DS1	2015-08-26	3	1.5000
Placides	DS1	2015-08-26	6.5	4.3200
Placides	DS1	2014-08-25	0	0.8060
Placides	DS1	2014-08-25	5.5	4.4600
Placides	DS1	2013-08-05	0	0.7920
Placides	DS1	2013-08-05	5	2.6000
Placides	DS1	2011-08-23	0	0.9600
Placides	DS1	2011-08-23	5	2.1000
Placides	DS1	2010-09-27	0	0.8200
Placides	DS1	2010-09-27	6	0.8300
Placides	DS1	2009-10-21	0	0.7200
Placides	DS1	2009-10-21	5.8	0.7000
Placides	DS1	2008-08-14	0	0.7400
Placides	DS1	2008-08-14	7	5.2000
Porcupine	DS1	2018-08-29	0	0.0100
Porcupine	DS1	2018-08-29	7.5	0.0280
Porcupine	DS1	2018-08-29	11.3	0.1380
Porcupine	DS1	2017-08-29	0.25	0.0130
Porcupine	DS1	2017-08-29	5	0.0120
Porcupine	DS1	2017-08-29	7	0.0160
Porcupine	DS1	2016-08-30	0.25	0.0170
Porcupine	DS1	2016-08-30	4.6	0.0190
Porcupine	DS1	2016-08-30	8.5	0.0560
Porcupine	DS1	2015-08-26	0.25	0.0160
Porcupine	DS1	2015-08-26	6	0.0230
Porcupine	DS1	2015-08-26	11	0.0620
Porcupine	DS1	2014-08-25	0	0.0160
Porcupine	DS1	2014-08-25	8	0.0420
Porcupine	DS1	2014-08-25	11.5	0.0580

Lake	Station	Date	Depth (m)	Total Phosphorus (mg/L)
Porcupine	DS1	2013-08-05	0	0.0320
Porcupine	DS1	2013-08-05	11	0.0440
Porcupine	DS1	2011-08-15	0	0.0140
Porcupine	DS1	2010-09-27	0	0.0210
Porcupine	DS1	2009-10-27	0	0.0340
Porcupine	DS2	2009-10-27	0	0.0350
Porcupine	DS1	2009-10-27	12.7	0.0330
Porcupine	DS1	2008-08-13	0	0.0120
Porcupine	DS1	2008-08-13	6	0.0210
Parr	DS1	2018-08-23	1.025	0.0560
Parr	DS1	2018-08-23	5	0.0590
Parr	DS1	2017-08-20	5.8	0.0630
Parr	DS1	2016-08-21	1.475	0.0550
Parr	DS1	2016-08-21	5.1	0.0690
Parr	DS1	2015-08-20	2	0.0750
Parr	DS1	2015-08-20	6	0.1340
Parr	DS1	2014-08-25	0.25	0.1110
Parr	DS1	2014-08-25	6	0.1240
Parr	DS1	2013-08-12	0.25	0.1050
Parr	DS1	2013-08-12	6	0.1070
Parr	DS1	2011-08-25	0	0.0750
Parr	DS1	2011-08-25	6	0.0760
Parr	DS1	2010-09-27	0	0.0610
Parr	DS1	2009-10-22	0	0.9600
Parr	DS1	2009-10-22	6.2	0.9500
Parr	DS1	2008-08-15	0	0.0330
Parr	DS1	1986-07-03	0	0.0060
Ogden	DS1	2018-08-26	1.625	0.0180
Ogden	DS1	2018-08-26	17	0.0380
Ogden	DS1	2017-08-20	19.0	0.0260
Ogden	OL1	2017-08-20	0.25	0.0270
Ogden	DS1	2016-08-21	1.375	0.0240
Ogden	DS1	2016-08-21	17.6	0.2050
Ogden	DS1	2015-08-20	1	0.0220
Ogden	DS1	2015-08-20	14	0.0580

Lake	Station	Date	Depth (m)	Total Phosphorus (mg/L)
Ogden	DS1	2014-08-25	0.25	0.0460
Ogden	DS1	2014-08-25	17	0.1020
Ogden	DS1	2013-08-05	0	0.0520
Ogden	DS1	2013-08-05	14	0.9600
Ogden	DS1	2011-08-25	0	0.0220
Ogden	DS1	2011-08-25	15	0.0940
Ogden	DS1	2010-09-28	0	0.0290
Ogden	DS1	2010-09-28	16	0.2600
Ogden	DS1	2009-10-22	0	0.0140
Ogden	DS1	2009-10-22	9	0.0180
Ogden	DS1	2009-10-22	18	0.0970
Ogden	DS1	2008-08-15	0	0.0140
Ogden	DS1	2008-08-15	9	0.0180
Ogden	DS1	2008-08-15	18	0.0970
Fanning	DS1	2018-08-27	1.925	0.0140
Fanning	DS1	2018-08-27	8.5	0.0860
Fanning	DS1	2017-08-23		0.0220
Fanning	DS1	2017-08-23	10?	0.0670
Fanning	DS1	2017-08-23	10	0.0100
Fanning	DS1	2016-08-21	1.675	0.0230
Fanning	DS1	2016-08-21	1.675	0.0230
Fanning	DS1	2016-08-21	6	0.0410
Fanning	DS1	2015-08-16	1.5	0.0190
Fanning	DS1	2015-08-16	6	0.0390
Fanning	DS1	2014-08-24	0.25	0.0270
Fanning	DS1	2014-08-24	5.5	0.0360
Fanning	DS1	2013-08-11	0.9	0.0450
Fanning	DS1	2013-08-11	5	0.0440
Fanning	DS1	2011-08-18	0	0.0230
Fanning	DS1	2011-08-18	9	0.0820
Fanning	DS2	2010-09-30	0	0.0190
Fanning	DS3	2010-09-30	0	0.0210
Fanning	DS1	2009-09-13	0	0.0560
Fanning	DS2	2009-09-13	0	0.0560
Fanning	DS1	2009-09-13	7.9	0.0600

Lake	Station	Date	Depth (m)	Total Phosphorus (mg/L)
Fanning	DS1	2008-08-17	0	0.0110
Fanning	DS1	2008-08-17	7	0.0230
Fanning	DS1	2008-08-17	9	0.0970
Fanning	DS1	1986-07-11	0	0.0040
Sloans	DS1	2018-08-27	9.875	0.0030
Sloans	DS1	2018-08-27	19.5	0.0060
Sloans	DS1	2017-08-21	0	0.0040
Sloans	DS1	2017-08-21	21	0.0060
Sloans	DS2	2017-08-21	0	0.0030
Sloans	DS2	2017-08-21	15.5	0.0020
Sloans	DS1	2016-08-28	6.375	0.0040
Sloans	DS1	2016-08-28	22	0.0320
Sloans	DS1	2015-08-16	5.5	0.0040
Sloans	DS1	2015-08-16	20	0.0050
Sloans	DS1	2014-08-24	4.65	0.0040
Sloans	DS1	2014-08-24	20	0.0080
Sloans	DS1	2013-08-11	0.25	0.0050
Sloans	DS1	2013-08-11	3.1	0.0040
Sloans	DS1	2013-08-11	17	0.0040
Sloans	DS1	2011-08-16	0	0.0050
Sloans	DS1	2011-08-16	14	0.0100
Sloans	DS1	2010-10-01	0	0.0090
Sloans	DS1	2010-10-01	14	0.0070
Sloans	DS1	2009-09-10	0	0.0050
Sloans	DS1	2009-09-10	8	0.0060
Sloans	DS1	2009-09-10	16	0.0050
Sloans	DS1	1986-07-03	0	0.0030
Vaughan	DS1	2018-08-21	1.775	0.0100
Vaughan	DS1	2018-08-21	17	0.0810
Vaughan	DS1	2017-08-24	1.75	0.0150
Vaughan	DS1	2017-08-24	17.5	0.1360
Vaughan	DS1	2016-08-24	1.925	0.0080
Vaughan	DS1	2016-08-24	13.3	0.0530
Vaughan	DS1	2015-08-18	2	0.0100
Vaughan	DS1	2015-08-18	15	0.0830

Lake	Station	Date	Depth (m)	Total Phosphorus (mg/L)
Vaughan	DS1	2014-08-18	0.25	0.0120
Vaughan	DS1	2014-08-18	12.5	0.0400
Vaughan	DS1	2013-08-13	0.25	0.0160
Vaughan	DS1	2013-08-13	14	0.0150
Vaughan	DS1	2011-08-17	0	0.0100
Vaughan	DS1	2011-08-17	15	0.0870
Vaughan	DS1	2010-10-01	0	0.0180
Vaughan	DS1	2010-10-01	12	0.0780
Vaughan	DS1	2009-10-28	0	0.0330
Vaughan	DS1	2009-10-28	18.5	0.0340
Vaughan	DS1	2008-09-05	0	0.0050
Vaughan	DS1	2008-09-05	9.5	0.0120
Vaughan	DS1	2008-09-05	14	0.0450
Vaughan	DS1	1979-08-01	0	0.0000

Appendix C: Bathymetric Maps

Sourced from the Nova Scotia Department of Fisheries Lake Inventory Map Set

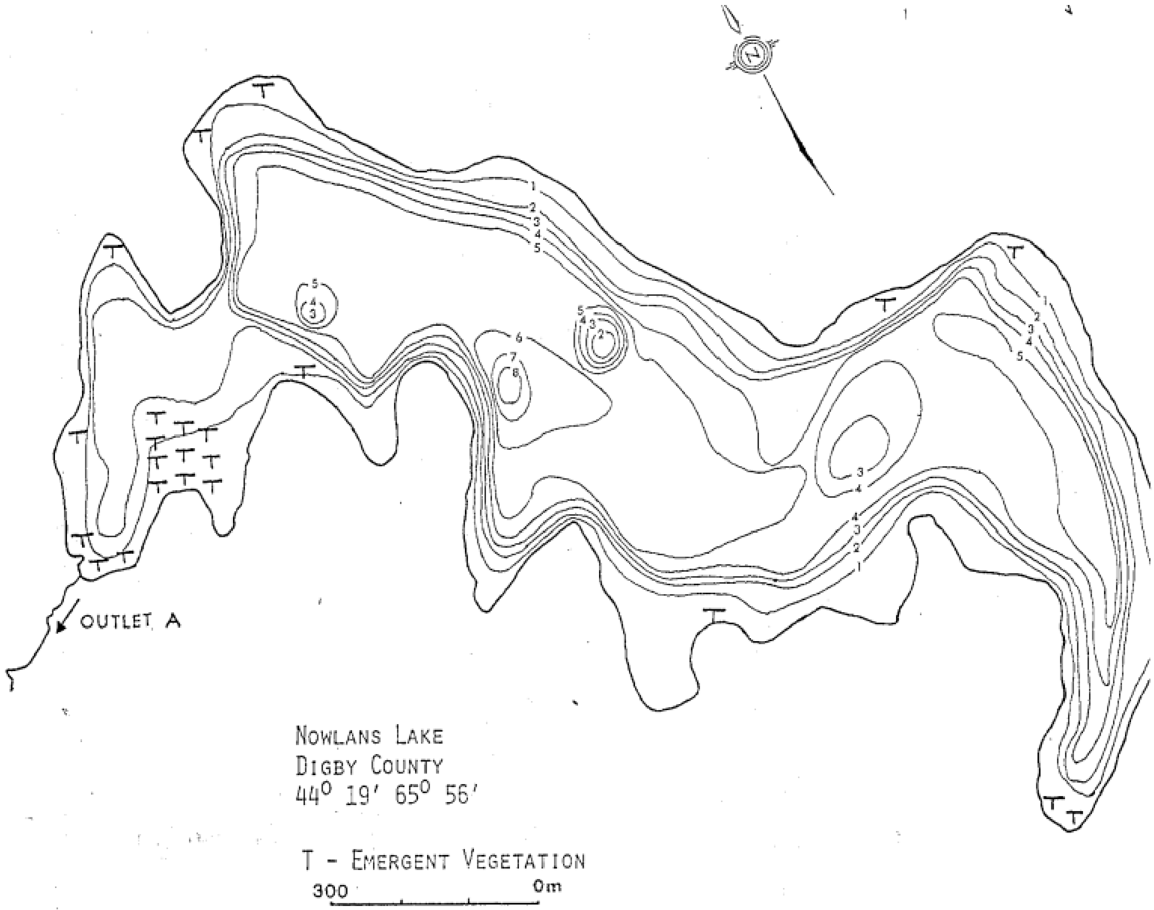

Figure 23: Bathymetric map of Nowlans Lake

Figure 24: Bathymetric map of Provost Lake

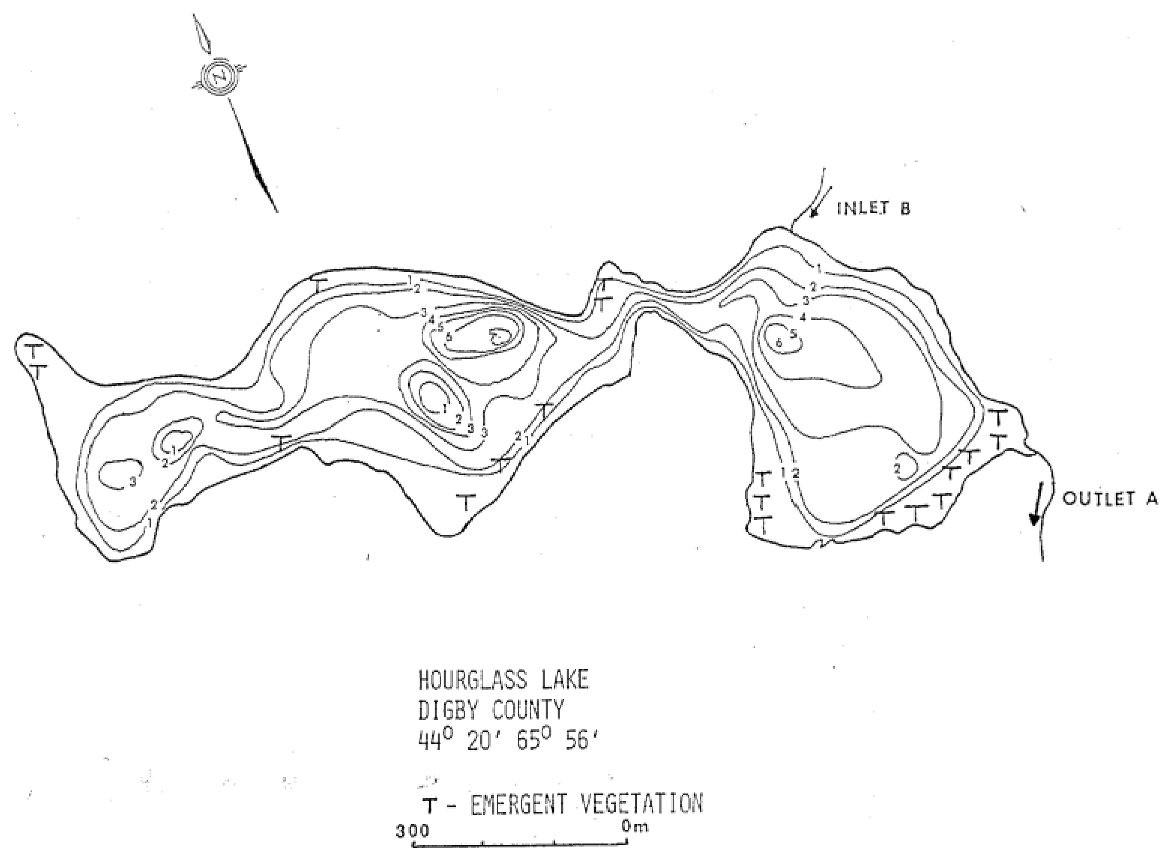

Figure 25: Bathymetric map of Hourglass Lake

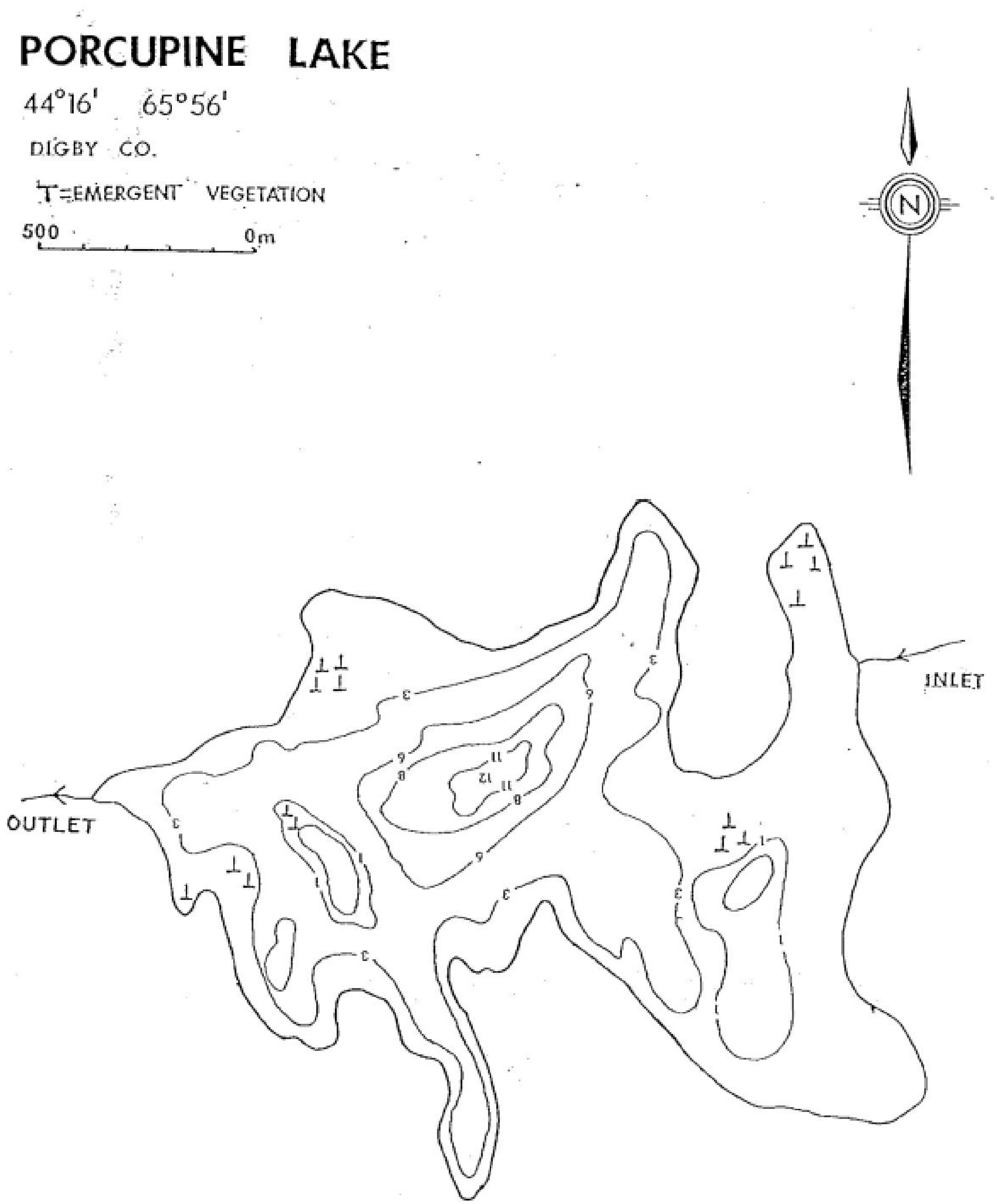

Figure 26: Bathymetric map of Porcupine Lake

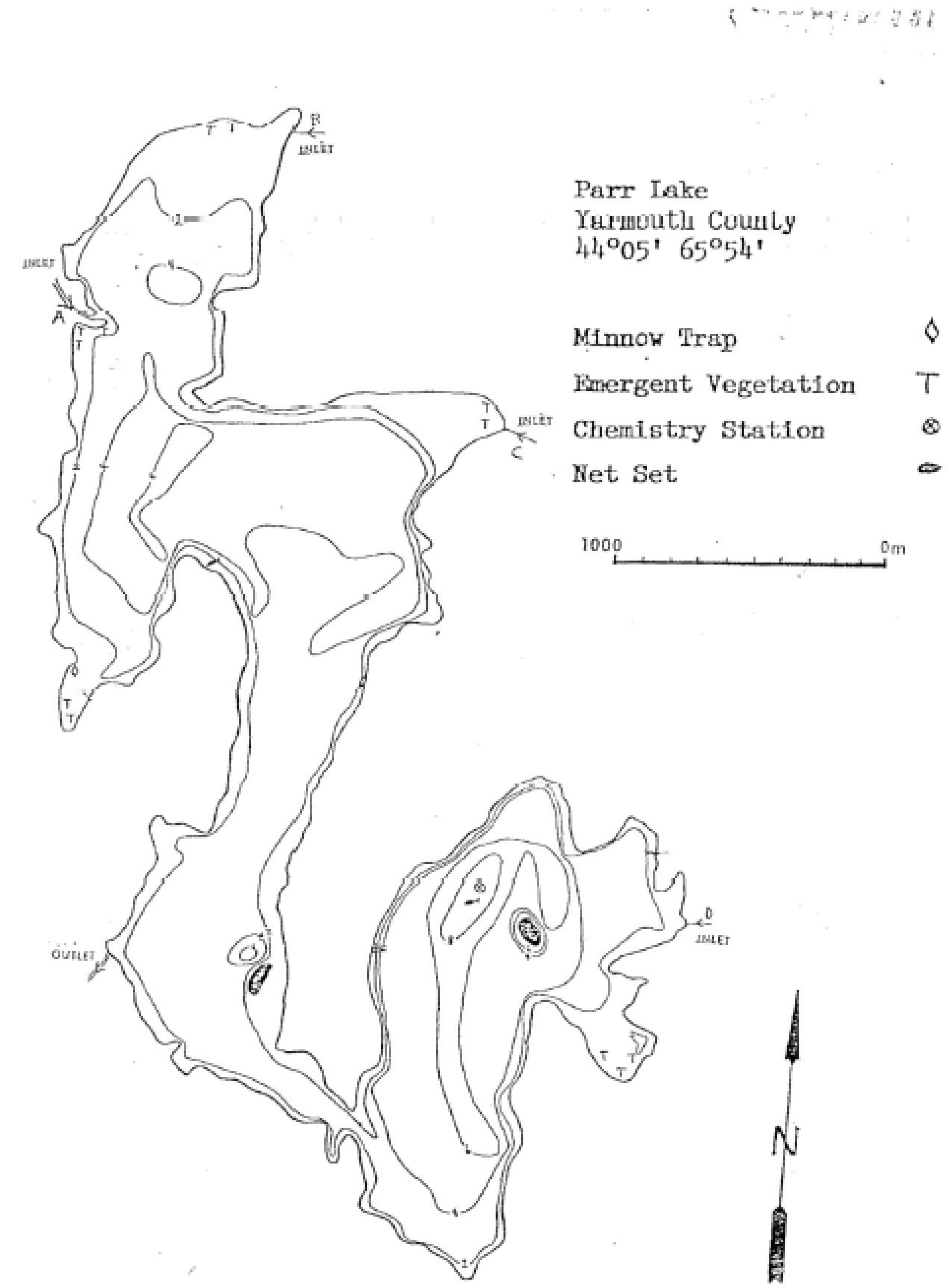

Figure 27: Bathymetric map of Parr Lake

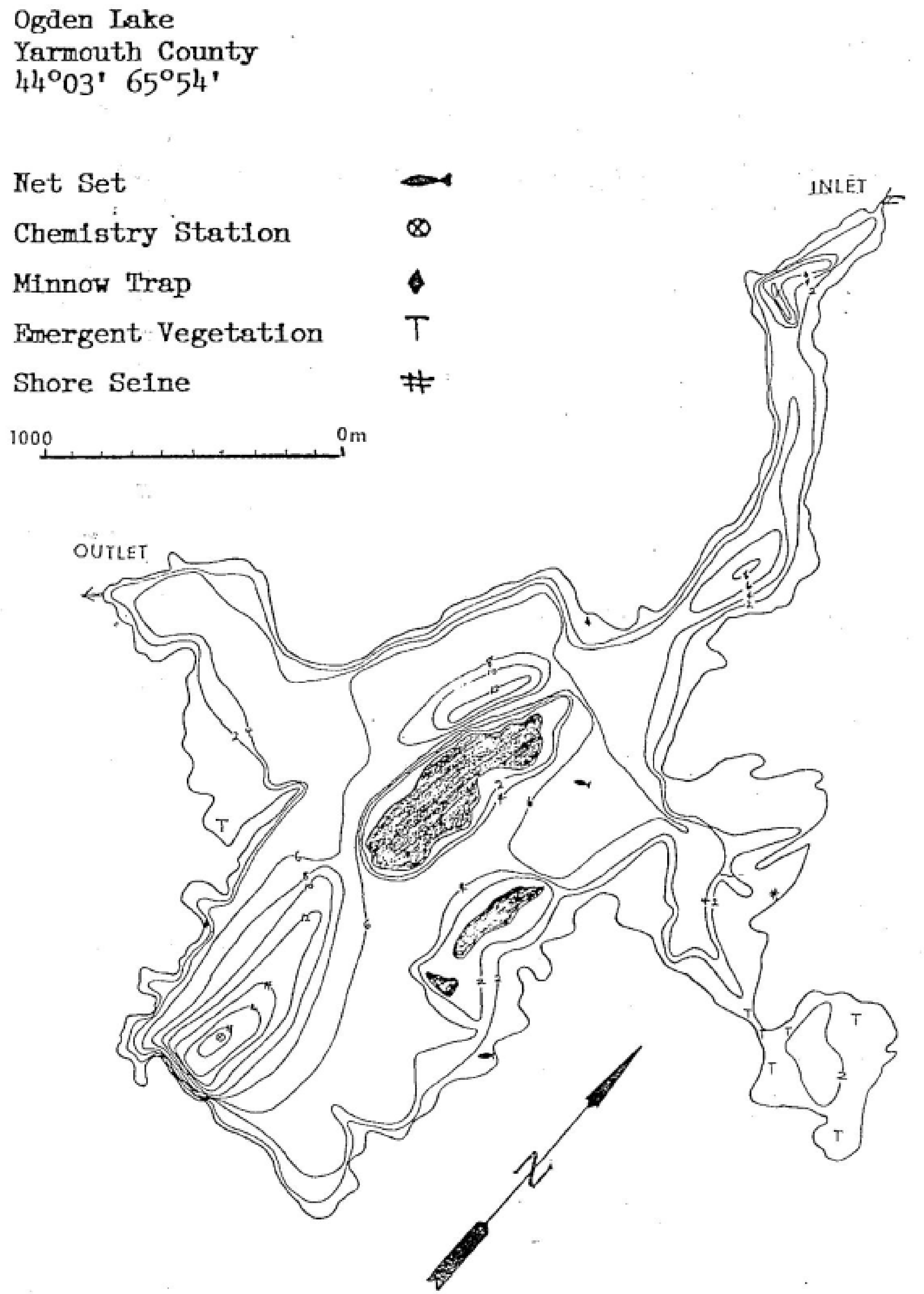

Figure 28: Bathymetric map of Ogden Lake

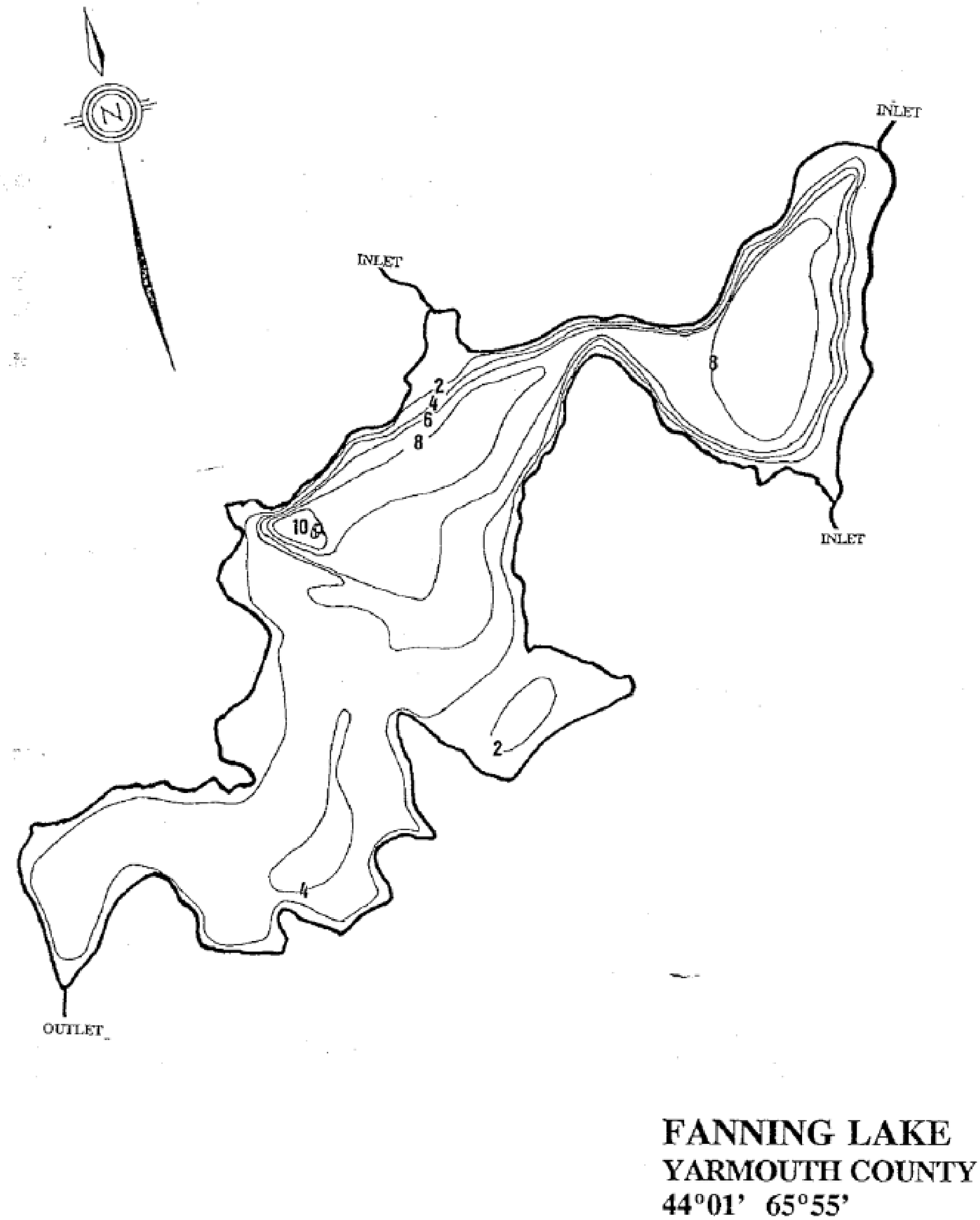

Figure 29: Bathymetric map of Fanning Lake

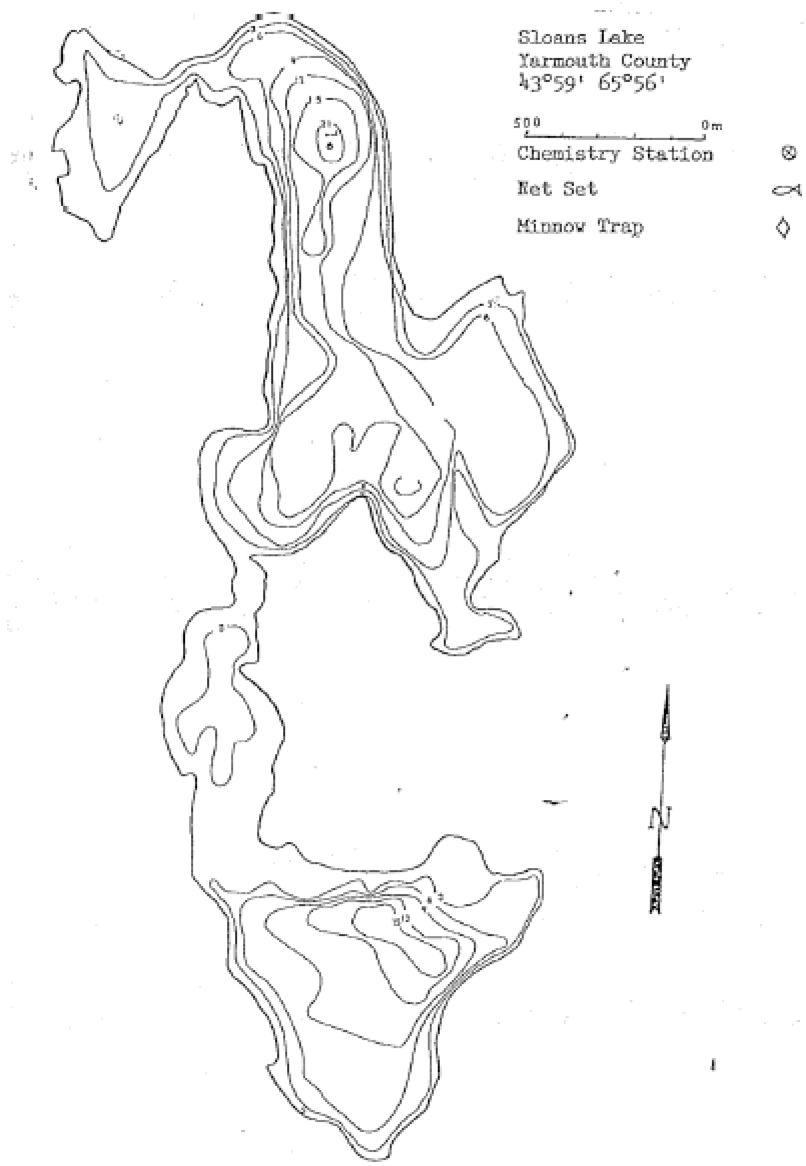

Figure 30: Bathymetric map of Sloans Lake

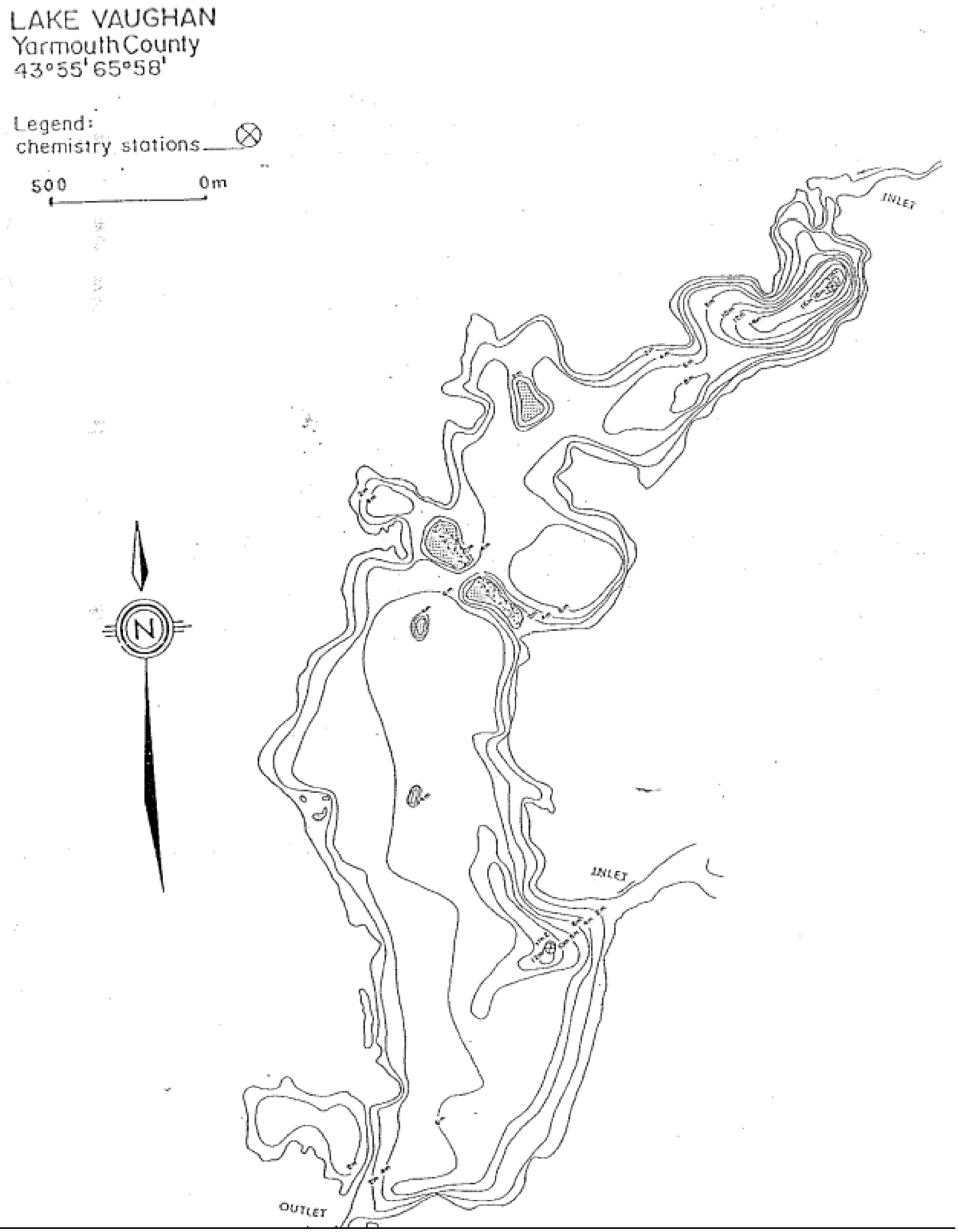

Figure 31: Bathymetric map of Vaughan Lake

APPENDIX D: MINK FARM AND RESIDENCE MAPS

Includes all identified mink farms in watershed and residences within 300 m of lakes shoreline in subcatchement for each study lake (as used in POWSIM model).

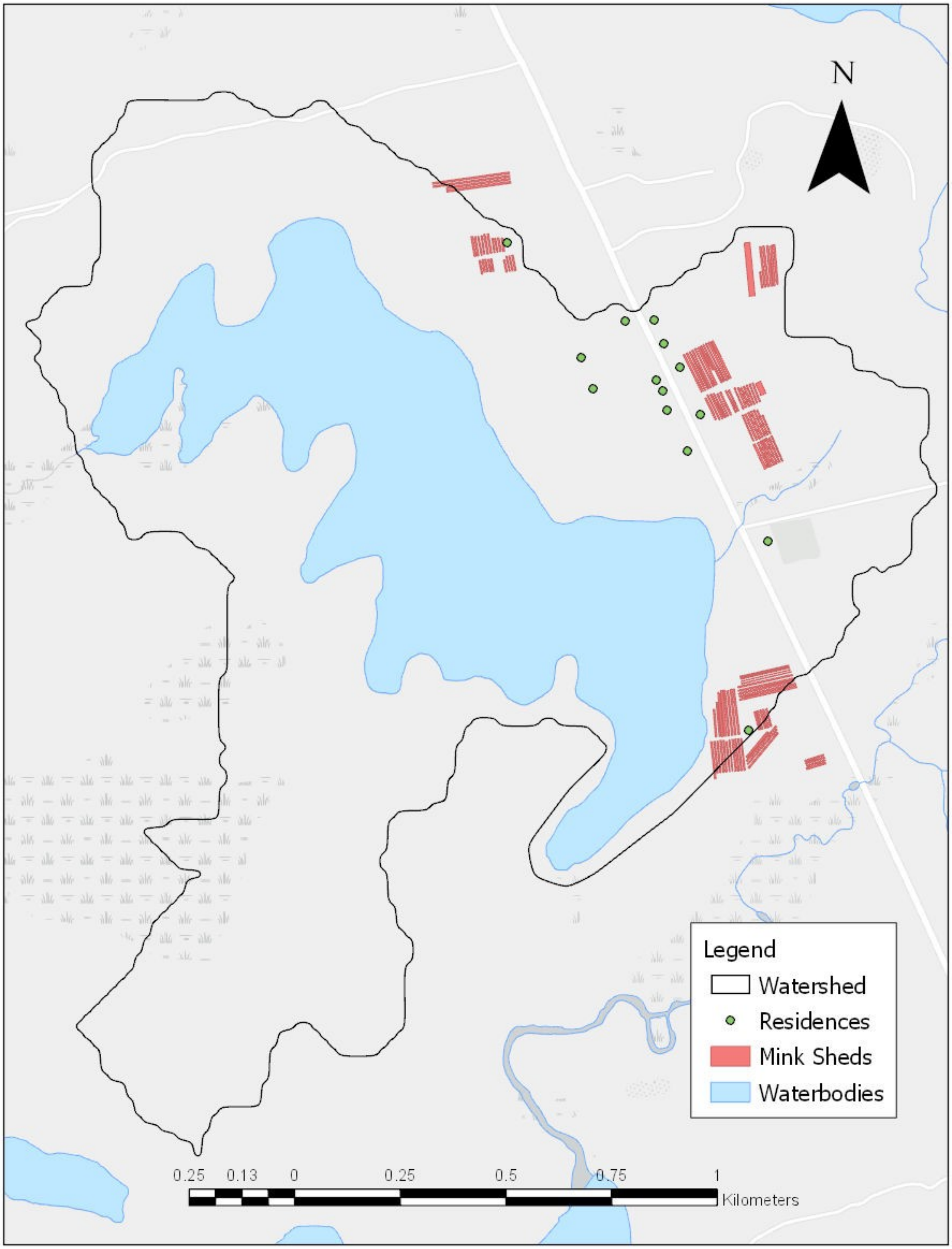

Figure 32: Map of mink sheds and residences in the Nowlans Lake watershed

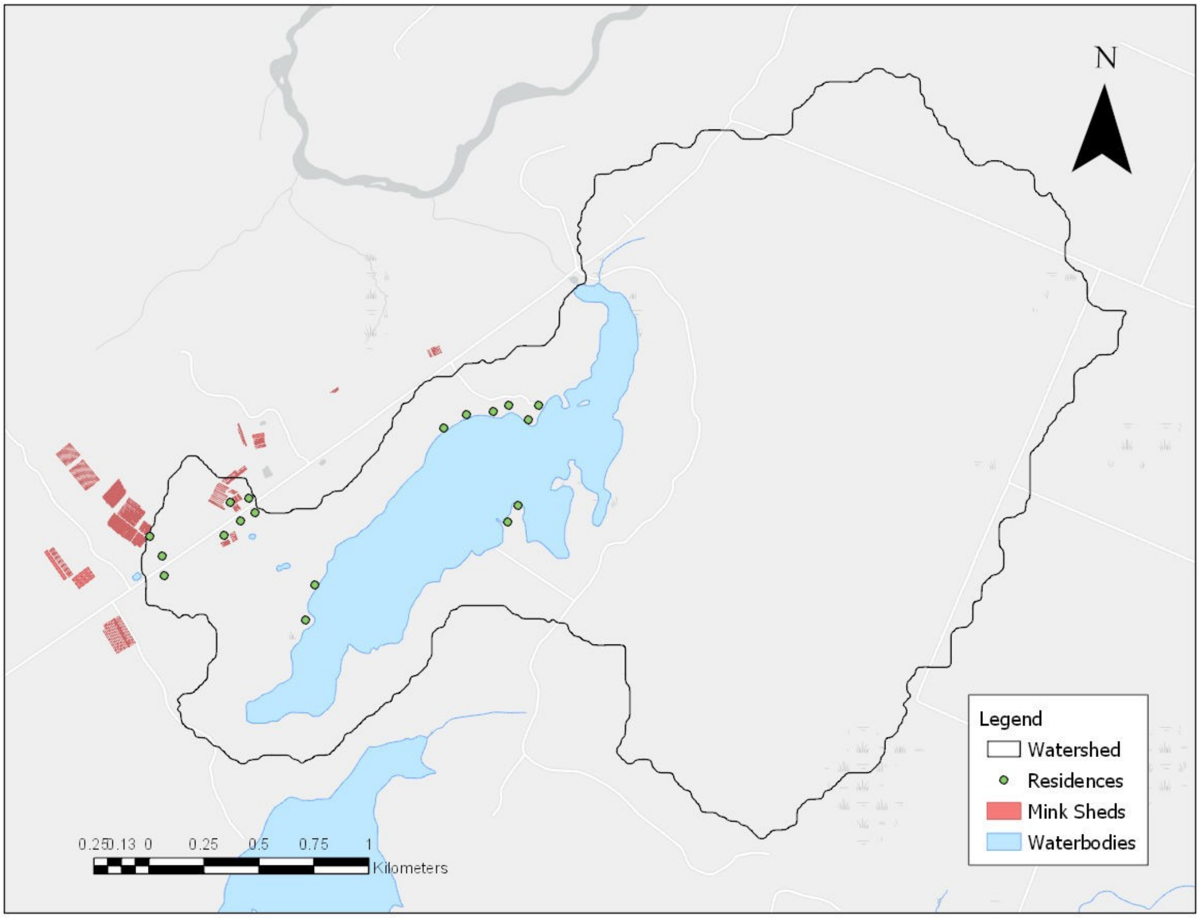

Figure 33: Map of mink sheds and residences in the Provost Lake watershed

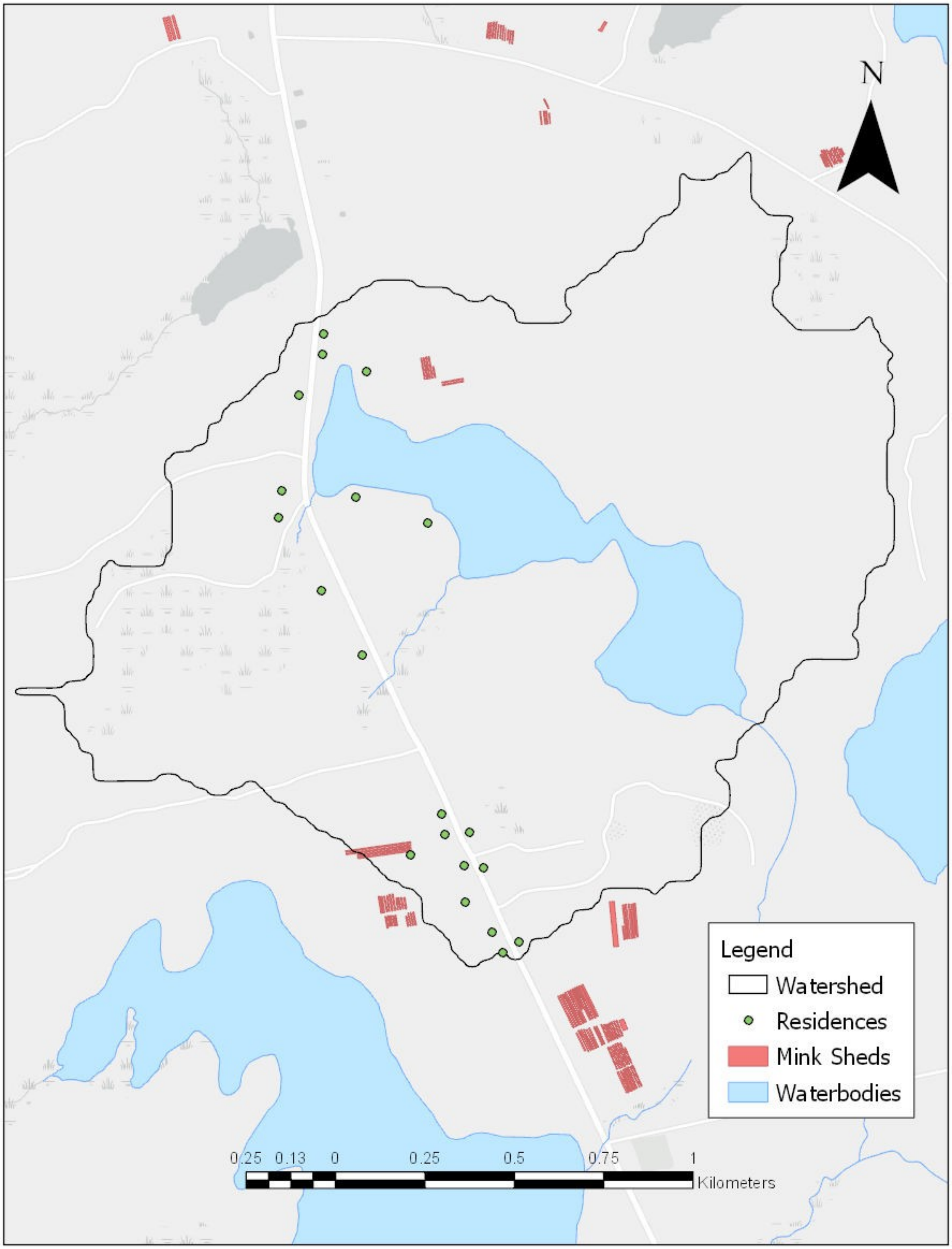

Figure 34: Map of mink sheds and residences in the Hourglass Lake watershed

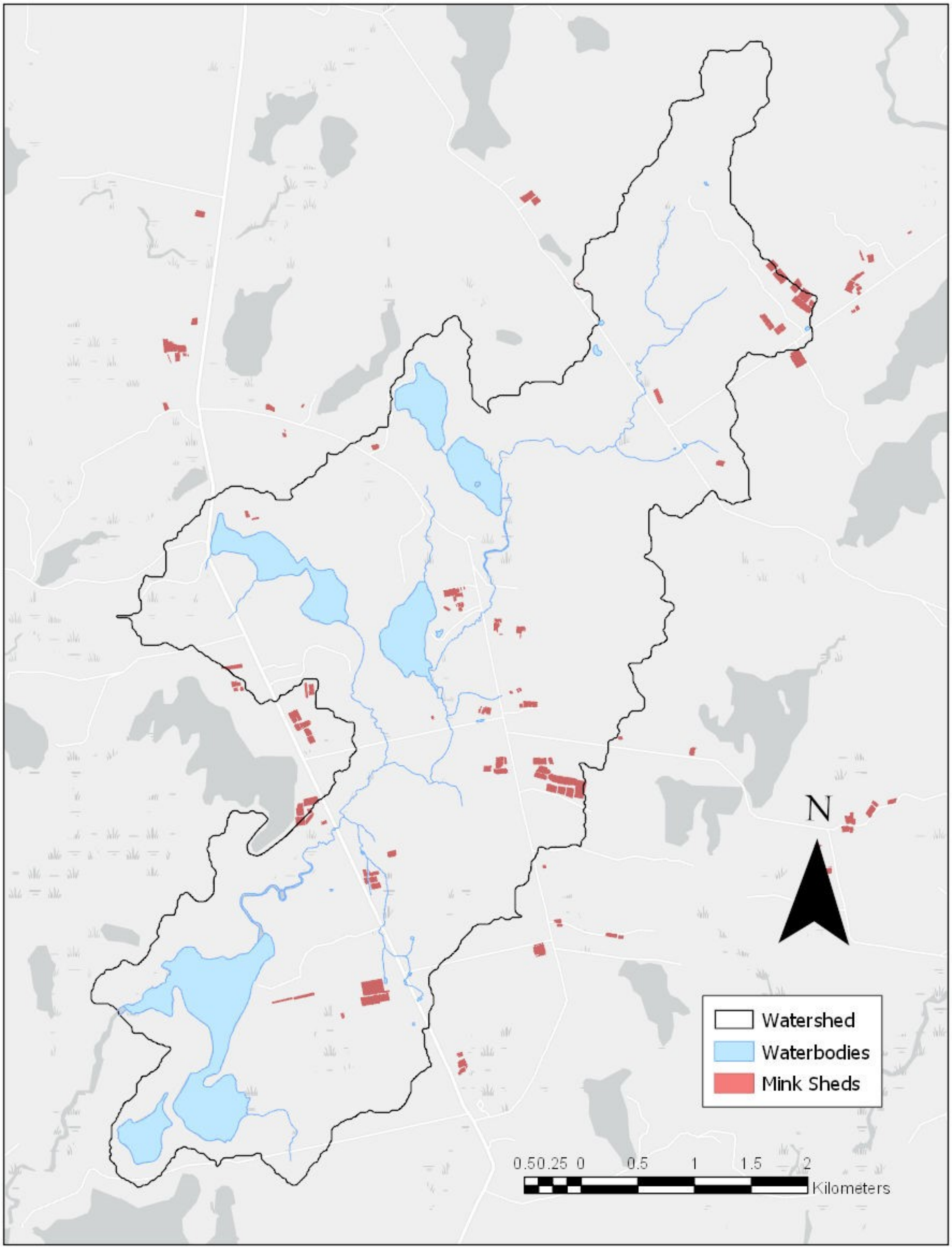

Figure 35: Map of mink farms in the Placides Lake watershed. There are no residences within 300m of the lake.

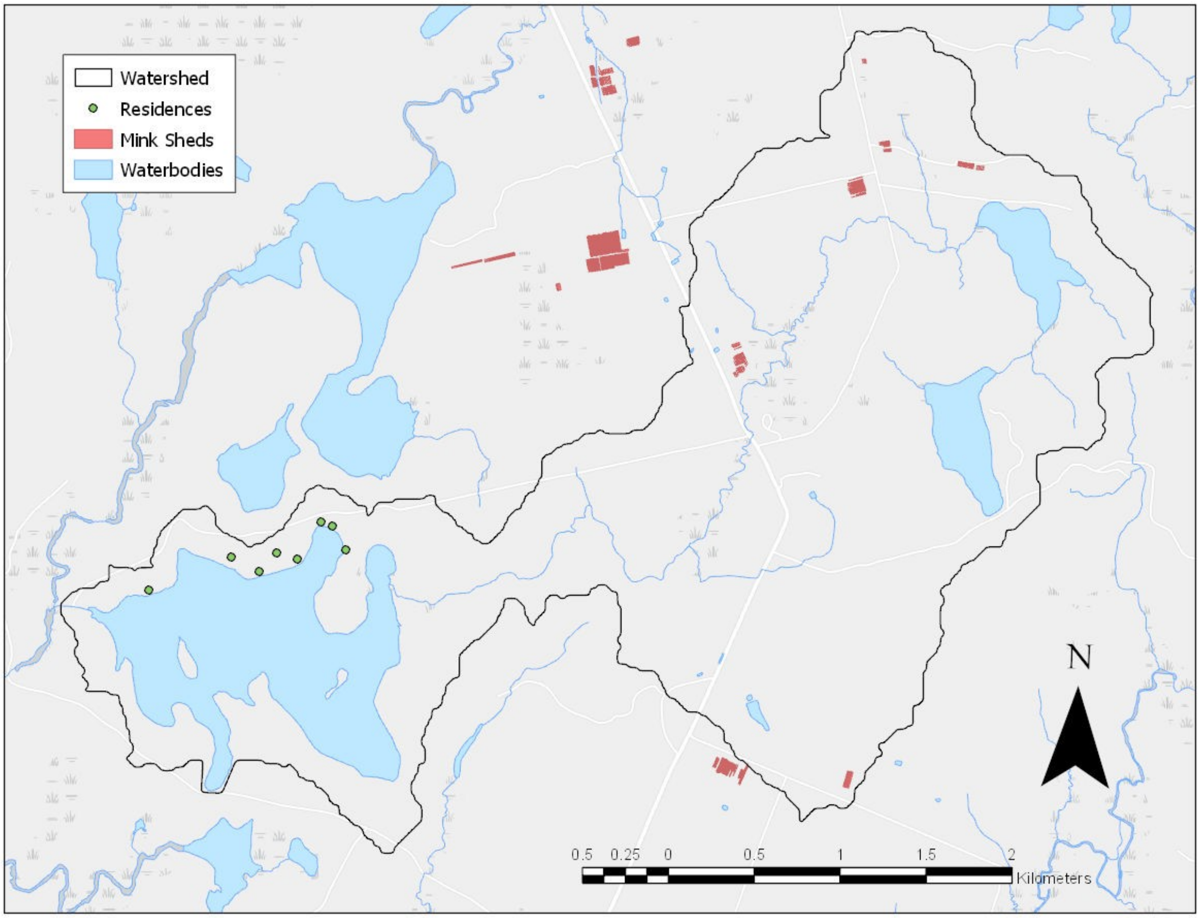

Figure 36: Map of mink farms and residences in the Porcupine Lake watershed

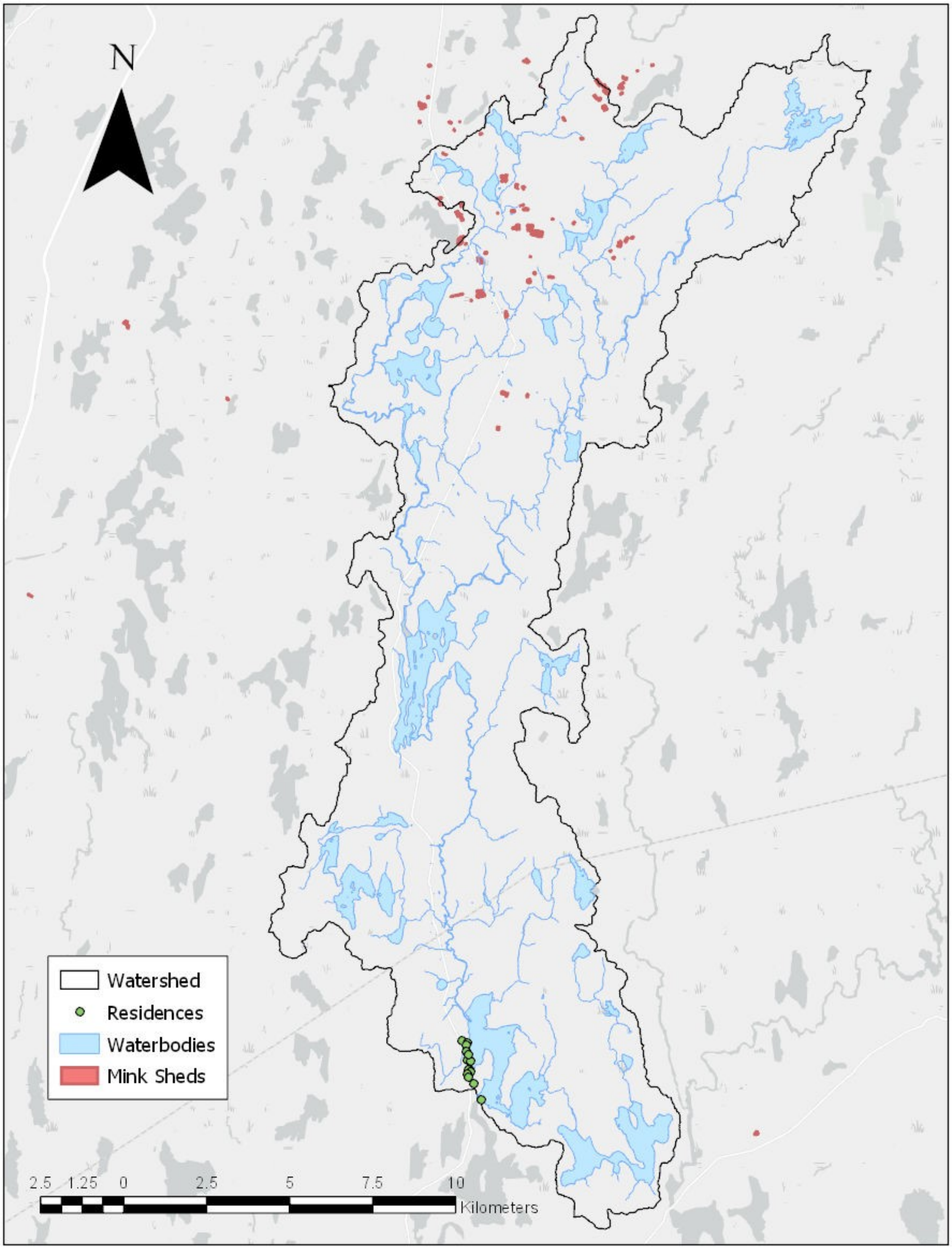

Figure 37: Map of mink farms and residences in the Parr Lake watershed

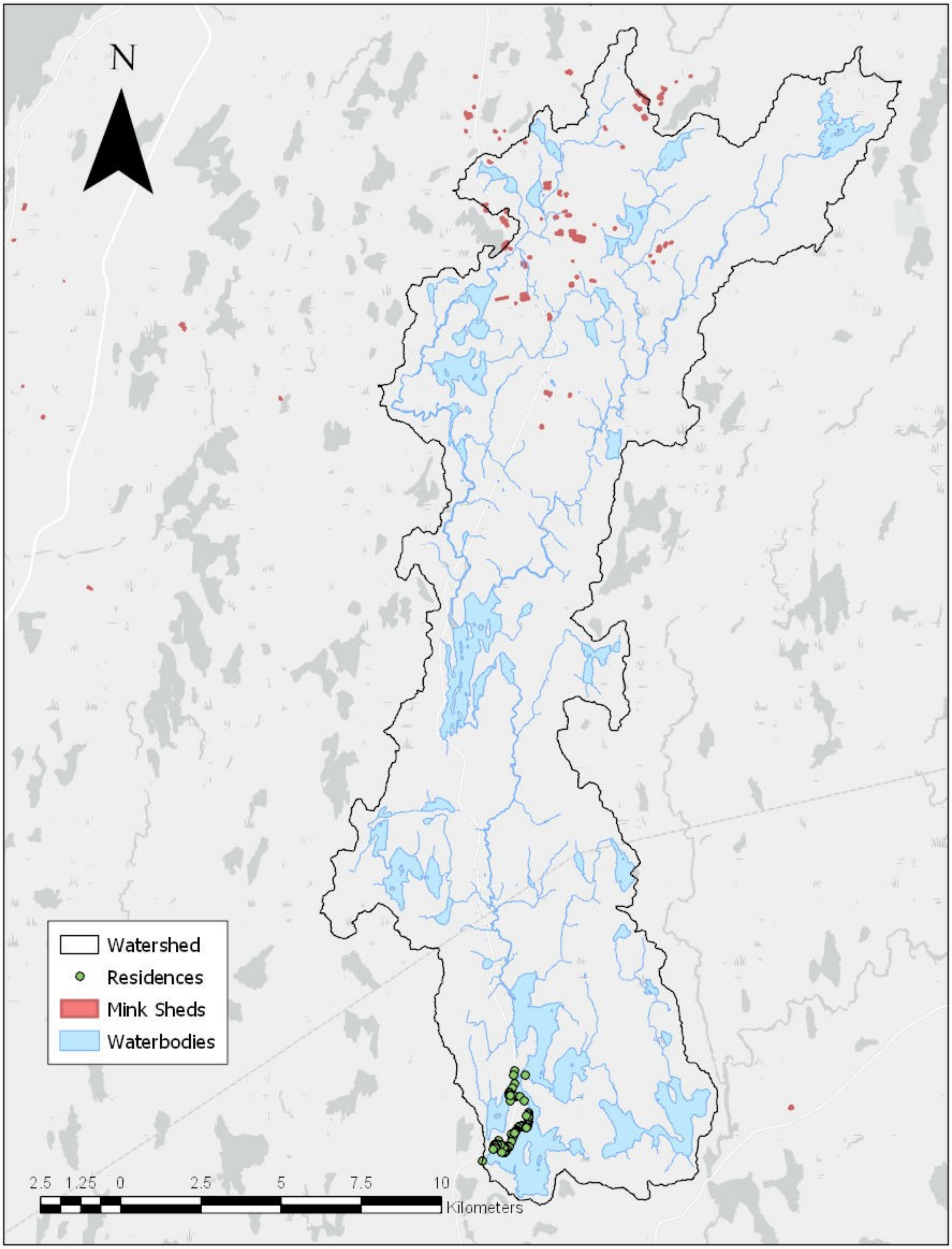

Figure 38: Mink farms and residences in the Ogden Lake watershed

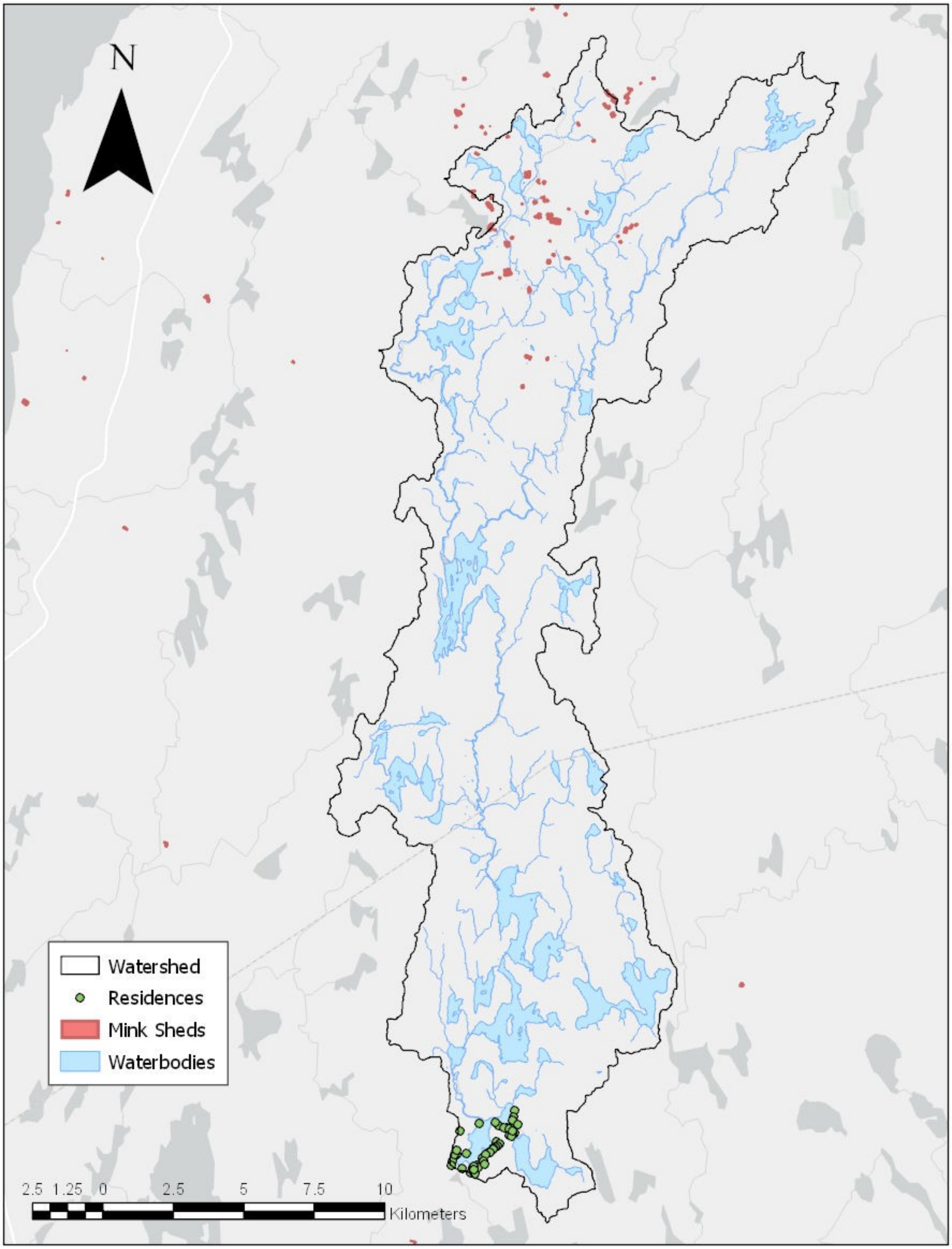

Figure 39: Mink farms and residences in the Fanning Lake watershed

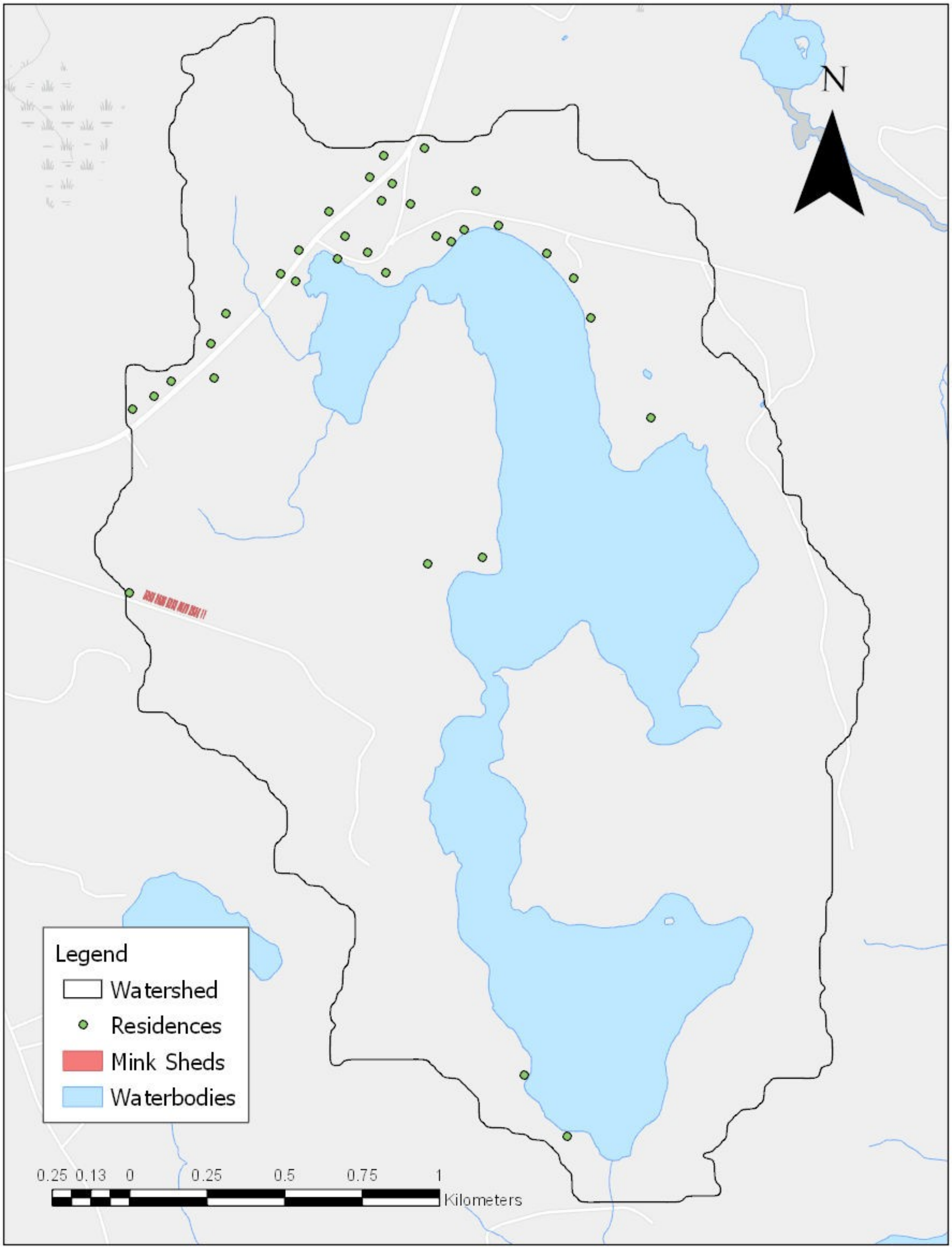

Figure 40: Mink farms and residences in the Sloans Lake watershed

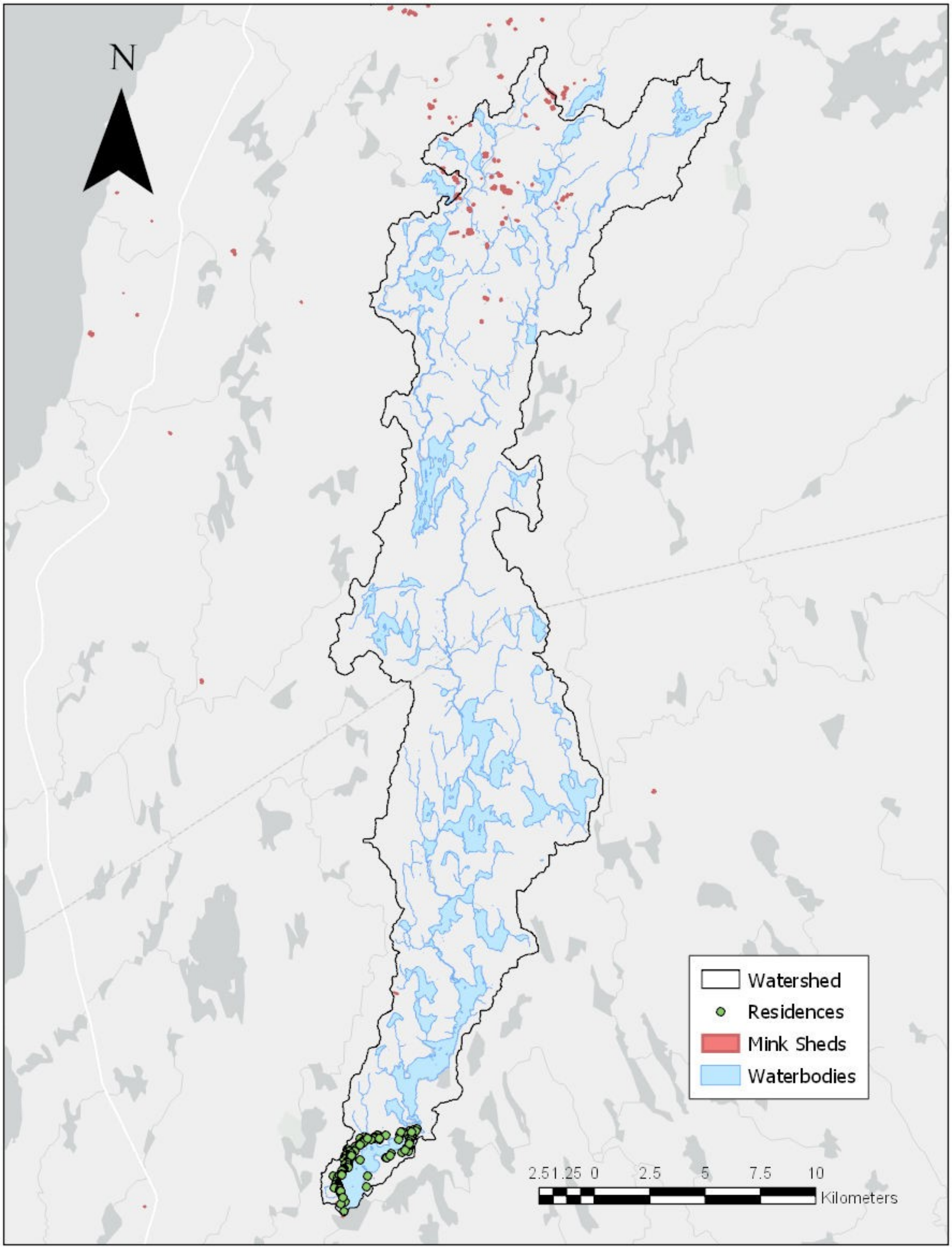

Figure 41: Mink farms and residences in the Vaughan Lake watershed

APPENDIX E: LAND USE MAPS – 2017

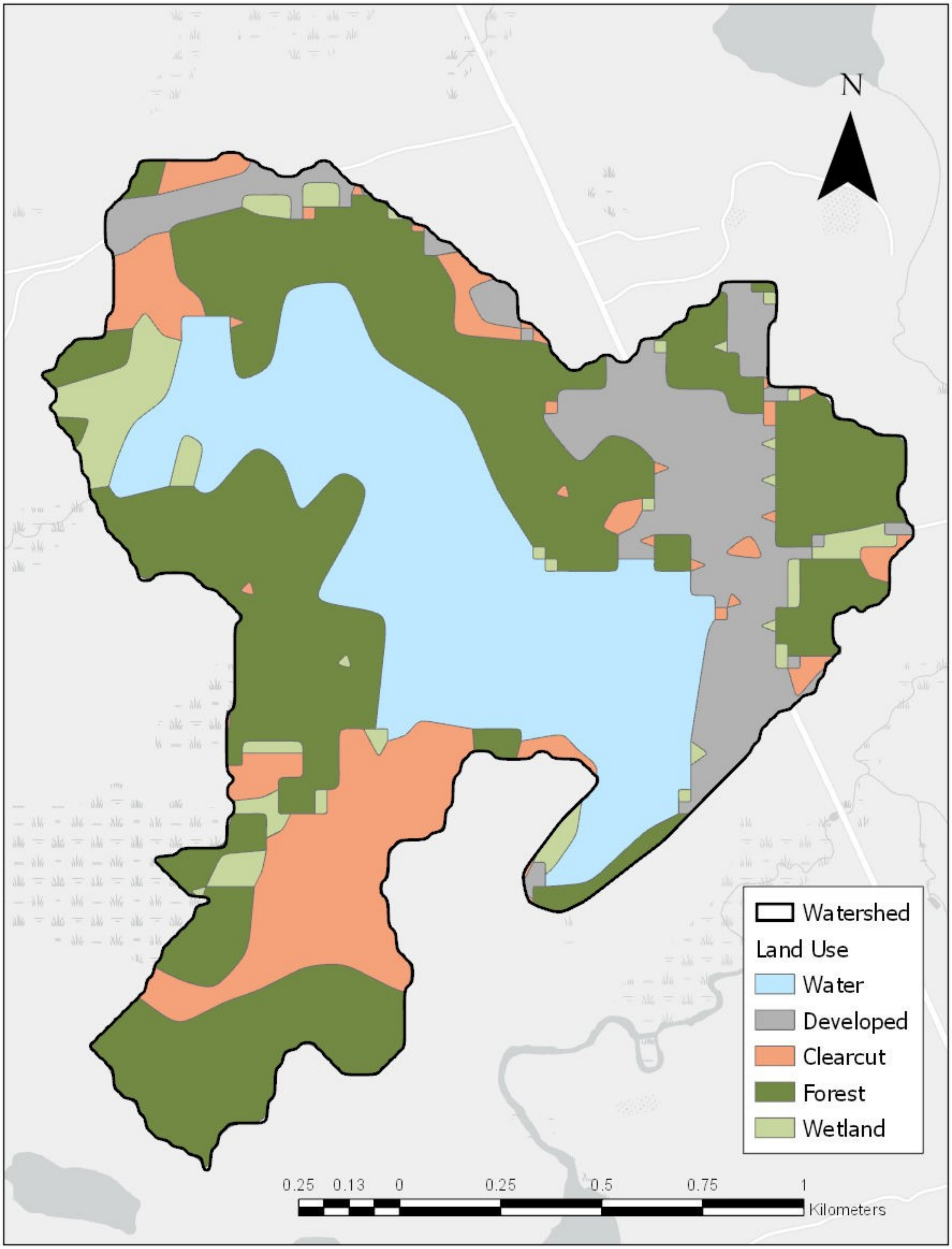

Figure 42: Land use classification in Nowlans Lake watershed in 2017

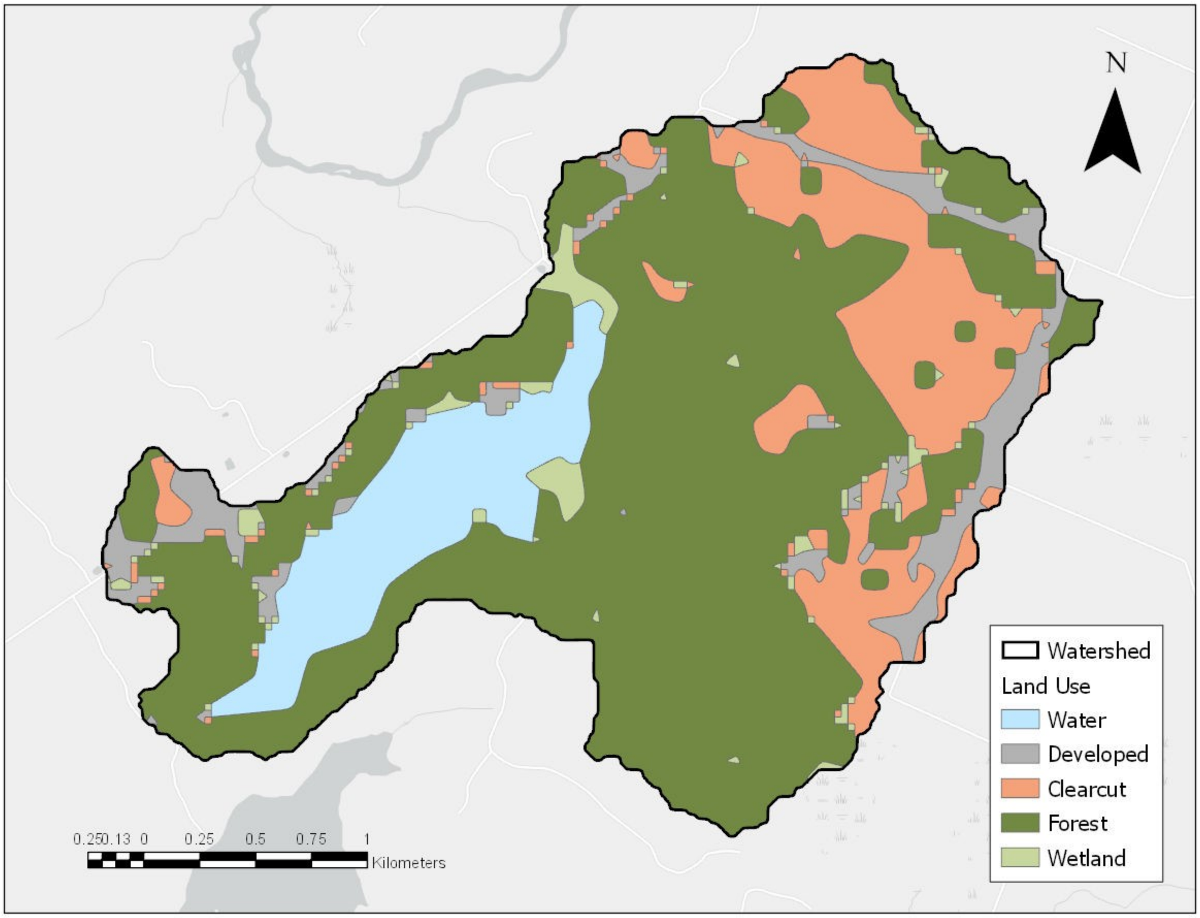

Figure 43: Land use classification in Provost Lake watershed in 2017

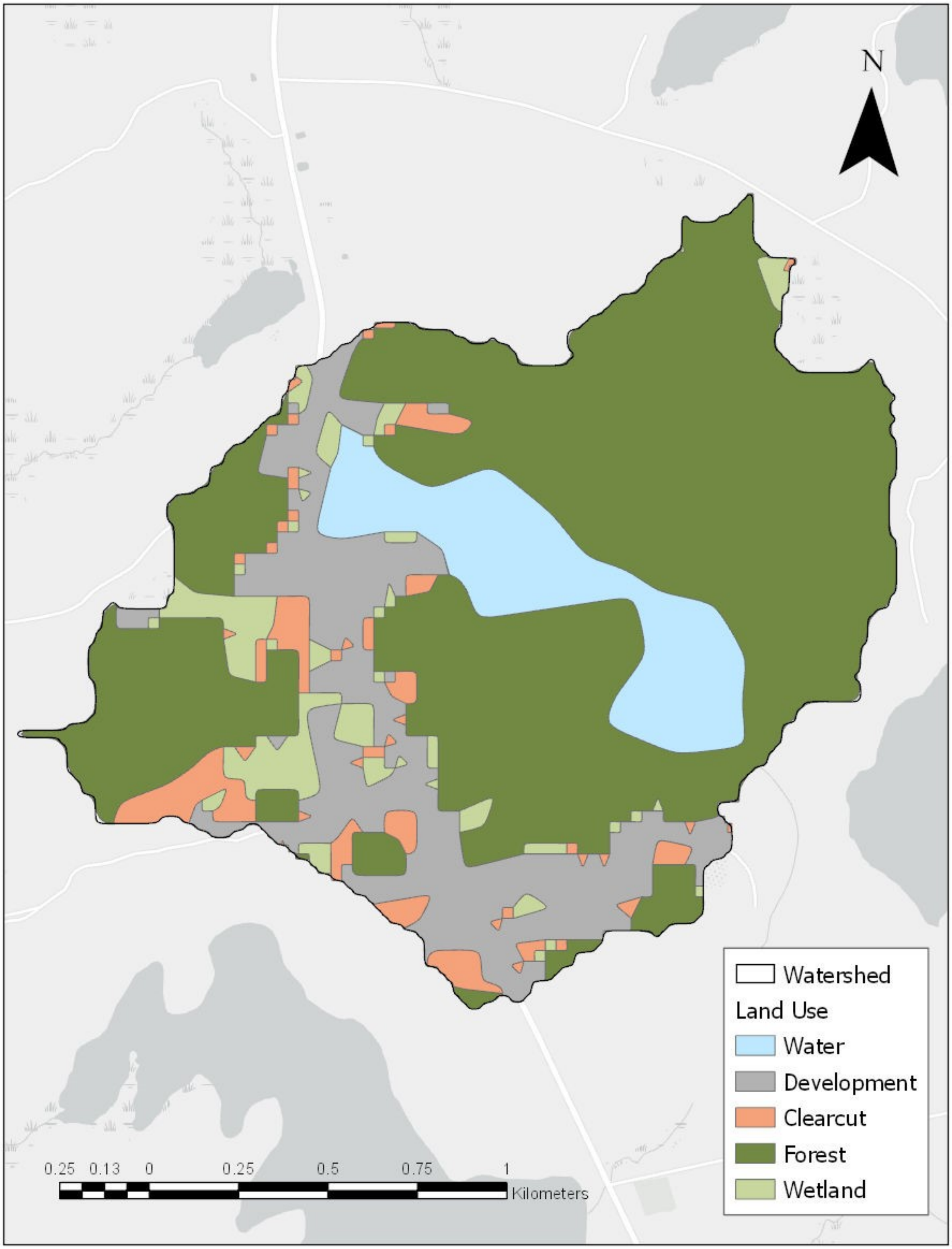

Figure 44: Land use classification in Hourglass Lake watershed in 2017

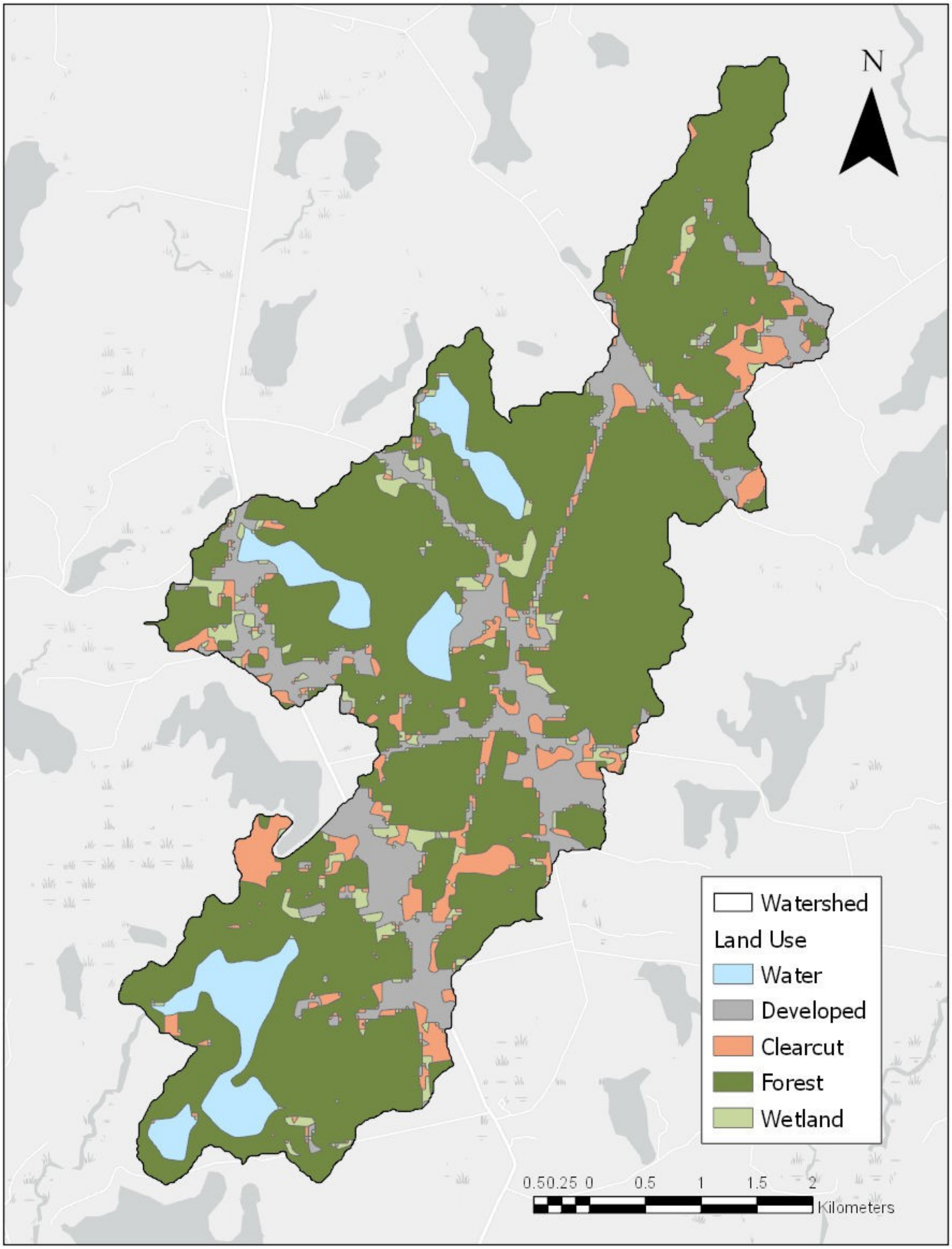

Figure 45: Land use classification in Placides Lake watershed in 2017

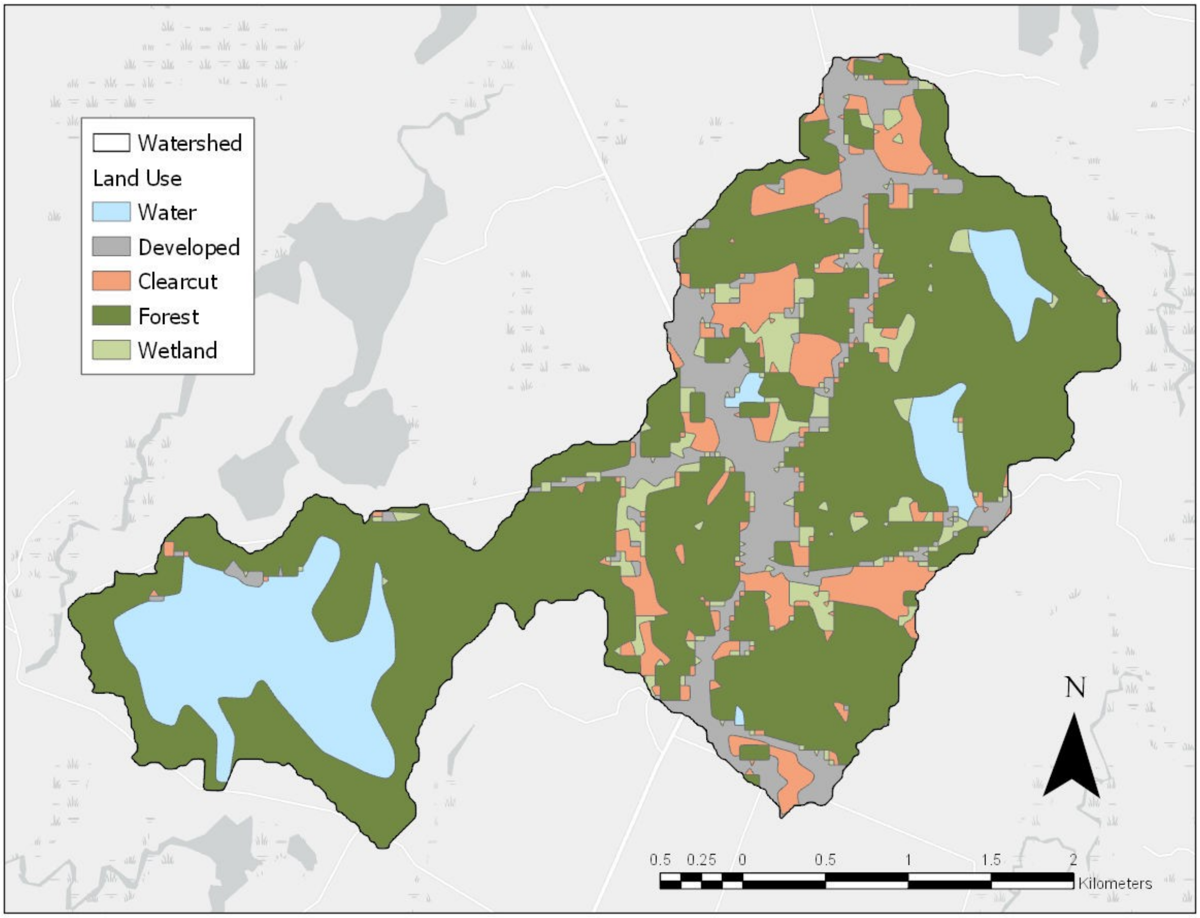

Figure 46: Land use classification in Porcupine Lake watershed in 2017

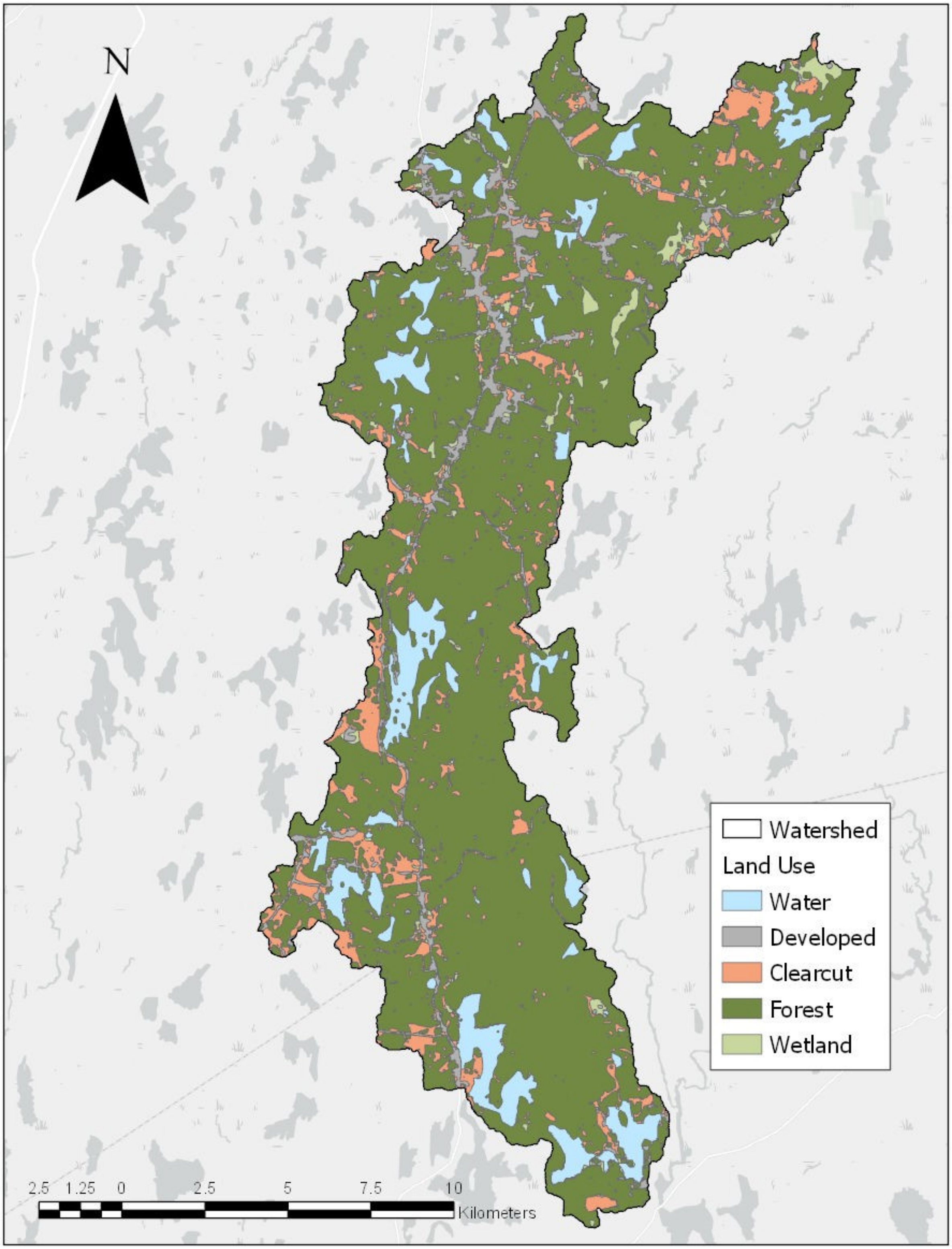

Figure 47: Land use classification in Parr Lake watershed in 2017

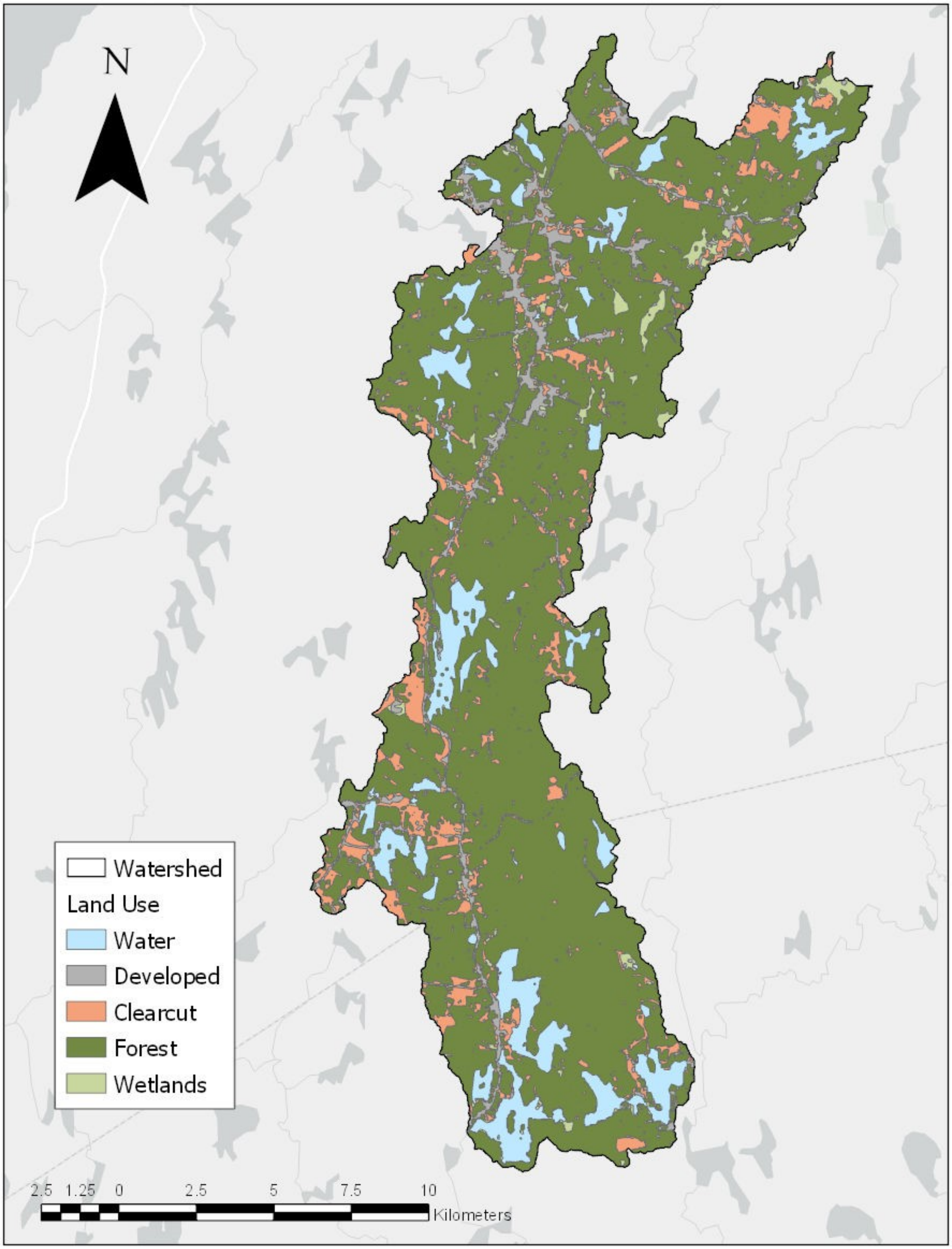

Figure 48: Land use classification in Ogden Lake watershed in 2017

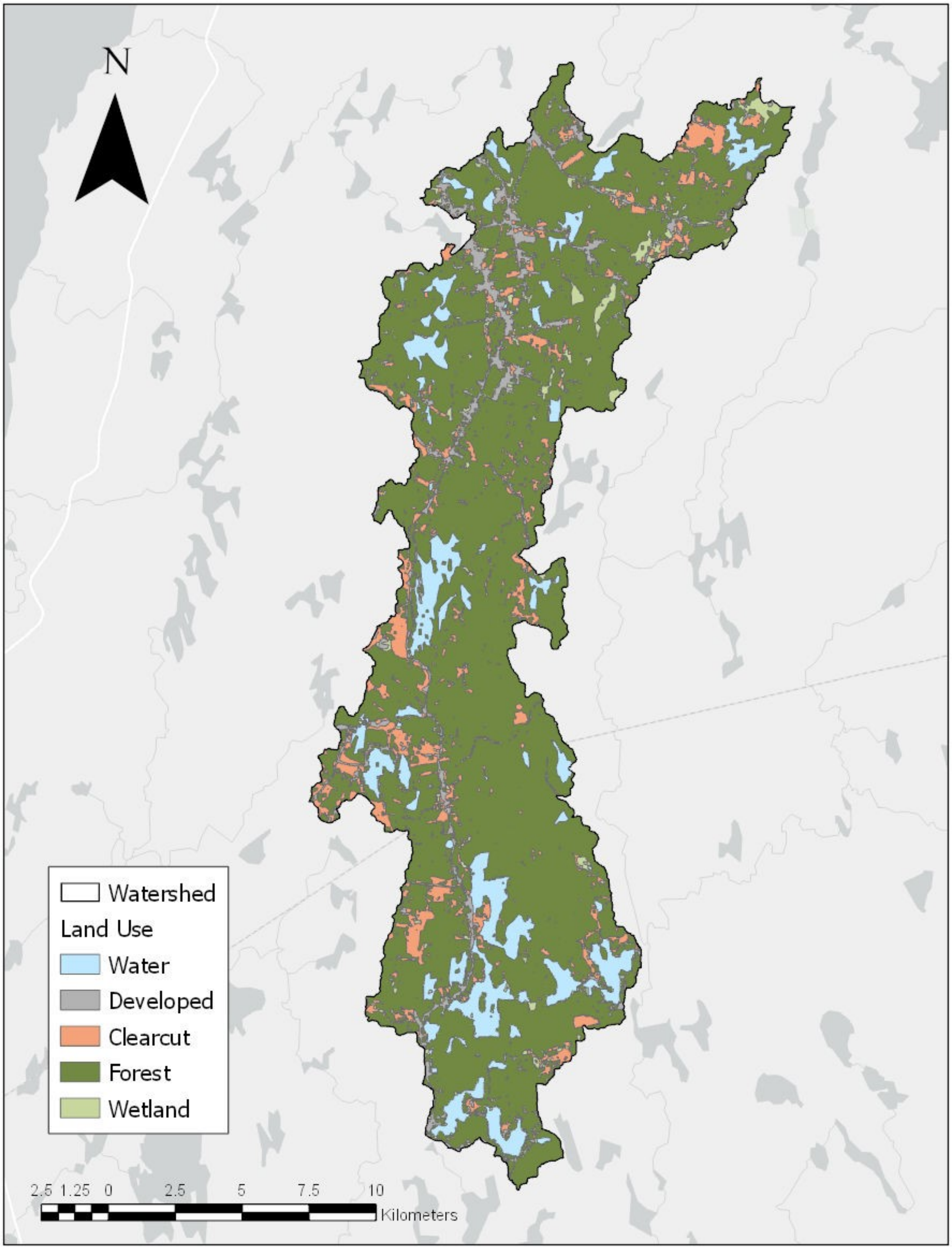

Figure 49: Land use classification in Fanning Lake watershed in 2017

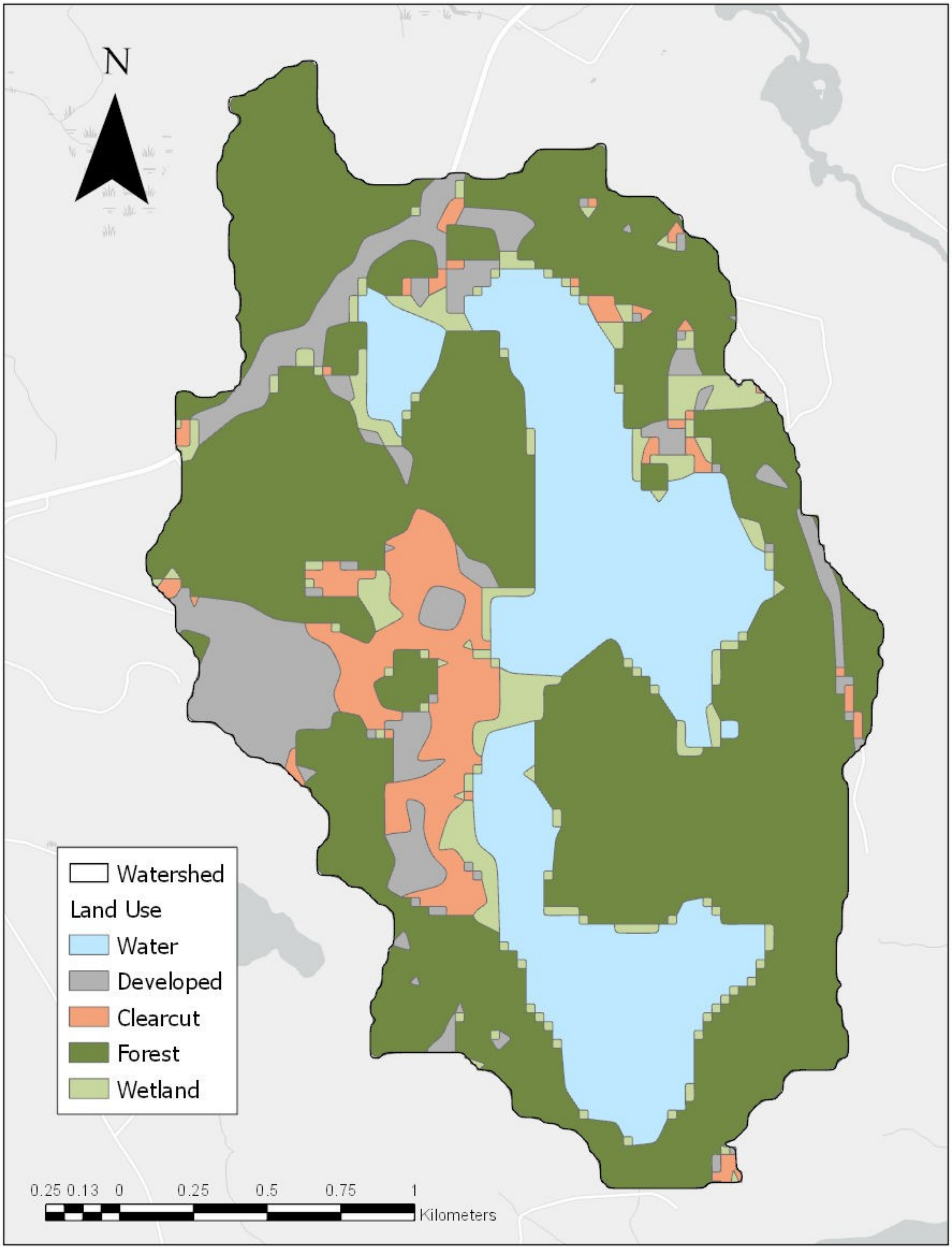

Figure 50: Land use classification in Sloans Lake watershed in 2017

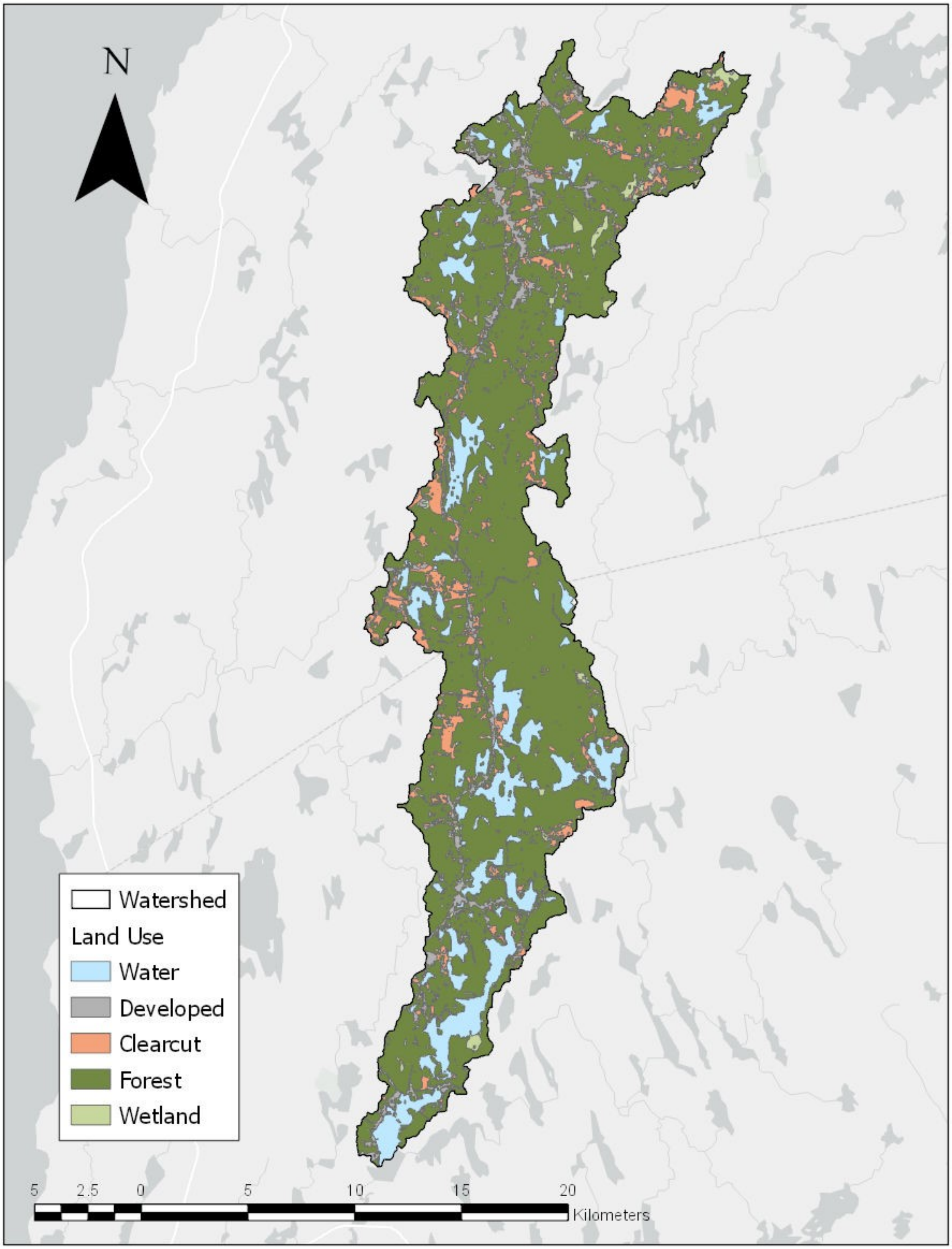

Figure 51: Land use classification in Vaughan Lake watershed in 2017

APPENDIX F: LAND USE MAPS – 2008

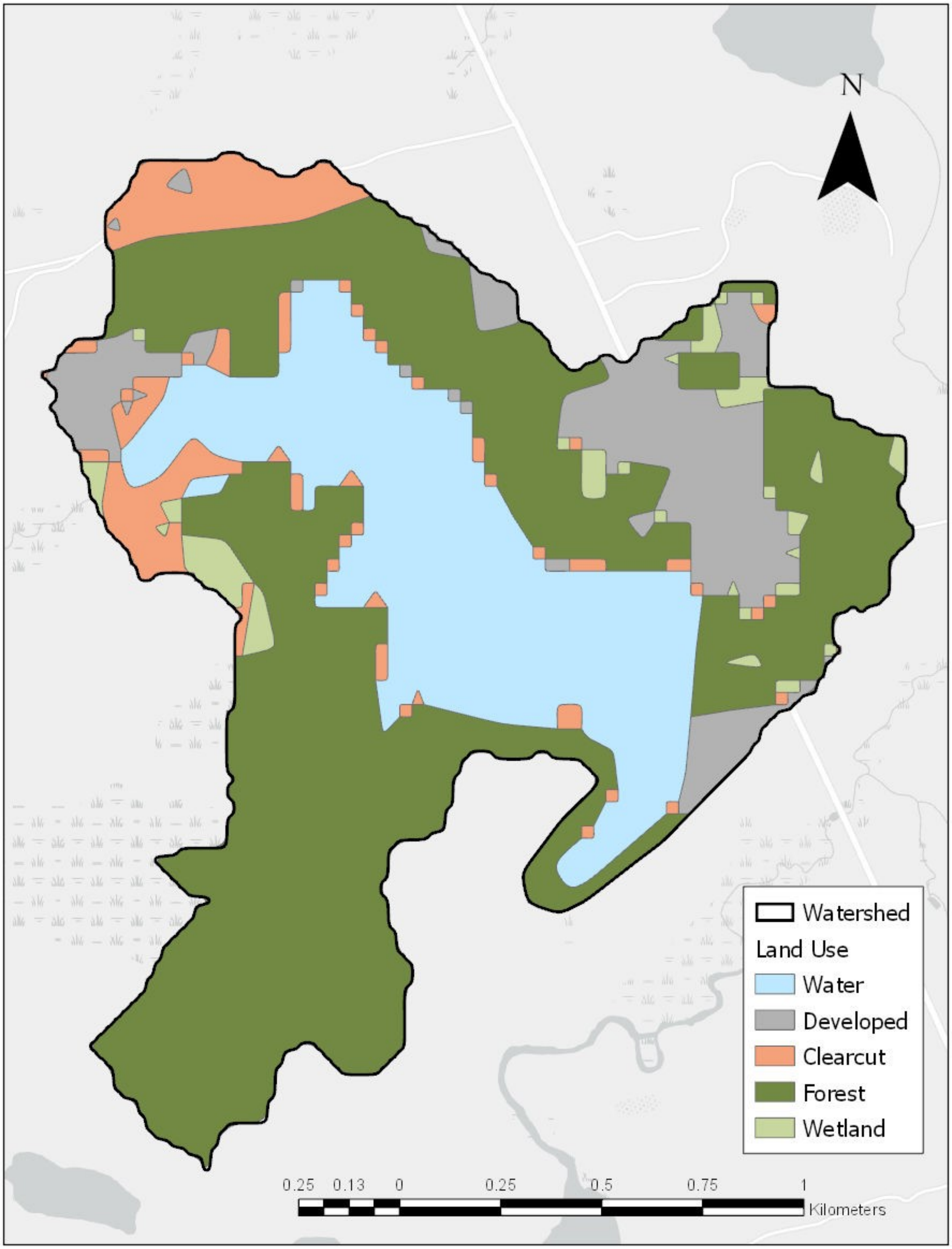

Figure 52: Land use classification in Nowlans Lake watershed in 2008

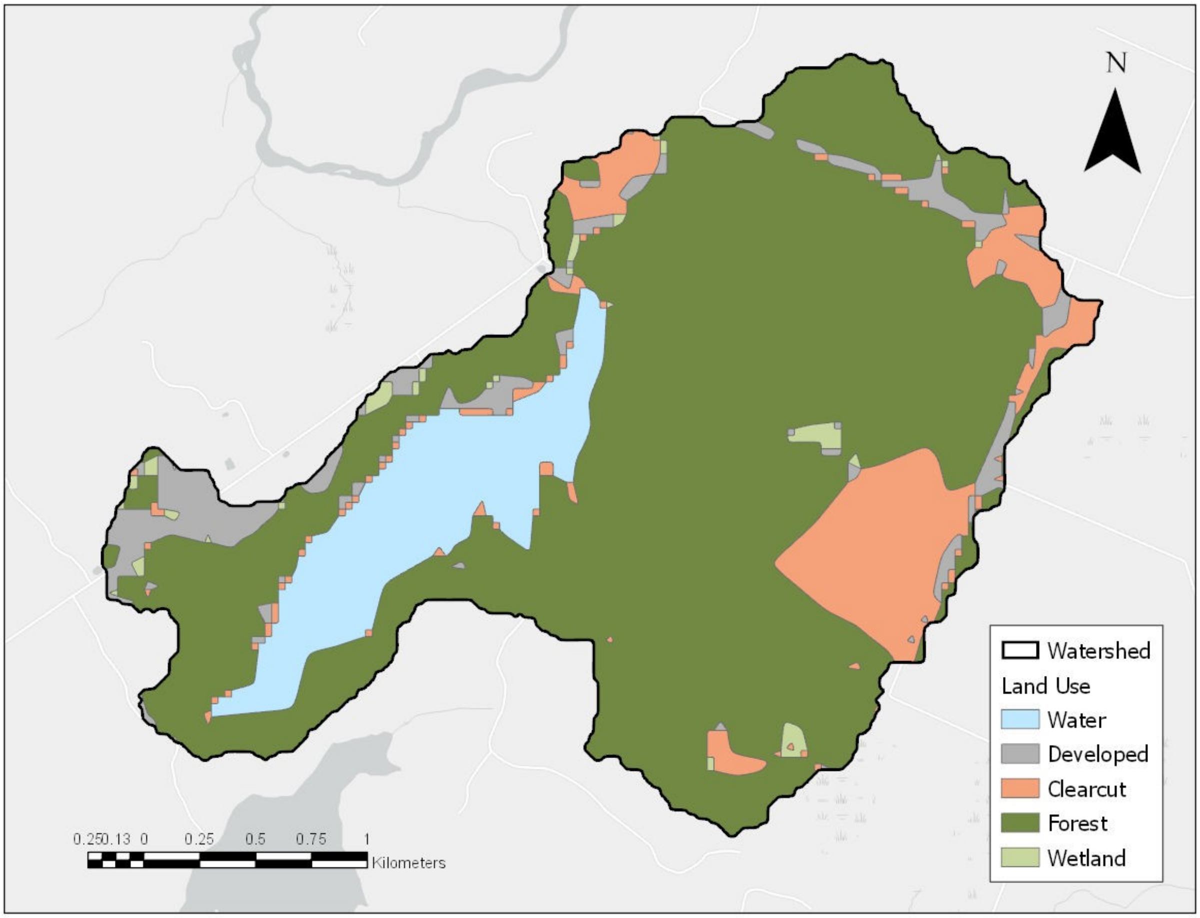

Figure 53: Land use classification in Provost Lake watershed in 2008

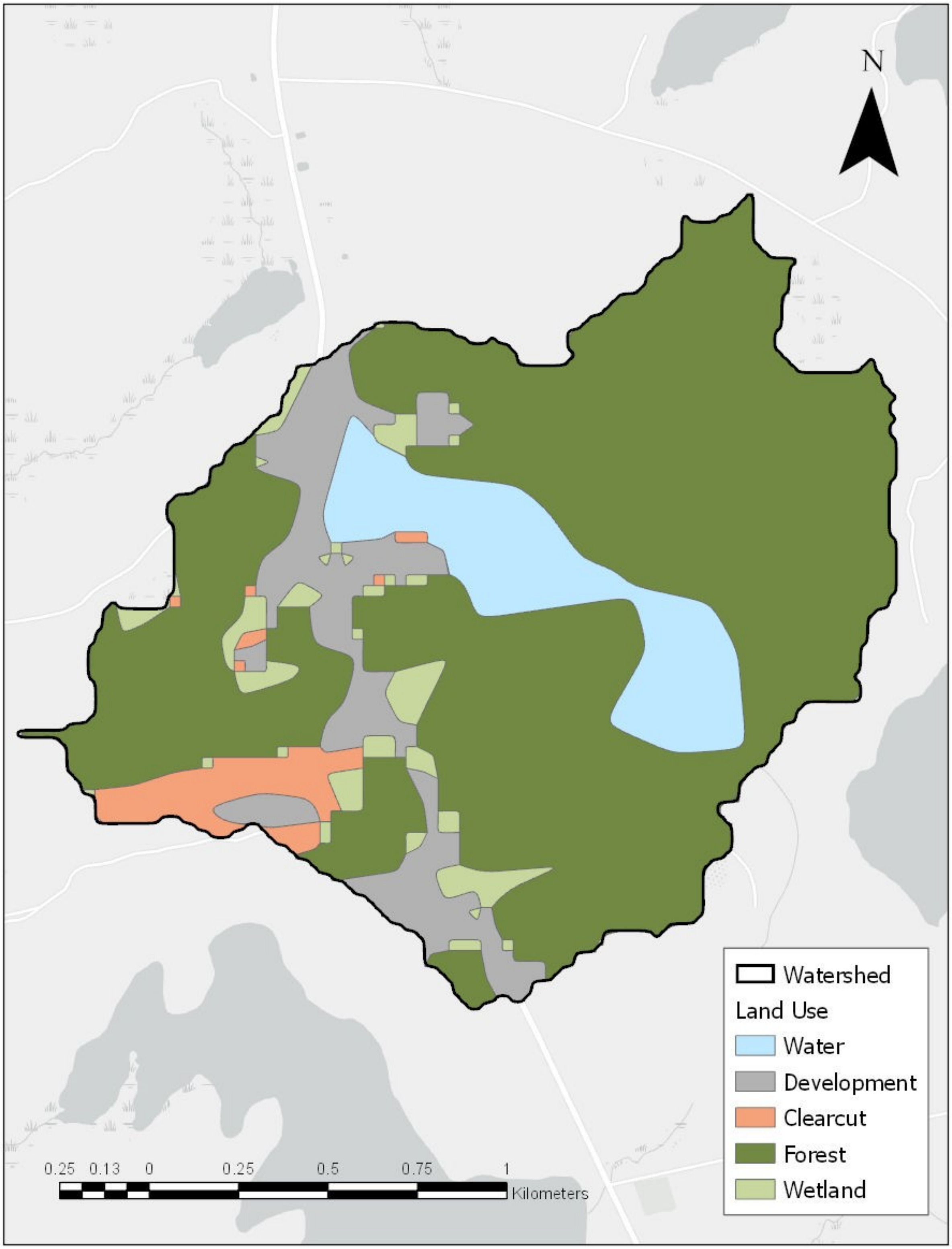

Figure 54: Land use classification in Hourglass Lake in 2008

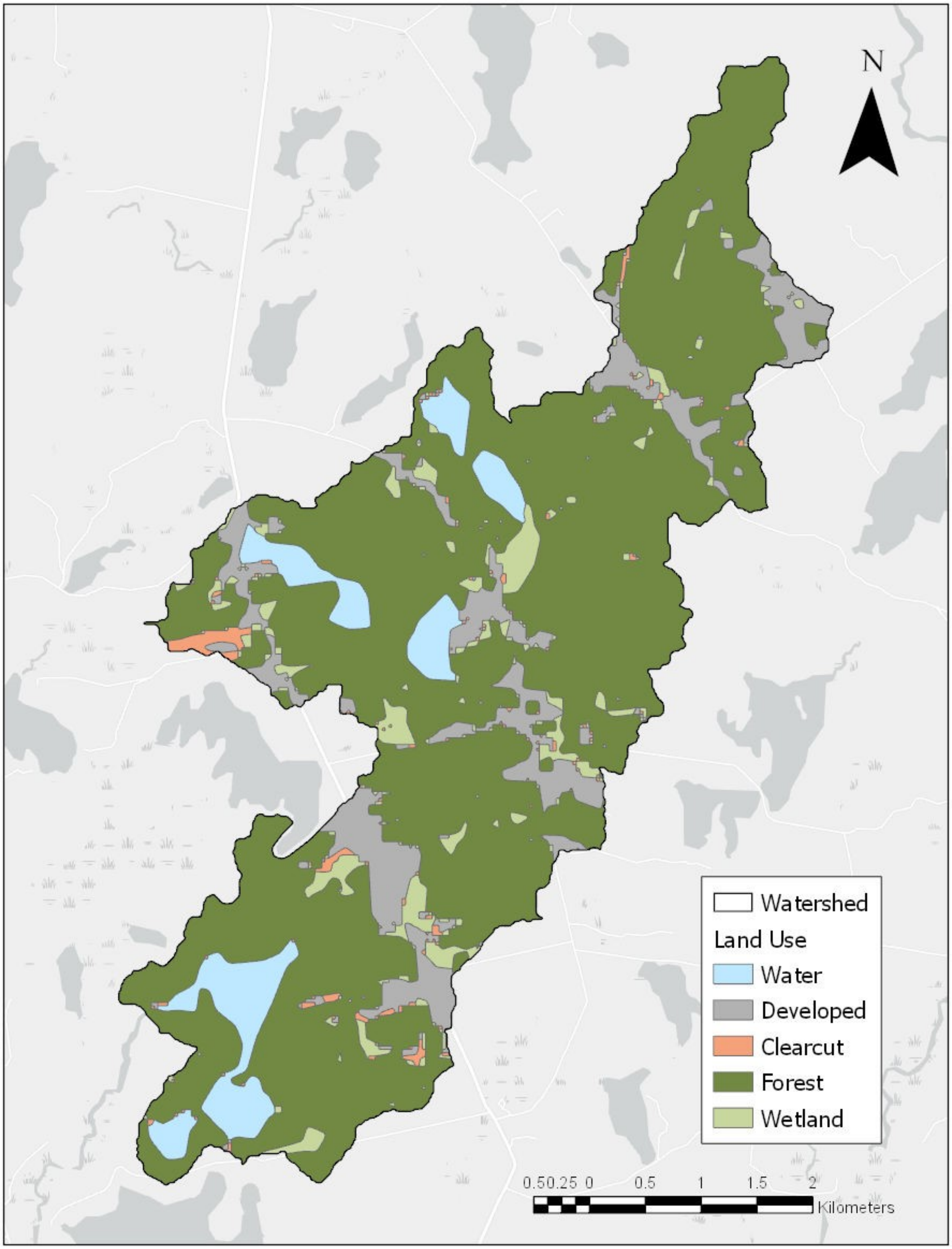

Figure 55: Land use classification in Placides Lake watershed in 2008

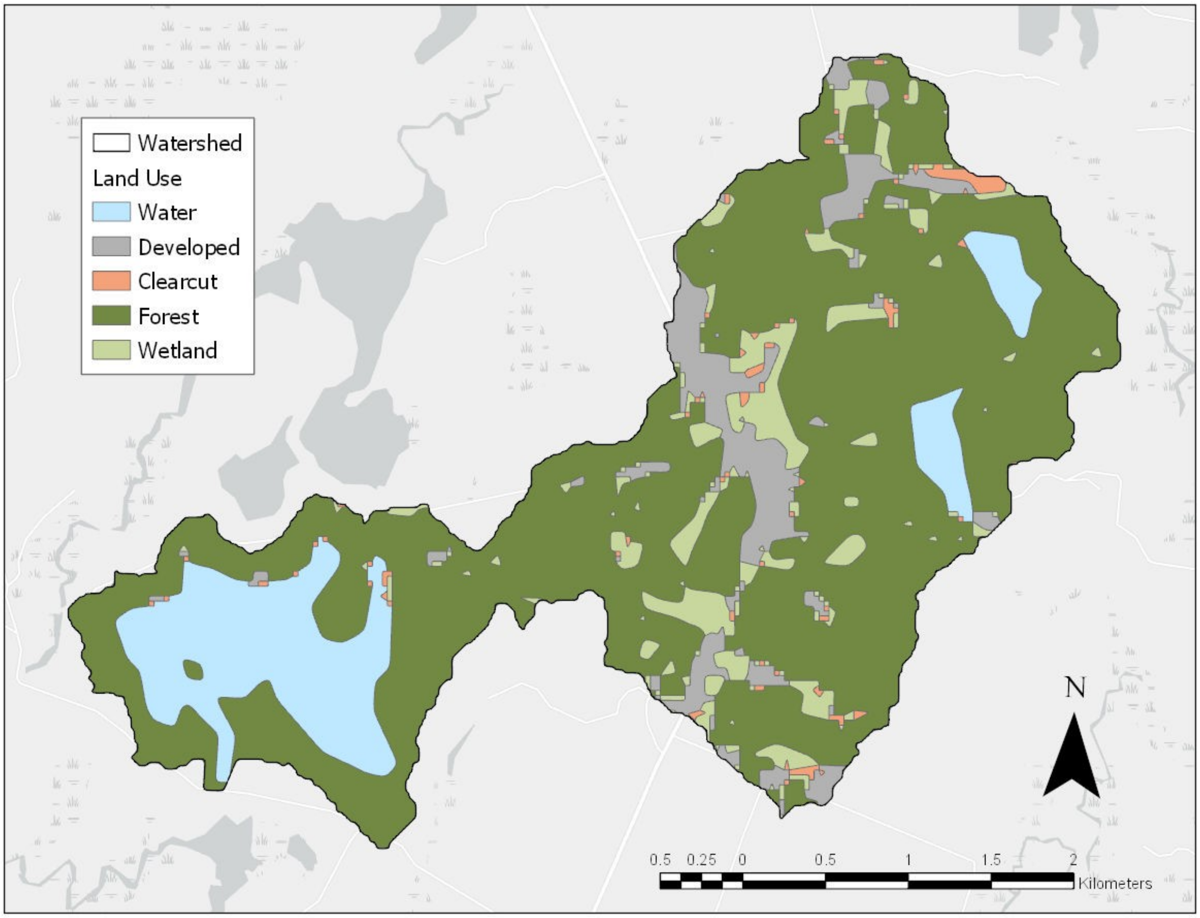

Figure 56: Land use classification in Porcupine Lake watershed in 2008

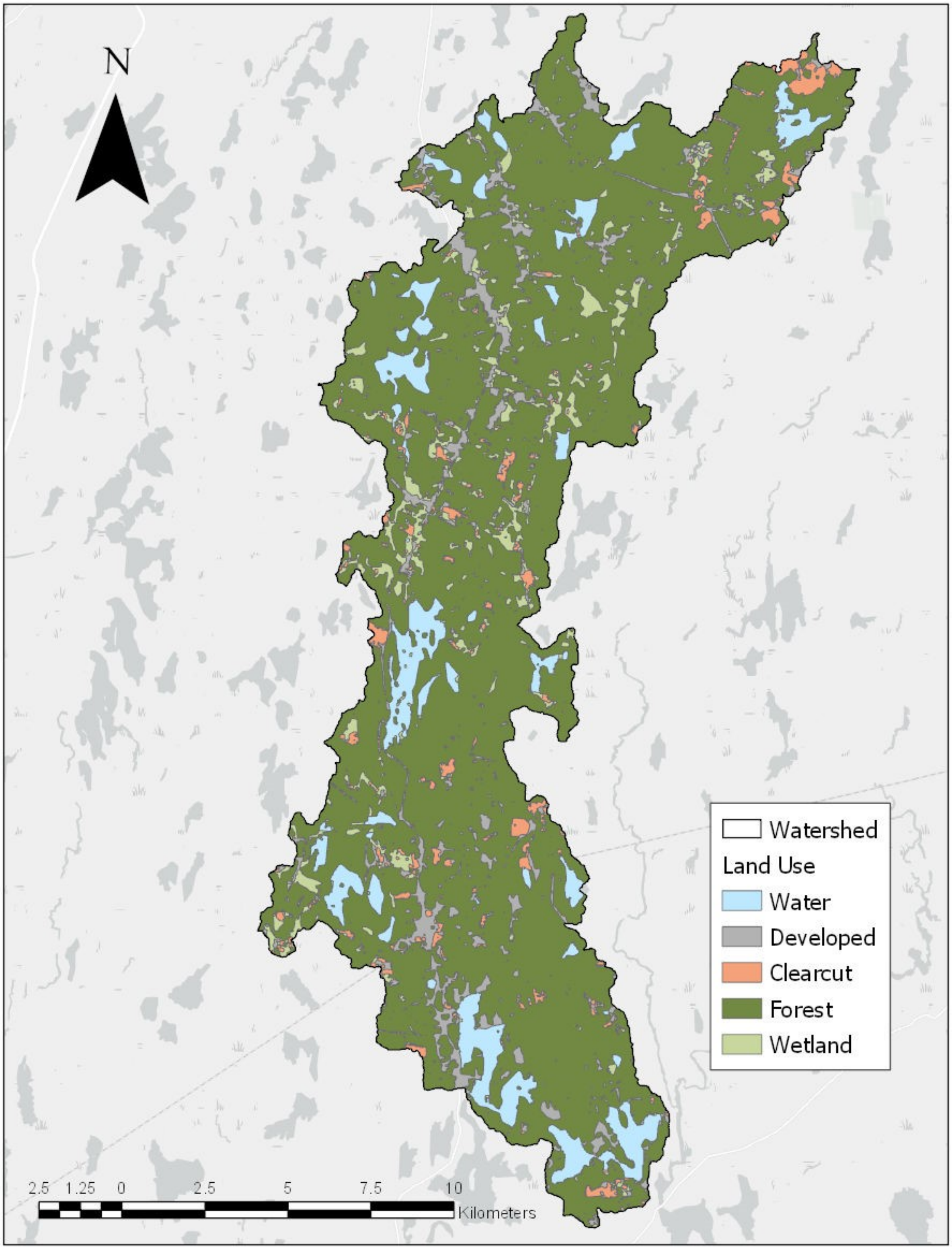

Figure 57: Land use classification in Parr Lake watershed in 2008

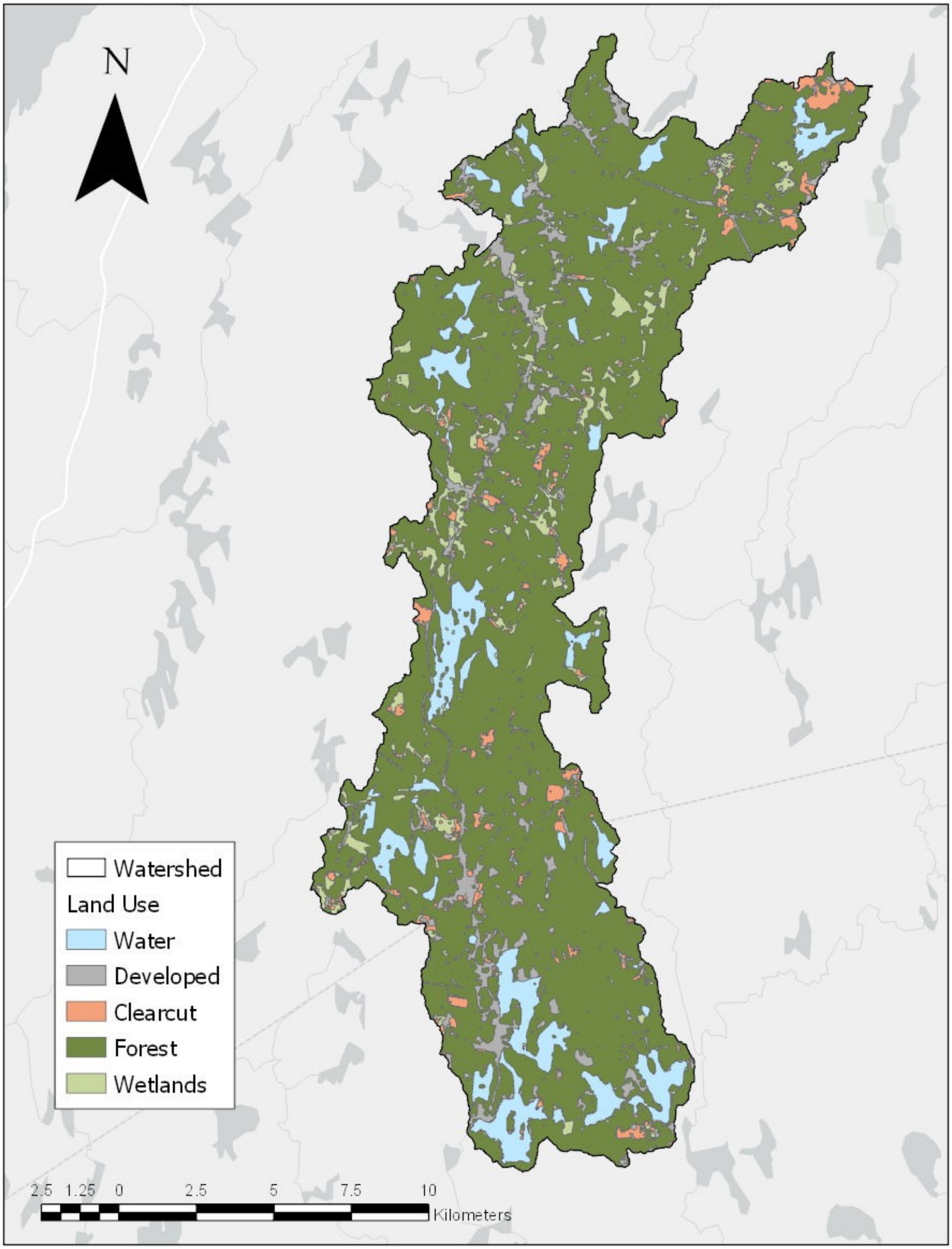

Figure 58: Land use classification in Ogden Lake watershed in 2008

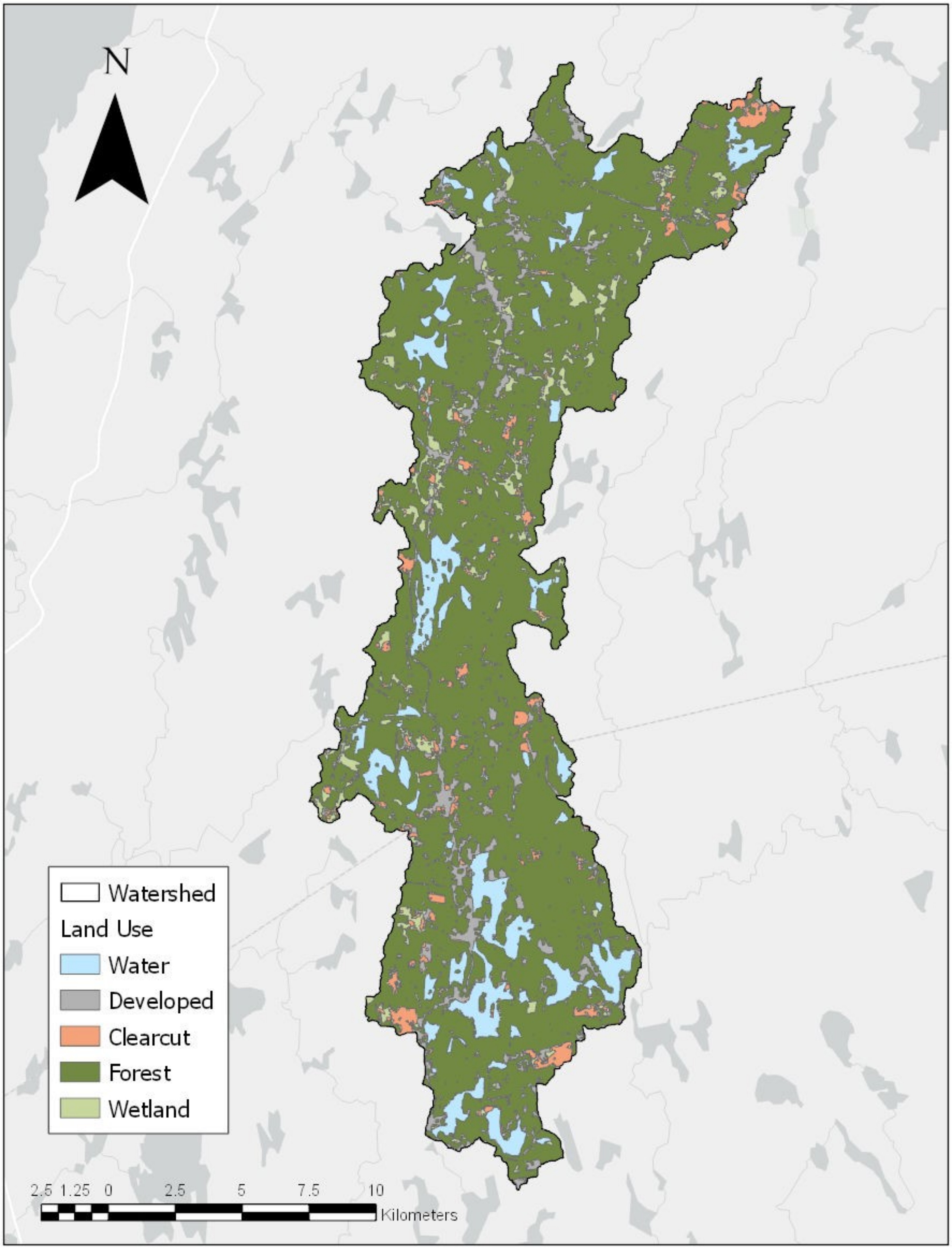

Figure 59: Land use classification in Fanning Lake watershed in 2008

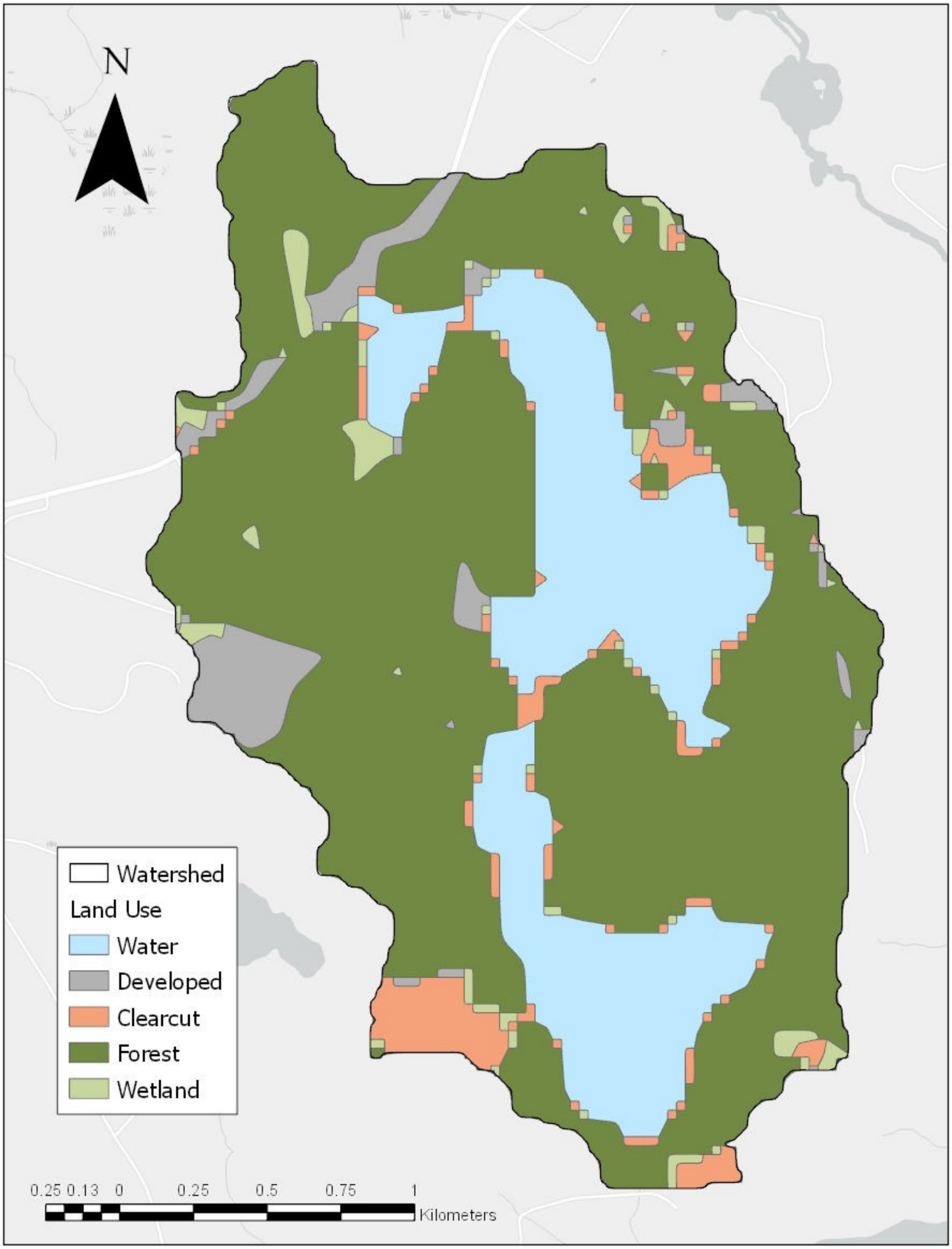

Figure 60: Land use classification in Sloans Lake watershed in 2008

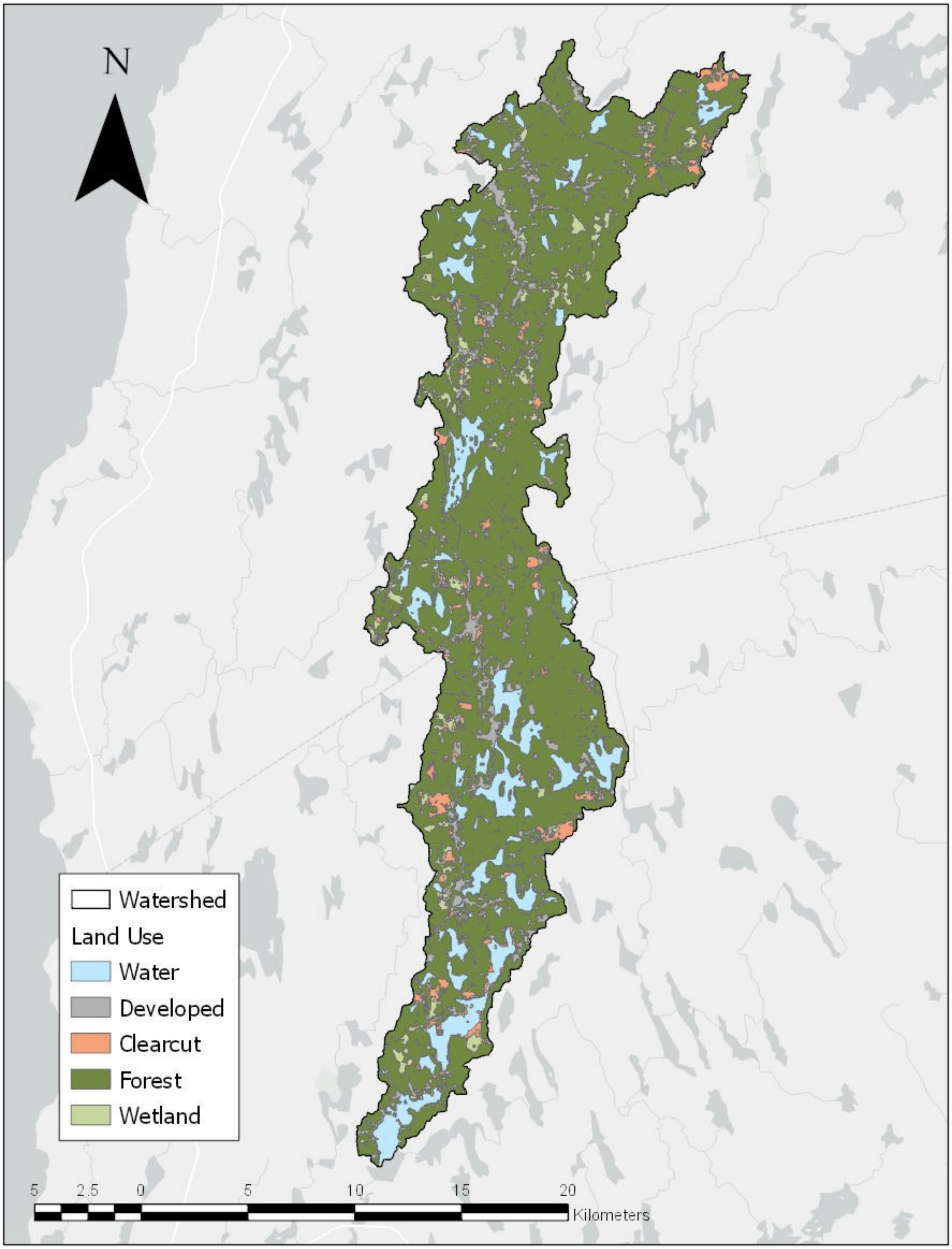

Figure 61: Land use classification in Vaughan Lake watershed in 2008

APPENDIX G: LAND USE MAPS – 1983

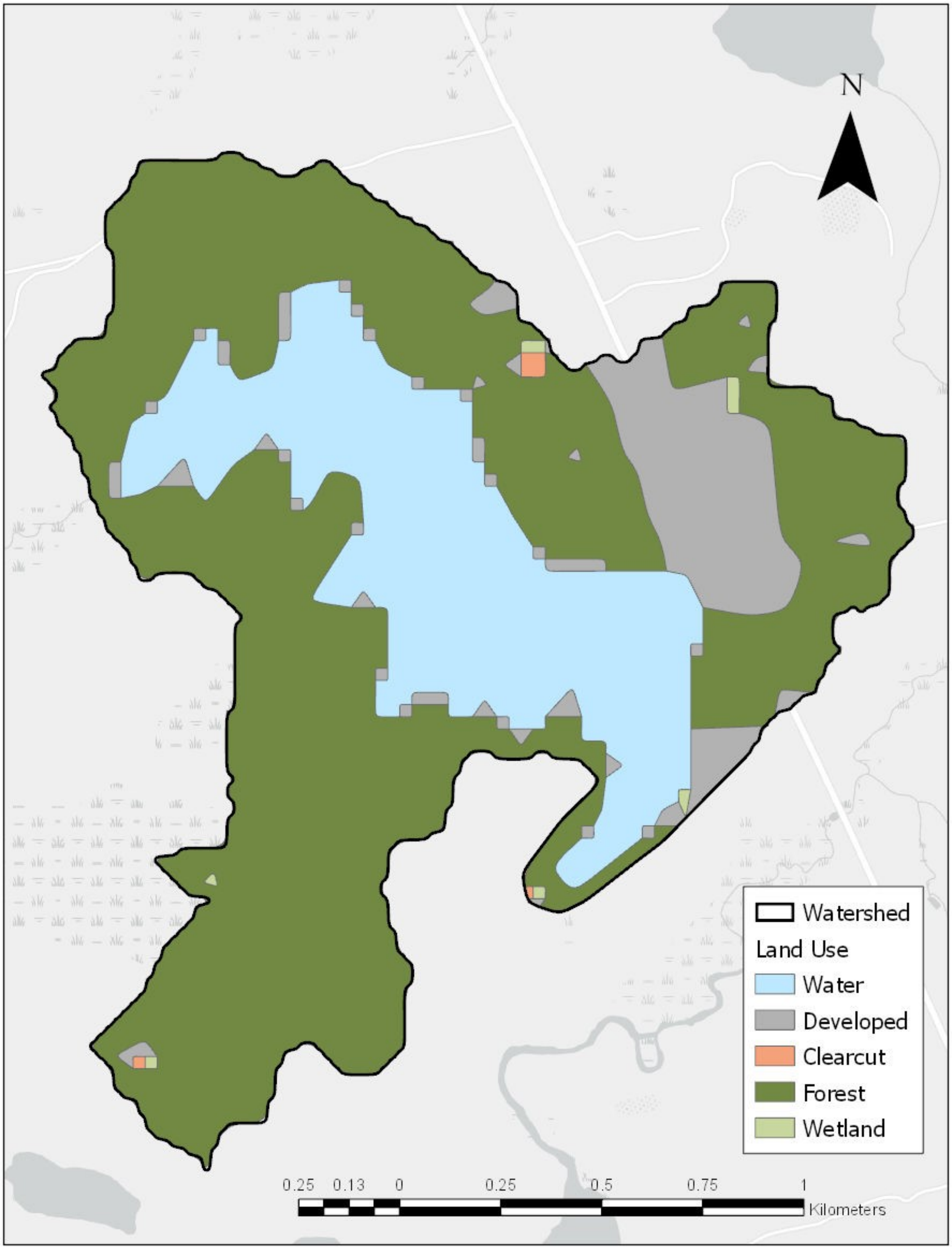

Figure 62: Land use classification in Nowlans Lake watershed in 1983

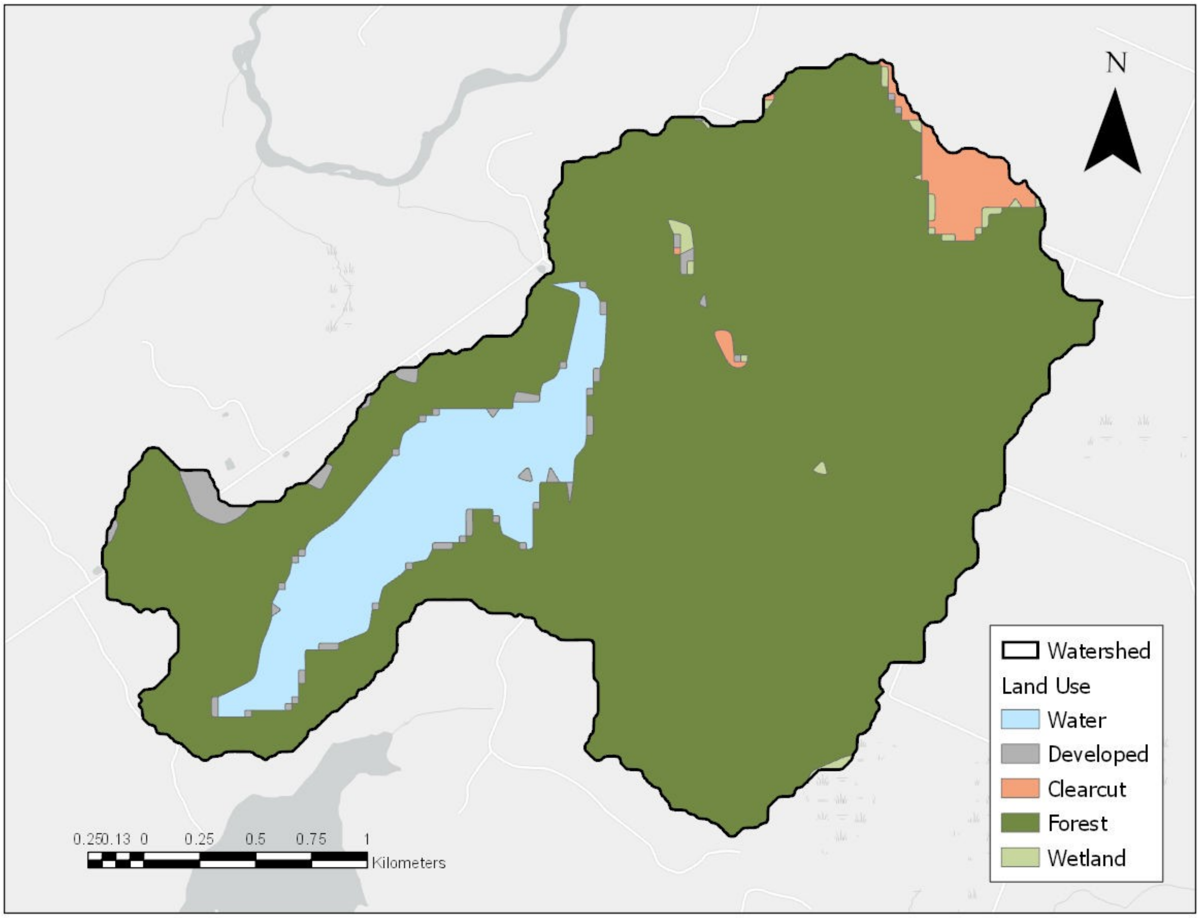

Figure 63: Land use classification in Provost Lake watershed in 1983

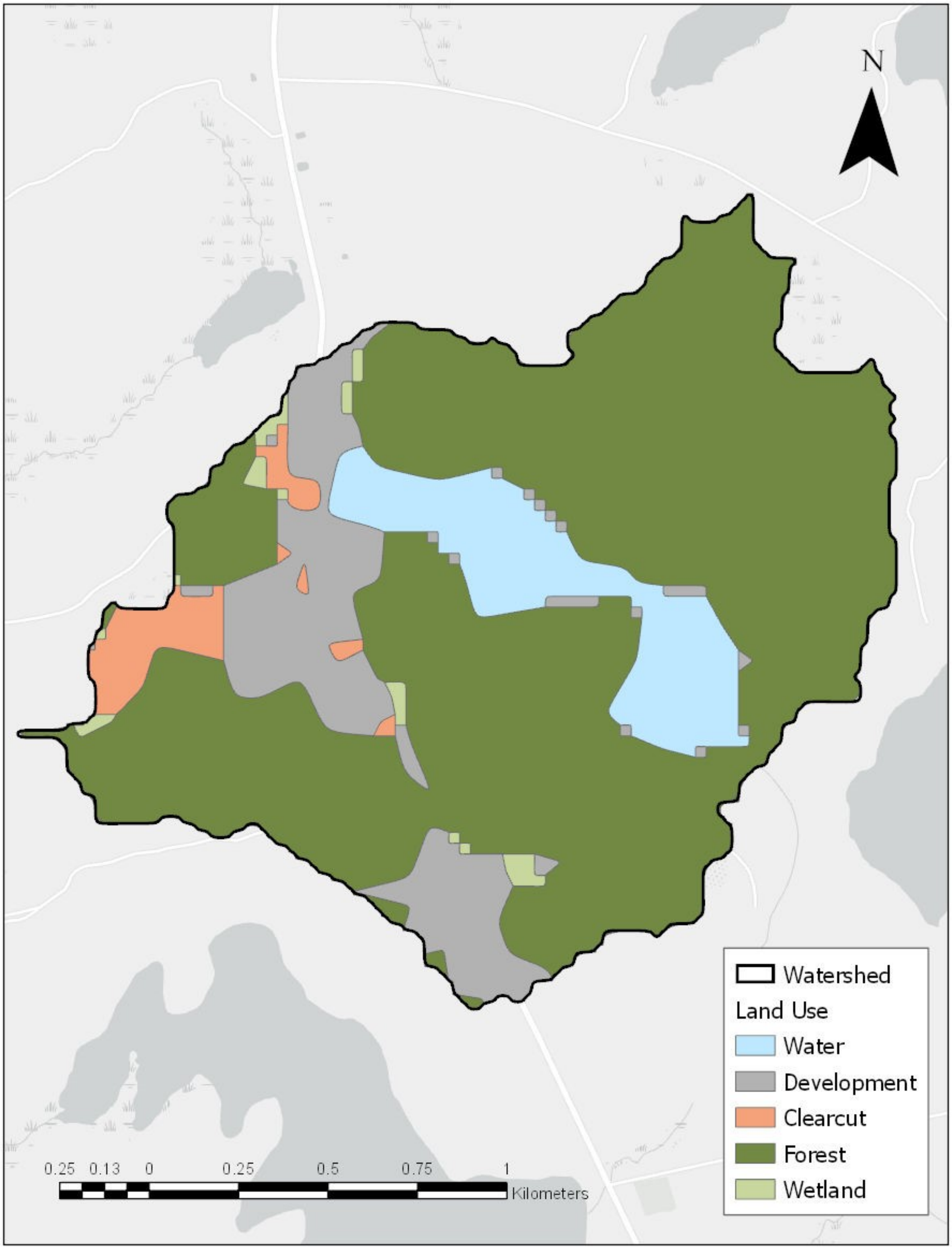

Figure 64: Land use classification in Hourglass Lake watershed in 1983

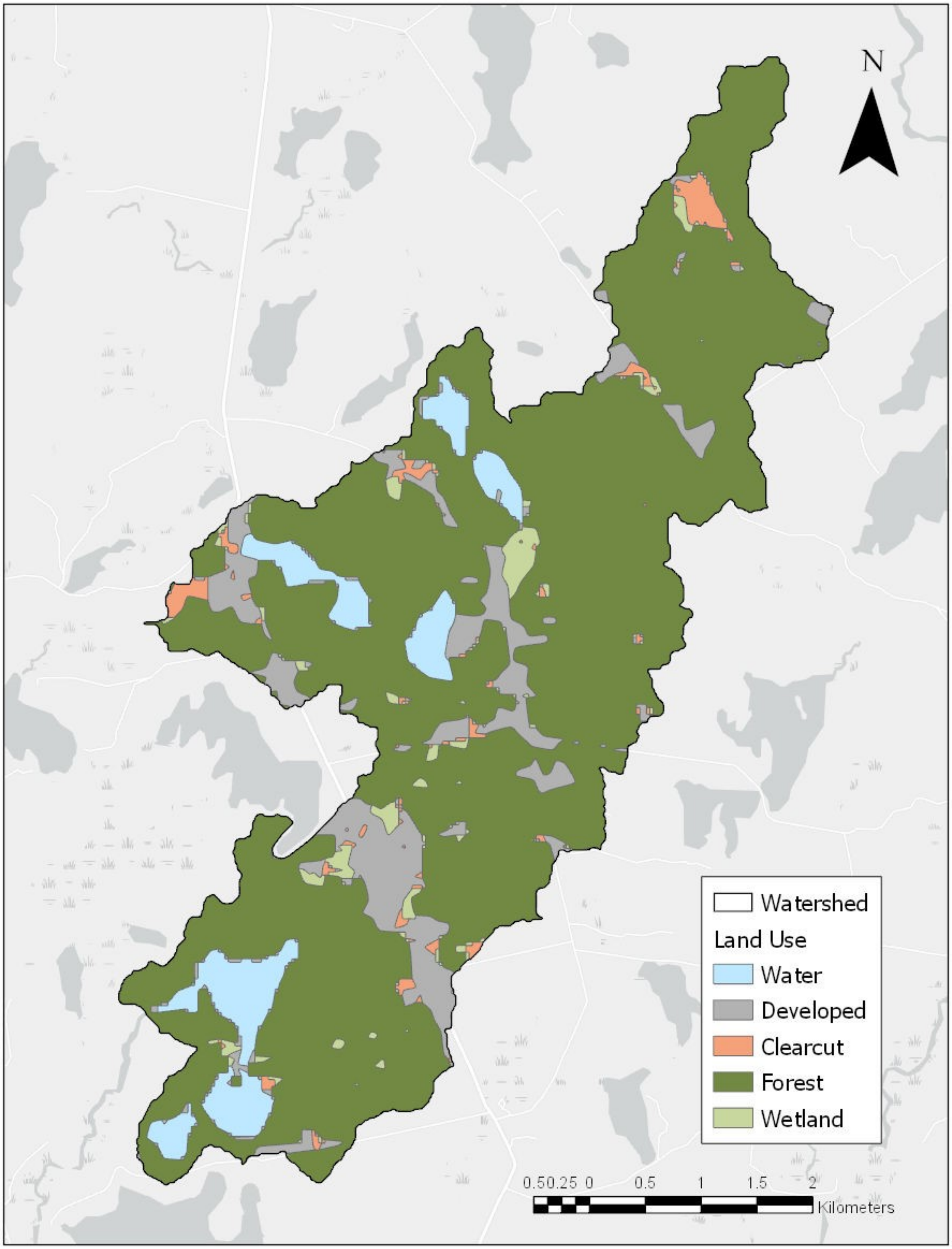

Figure 65: Land use classification of Placides Lake watershed in 1983

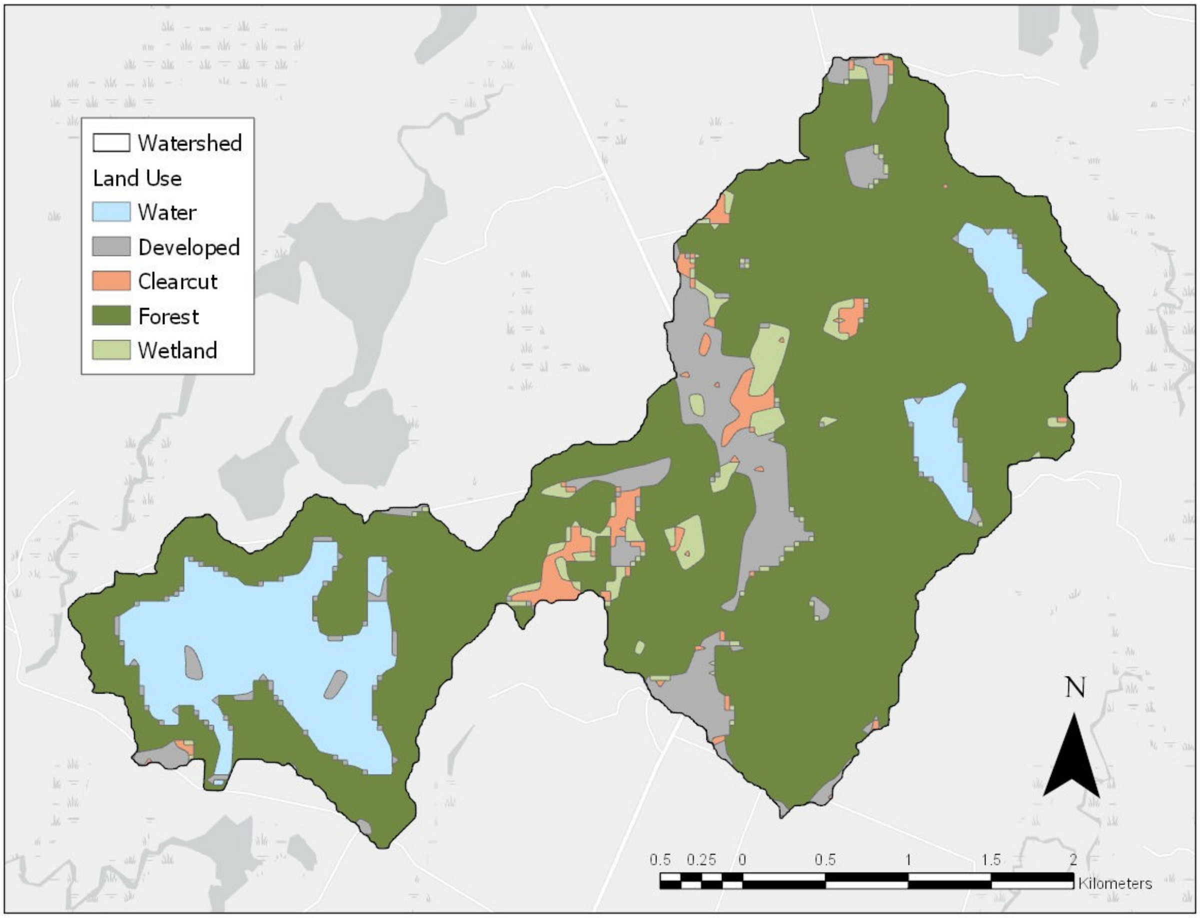

Figure 66: Land use classification of Porcupine Lake watershed in 1983

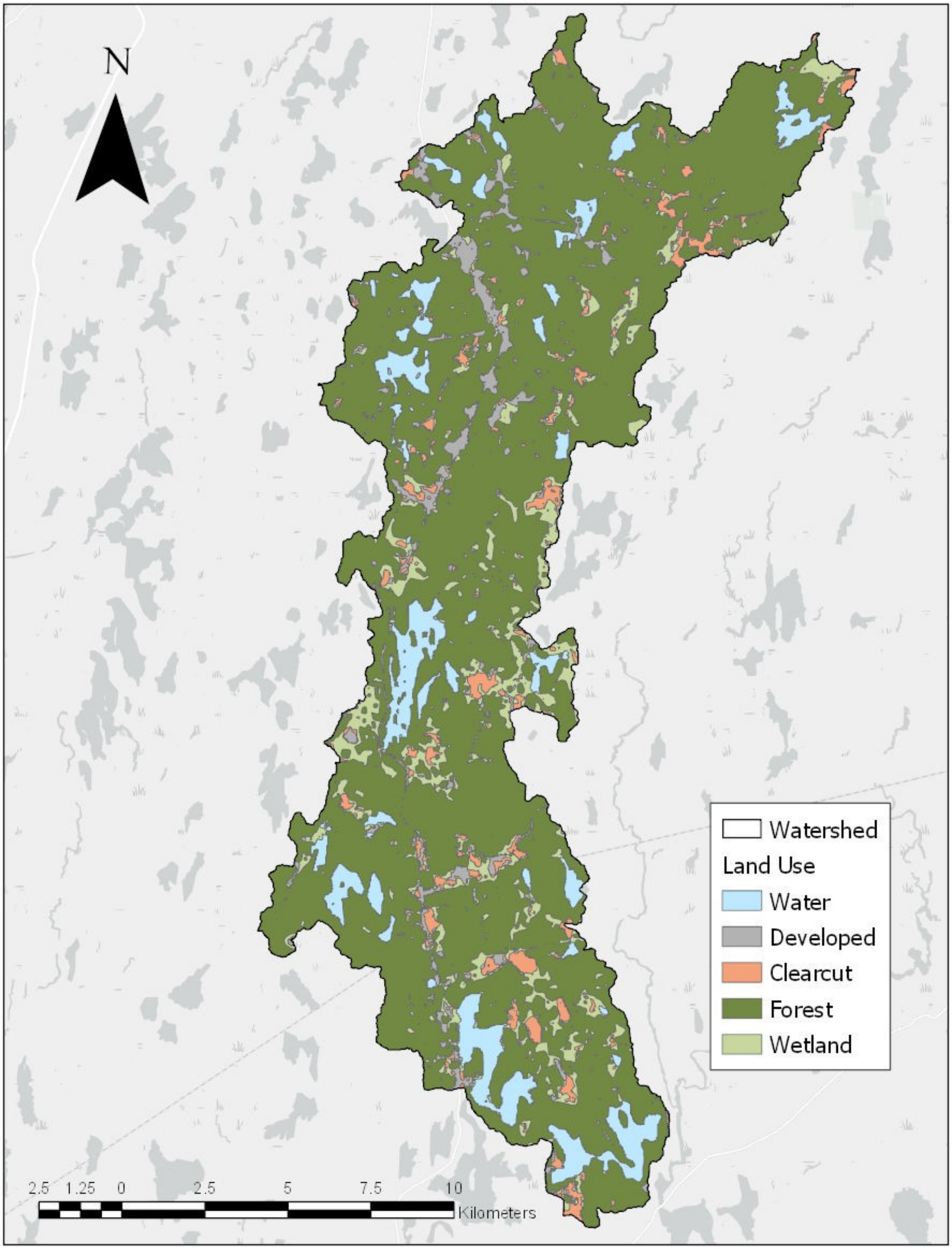

Figure 67: Land use classification in Parr Lake watershed in 1983

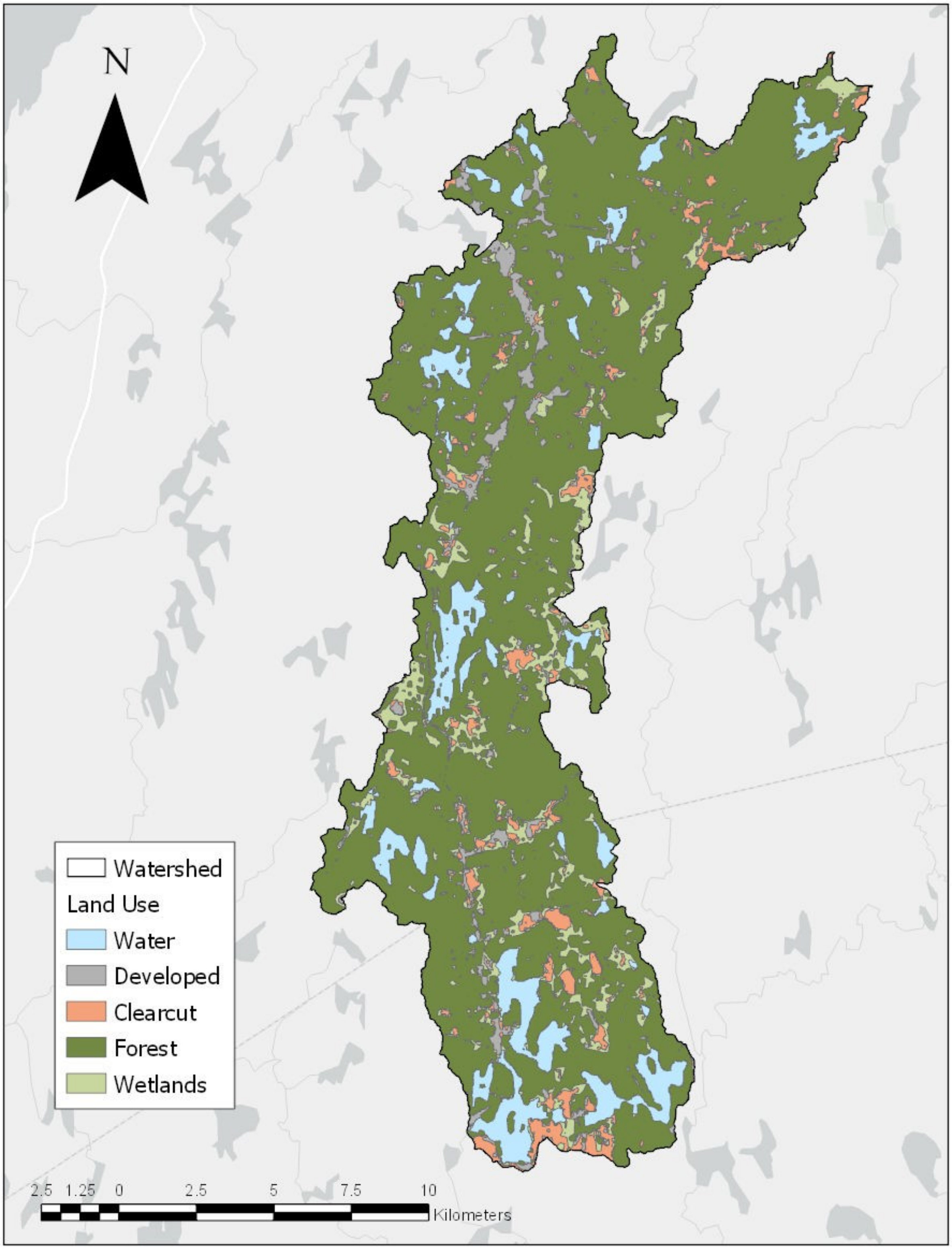

Figure 68: Land use classification in Ogden Lake watershed in 1983

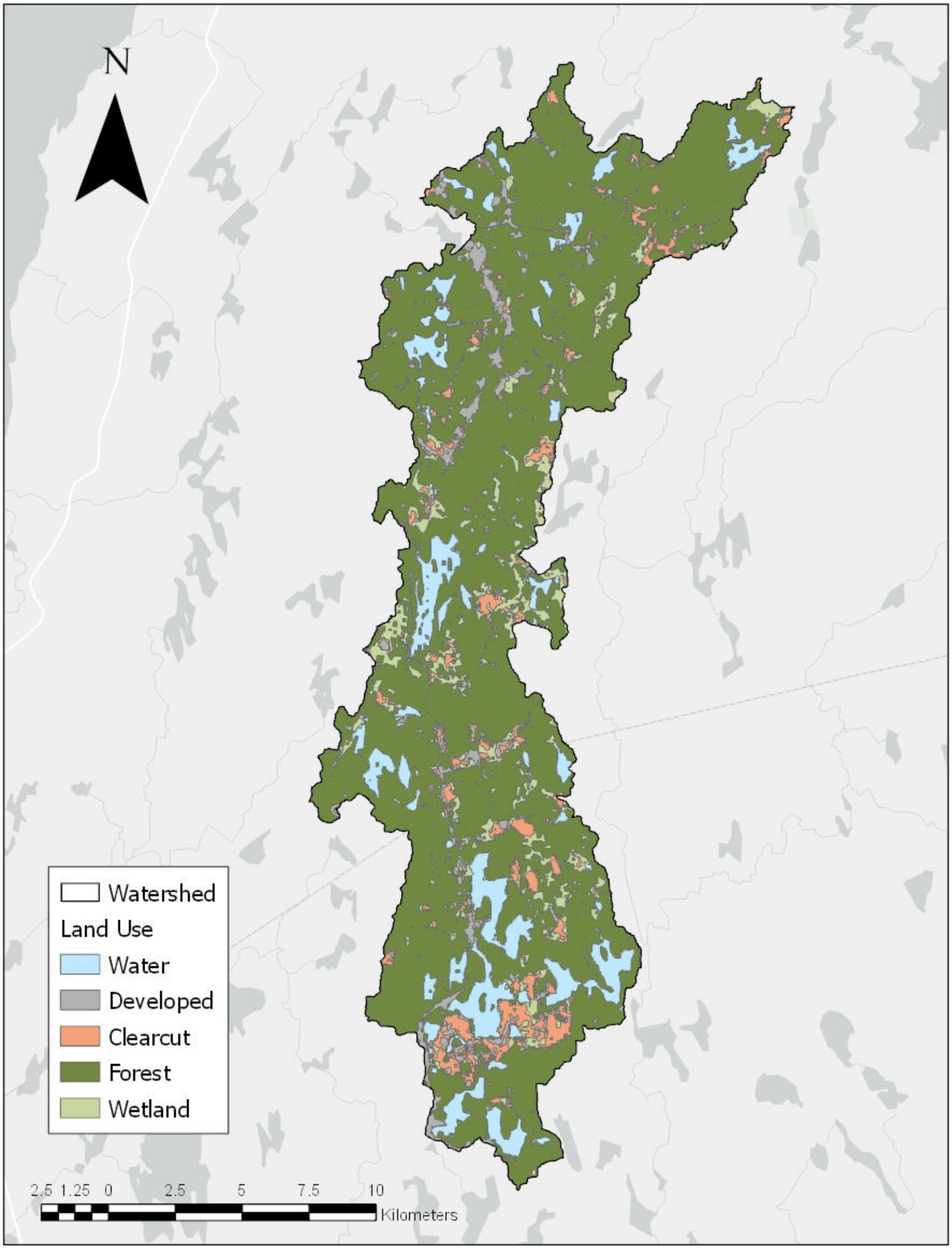

Figure 69: Land use classification in Fanning Lake watershed in 1983

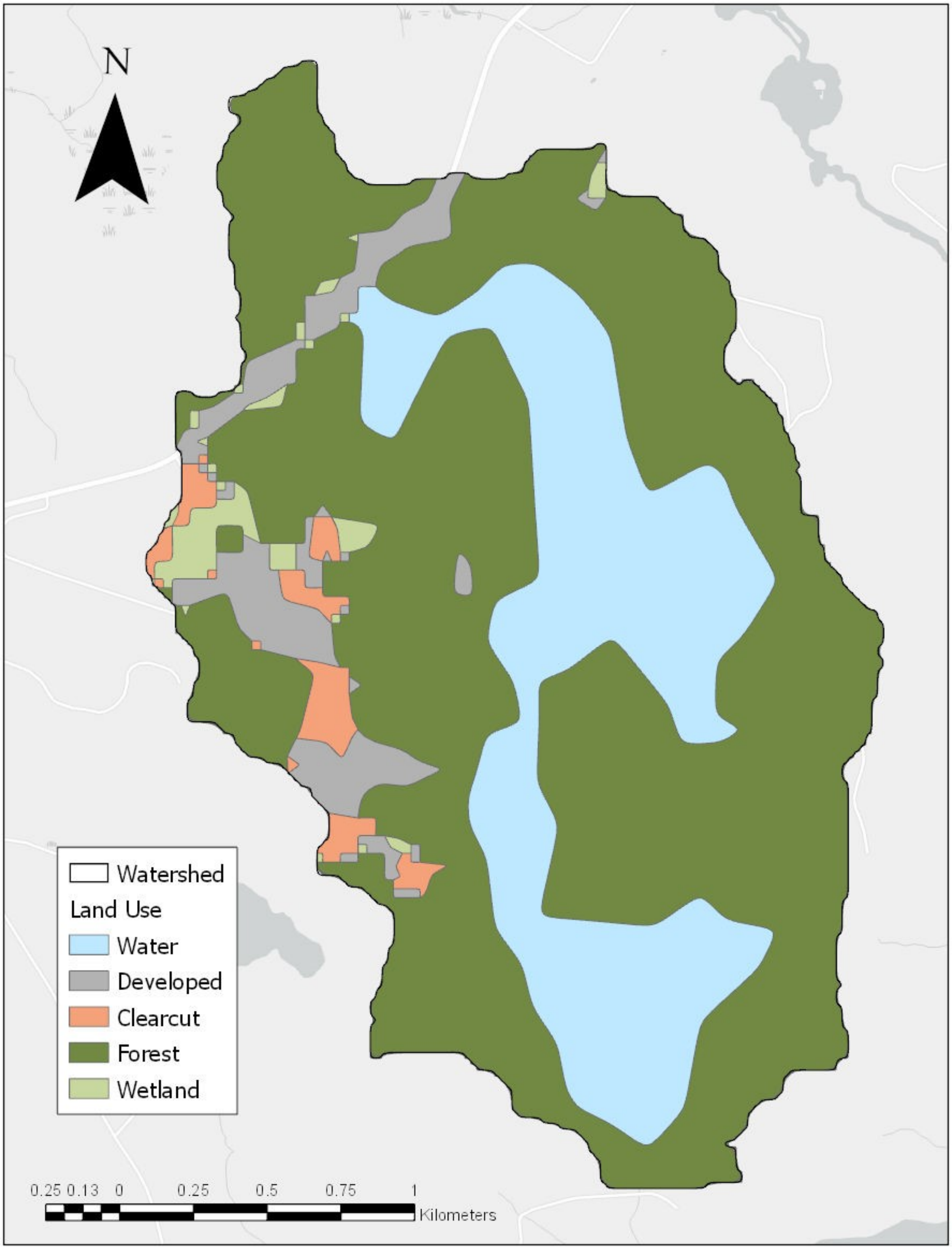

Figure 70: Land use classification in Sloans Lake watershed in 1983

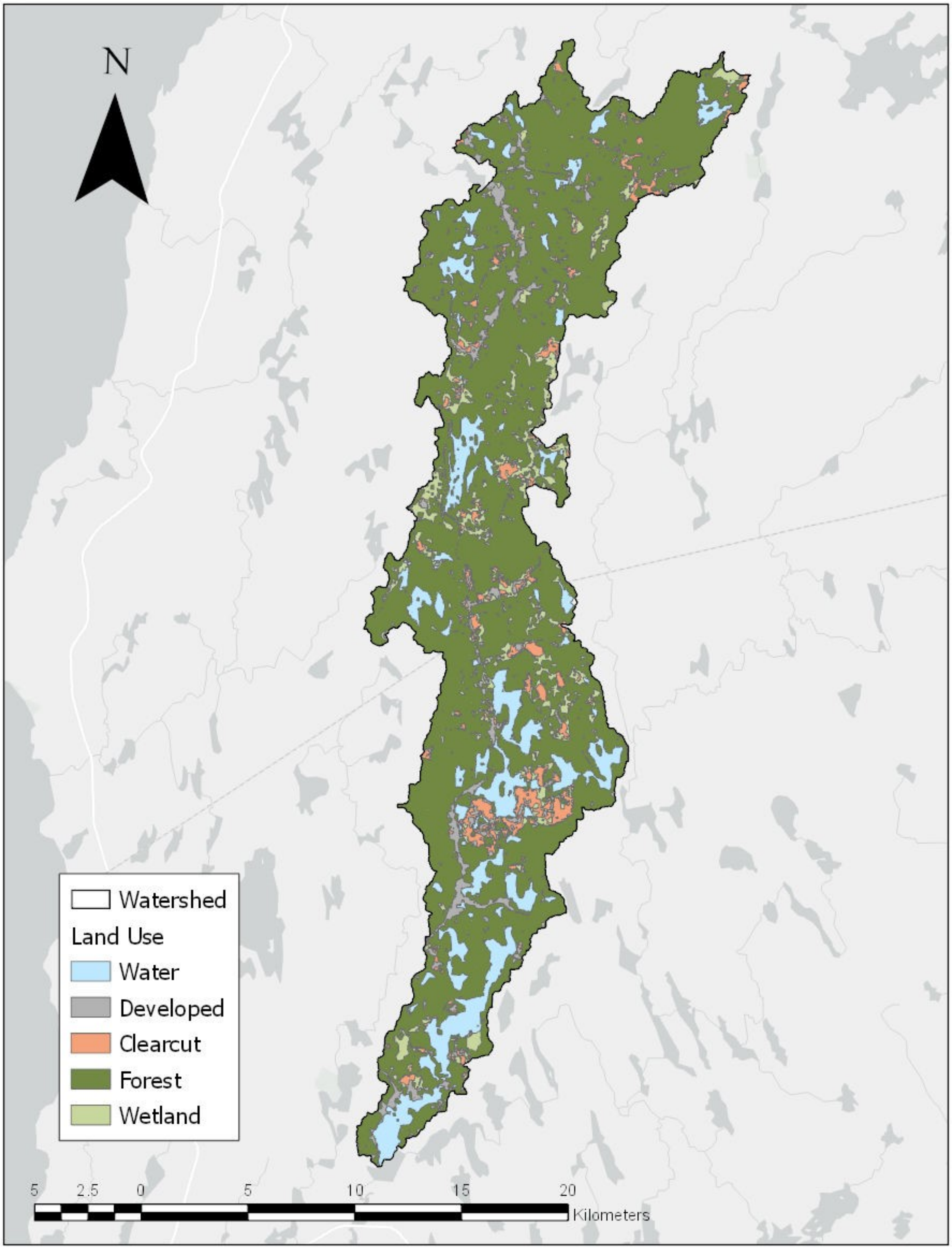

Figure 71: Land use classification in Vaughan Lake watershed in 1983