Pigeon Lake State of the Watershed Report

Prepared for:

Pigeon Lake Watershed Association

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Executive Summary

Pigeon Lake, located about 80 km southwest of Edmonton in the Counties of Wetaskiwin and Leduc, is one of the largest and most popular recreational lakes in Alberta. There are two provincial parks around the lake along with many campgrounds; day use and cottage use around the lake is heavy.

Pigeon Lake has a small drainage area, receiving water via several intermittent streams in the north and northwest of the lake and draining via Pigeon Lake Creek in the south of the lake into the Battle River. Water levels are relatively stable and the water residence time is very long. The lake is characterized by well-buffered, alkaline water that has relatively stable temperature and dissolved oxygen profiles throughout the water column. It is considered moderately productive (mesotrophic) to mildly overproductive (eutrophic), receiving the majority of its external nutrients from landuse activities in its vicinity. Lake sediments consist primarily of clay and silt with abundant concentrations of iron, aluminum, and calcium. The intensity of commercial and sport fisheries has increased since the 1960s, which has threatened primarily walleye, pike, and whitefish fisheries. Despite stocking efforts, most commercial and sport fish species remain either vulnerable or are on the verge of collapse. The pressure on fish populations is exacerbated by extensive shoreline modifications, which have resulted in the widespread destruction of crucial fish spawning, feeding, and rearing young habitat.

Recently, local residents and visitors raised concerns about the water quality in the Pigeon Lake in response to re-occurring toxic algal blooms. The primary factors contributing to the decline in water quality include agricultural and residential developments, which have likely led to excessive nutrient inputs, particularly phosphorus, into Pigeon Lake. Phosphorus loading (eutrophication) into aquatic ecosystems is the major cause of toxic algal blooms, which have been shown to significantly reduce water quality and negatively impact fish, waterfowl and waterbird, invertebrate, and plant habitat. Current phosphorus concentrations in Pigeon Lake are not unusual for lakes in Alberta, and water quality analyses have not shown fecal coliform counts to be elevated above Health Canada or Canadian Council of the Ministers of Environment (CCME) recreation guidelines. Nonetheless, decreasing aesthetic appeal of discoloured lake water and potentially harmful effects of the algal blooms have precipitated the need for the initiation of the watershed management planning process for Pigeon Lake.

The purpose of this report is to synthesize current environmental information for the Pigeon Lake watershed. This report will be used for the development of a comprehensive watershed management plan for Pigeon Lake and can be utilized in any future Battle River watershed management plans.

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1.0 Introduction

1.1 Purpose of Report

Pigeon Lake is one of the largest and most popular recreational lakes in Alberta. It is located about 80 km southwest of Edmonton in the Counties of Wetaskiwin and Leduc. Presently it is one of the most heavily used recreational lakes in Alberta. Due to the intense development in the watershed and recent algal blooms, concerns over water quality have been raised by residents and visitors.

The purpose of this report is to summarize available current and historic information on the Pigeon Lake watershed. This report will provide a benchmark against which the effectiveness of future stewardship activities and best management practices aimed at improving watershed health can be assessed. It will provide landowners, stakeholders, municipalities and stewardship groups the information needed to make sound management decisions aimed at implementing beneficial management practices and developing possible solutions to protect and/or enhance their land and water resources. Lastly, this report prioritizes the issues that need to be addressed and makes recommendations toward the development of strategies to address those issues and opportunities.

1.2 Scope of Report

This report provides information on the watershed, lake water quality/quantity, land-use and the potential effects of resource and land-use practices. Each section of this report is intended to provide and summarize known social, physical and environmental information. The report begins by summarizing public perceptions and concerns regarding the status of the watershed and then considers the physical aspects of the entire watershed, first at a broad scale and then on specific land and water resources. The report also identifies the jurisdictions of the various Federal, Provincial and Municipal regulators in an effort to decipher roles and mandates. The report then outlines how state of the basin reporting fits into the greater context of watershed management planning in Alberta under Alberta Environment's Water Strategy: *Water for Life* and identifies legislation and policies affecting watershed management in Alberta. A special emphasis has been placed upon the role of this document in future planning in the Pigeon Lake watershed.

2.0 Public Perception and Concerns

The major concerns for Pigeon Lake are:

- Toxic algal blooms in recent summers (2006, 2007);
- Perception of declining fish stocks;
- Higher density real estate development; and
- Oil and gas activities in the watershed.

The first three issues are related in that increased shoreline development in the past has resulted in the removal of riparian marshes, which have the capacity to remove excess nutrients directly from lake water or from seepage from sewage lagoons into the lake. Of particular concern are phosphorus levels in the lake, because phosphorus is generally the limiting nutrient in aquatic ecosystems, and increased loading rates of this nutrient often results in algal blooms. These algal blooms significantly reduce water quality by increasing animal and human toxins and irritants in the water, decreasing the aesthetic appeal of the lake and negatively impacting habitat for aquatic organisms, such as fish.

3.0 Institutional and Regulatory Authorities

This section provides a regulatory overview of the main legislation that impacts lakes and surface water bodies in Alberta.

3.1 Federal Government

The *Canadian Environmental Protection Act* (CEPA) is the main federal law to protect the environment. With respect to water resources, CEPA empowers the federal government to create and enforce regulations regarding toxic substances, fuels and nutrients in lakes and surface water bodies. CEPA enables the federal government to undertake environmental research, develop guidelines and codes of practice and conclude agreements with provinces and territories. Environment Canada administers CEPA but assesses and manages the risk of toxic substances jointly with Health Canada.

Fisheries and Oceans Canada has the authority to protect fish and fish habitat under the guidelines of the *Fisheries Act* and the *Species at Risk Act*. Fish habitat by definition includes spawning grounds and nurseries, rearing, food supply and migration areas on which fish depend to carry out their life processes (Fisheries Act, 1985). It is their mandate to preserve healthy marine and freshwater aquatic ecosystems in support of scientific, ecological, social and economic interests. The *Fisheries Act* prohibits any activity that results in the harmful alteration, disruption or destruction of fish habitat, protects fish populations from pollution and recommends mitigation measures where loss of habitat is unavoidable. Work carried out near a fish-bearing watercourse must have the approval of Fisheries and Oceans Canada. Failure to comply with the Act may result in fines or imprisonment.

3.2 Provincial Government

The Government of Alberta is committed to sustainable development through an integrated resource management (IRM) approach to protect the environment and manage Alberta's resources (Alberta Environment, 2002). IRM requires a comprehensive, interdisciplinary approach to the management of water, timber, air, public land, fish, wildlife, range, oil, gas and mineral resources. The Alberta Government recently initiated a province-wide comprehensive strategy called *Water for Life: Alberta's Strategy for Sustainability*. The purpose of the Strategy is to identify short-, medium- and long-term plans to manage effectively the quantity and quality of the province's water systems and supply. The three main goals of the strategy are to ensure that Albertans have a safe and secure drinking water supply, healthy aquatic ecosystems and reliable and high- quality water supplies for a sustainable economy (Alberta Environment, 2003). The provincial government uses both the *Water Act* and the *Environmental Protection and Enhancement Act* (EPEA) to enforce regulations regarding the preservation of Alberta's water supplies.

The *Water Act* supports the conservation and management of water and allows for regional differences in water management to be reflected through the development of water management plans, as outlined in the *Framework for Water Management Planning* released in 2002. The EPEA is intended to support and promote the protection, enhancement and sustainable use of all aspects of the environment, from land to water. It covers conservation, reclamation, pesticide use, waste control and wastewater and storm drainage.

Other provincial acts that can be utilized to protect Alberta's water resources include the *Agricultural Operations Practices Act* (AOPA), *Safety Codes Act* (Municipal Affairs), *Regional Health Authorities Act*, *Wildlife Act* (Sustainable Resource Development (SRD)), *Public Lands Act* (SRD), *Provincial Parks Act*; *Wilderness Areas, Ecological Reserve, Natural Areas and Heritage Rangelands Act* and policies such as the Wetlands Policy (SRD). Brief descriptions of these acts are provided in Table 1.

- AOPA provides guidelines and regulations regarding environmental management in livestock operations. It allows the province to manage issues, including manure runoff, odour, noise, dust, smoke or other disturbances, resulting from an agricultural operation, and it provides clear manure management standards.

- The *Safety Codes Act* applies to the construction, installation and maintenance of septic systems. It ensures that septic systems follow minimum engineering standards for manufacture and installation, and that their integrity is preserved through regular maintenance. Leaking septic systems are a concern throughout the province. In particular, private septic systems in lakeside properties and recreational sites can cause contamination of groundwater and surface water bodies.

- The *Regional Health Authorities Act* ensures the preservation of the health and safety of Albertans. It can be used in conjunction with the *Safety Codes Act* to ensure water resources are kept free of sewage contamination.

- Alberta Sustainable Resource Development is responsible for enforcing many acts, which are designed to protect aquatic resources. These acts include the *Wildlife Act*, which governs the management of wildlife as a Crown resource, enables the hunting and trapping of wildlife, and addresses the conservation of species at risk (endangered, threatened). The *Public Lands Act* deals with the selling and transferring of public land, riparian rights, access to bed and shores and environmental reserves, as well as the management of rangeland and activities permitted on designated land.

- The *Provincial Parks Act* and the *Wilderness Areas, Ecological Reserve, Natural Areas and Heritage Rangelands Act* ensure the preservation and conservation of natural areas as parks or reserves. These acts prohibit development and limit access to protected areas to preserve their natural state and ecological integrity.

- The Wetlands Policy was developed in 1990 by Alberta Environment and is currently under review. The original policy examines mainly preservation of wetlands in settled areas (white zone) and recommends a "No Net Loss" policy for wetlands.

Current and past land use plans, guiding documents and bylaws enacted for the Pigeon Lake watershed are summarized in Table 1.

Table 1. Legislation and policy involving water and watershed management.

Legislation/Policy	Description
Federal *Fisheries Act* – Department of Fisheries and Oceans Canada (DFO)	Regulates and enforces on harmful alteration, disruption and destruction of fish habitat in Section 35. Section 33 deals with the deposition of deleterious materials in fish bearing waters (Environment Canada is responsible for the enforcement of Section 33).
Provincial *Water Act* – Alberta Environment (AENV)	Governs the diversion, allocation and use of water. Regulates and enforces actions that affect water and water use management, the aquatic environment, fish habitat protection practices and in-stream construction practices.
Provincial *Environmental Protection and Enhancement Act (EPEA)* – AENV	Management of storm water, contaminated sites, storage tanks, landfill management practices, hazardous waste management practices and enforcement.
Provincial *Agricultural Operations Practices Act* (AOPA) – Natural Resources Conservation Board (NRCB)	Regulates and enforces on confined feedlot operation and environment standards for livestock operations.
Provincial *Municipal Government Act* (MGA) – Municipal Affairs	Provides municipalities with authorities to regulate water on municipal lands, management of private land to control non-point sources, and authority to ensure that land use practices are compatible with the protection of aquatic environment. Allows municipalities to take Environmental Reserves during subdivision approval (Section 664).
Provincial *Public Lands Act* – Sustainable Resource Development (SRD)	Regulates and enforces on activities that affect Crown-owned beds and shores of water bodies and some Crown-owned uplands that may affect nearby water bodies.
Provincial *Safety Codes Act* – Municipal Affairs	Regulates and enforces septic system management practices, including installation of septic field and other subsurface disposal systems.
Regional Health Authorities Act – Alberta Health	RHA have the mandate to promote and protect the health of the population in the region and may respond to concerns that may adversely affect surface and groundwater.
Wildlife Act – SRD	Regulates and enforces on protection of wetland-dependent and wetland-associated wildlife, and endangered species (including plants).
Provincial Parks Act & Wilderness Areas, Ecological Reserve and Natural Areas Act – SRD and Community Development	Both Acts can be used to minimize the harmful effects of land use activities on water quality and aquatic resources in and adjacent to parks and other protected areas.
Provincial Wetlands Policy	This policy will be used to protect wetlands and mitigate losses through a "No Net Loss" policy. The new Provincial Wetlands Policy is slated for release in 2008.
Land Use Bylaws (Municipal)	The bylaw that divides the municipality into land use districts and establishes procedures for processing and deciding upon development applications. It sets out rules that affect how each parcel of land can be used and developed and includes a zoning map.
Area Structure Plans (Municipal)	Adopted by Council as a bylaw pursuant to the *Municipal Government Act* that provides a framework for future subdivisions, development, and other land use practices of an area, usually surrounding a lake.
Municipal Development Plans	The plan adopted by Council as a municipal development plan pursuant to the *Municipal Government Act*.

3.3 Municipal Governments

The following guiding documents can be used by municipalities to protect and maintain watershed health and integrity:

- The *Municipal Government Act* (MGA) provides municipalities with authorities to regulate the management of private land to control non-point sources. It also provides municipalities with the authority to enact bylaws and municipal land use to ensure that land use practices are compatible with the protection of aquatic environment.

- Land Use Bylaws divide municipalities into land use districts and establish procedures to process and evaluate development applications. It sets out rules that affect how each parcel of land can be used and developed and includes a zoning map.

- An Area Structure Plan or Land Use Plan is a plan adopted by Council as an area structure plan bylaw pursuant to the *Municipal Government Act* that provides a framework for future subdivisions and development of an area.

- A Municipal Development Plan is a plan adopted by Council as a municipal development plan pursuant to the Municipal Government Act. It is a policy document that clearly states how land will be used and how future developments will be zoned.

4.0 History

Pigeon Lake was previously known was Woodpecker Lake, which is a translation from the Cree name *Hmi-hmoo* (Mitchell and Prepas, 1990). The name was changed to Pigeon Lake in 1858, likely due to the flocks of Passenger Pigeons in the vicinity of the lake (Mitchell and Prepas, 1990).

In the mid-19th century, Pigeon Lake was a gathering place for First Nations peoples and the missionaries who were attempting to convert them to Christianity. In 1847, Reverend Robert Rundle received permission to establish a mission on Pigeon Lake from the Hudson's Bay Co. and the Wesleyan Missionary Society. After initially focusing on the Assiniboine, Rundle subsequently focused on the Cree by translating hymns and biblical scriptures into written and spoken Cree. At the time, there was also a Hudson's Bay Co. post at the lake, as well as a number of agricultural enterprises fostered by the mission; however, Rundle did not view his role as that of a "company man" or government representative. Instead, he sought to help the Aboriginal people around him survive in the face of incoming European settlement. When the Hudson's Bay Co. pressured him to establish further mission schools, he spent some time looking for an appropriate site, but intentionally did not establish any.

In 1965, Rundle's Mission was dedicated as a National Historic Monument. Rundle’s Mission is now held by the Government of Alberta and managed by the non-profit Rundle Mission Society.

4.1 Watershed Characteristics

The Pigeon Lake watershed is part of the Battle River Watershed located in the North Saskatchewan River Basin (Figure 1). It has a drainage area of 187 km^2 (Mitchell and Prepas, 1990). The region is part of the Dry Mixedwood Subregion of the Boreal Mixedwood Ecoregion and is dominated by trembling aspen (*Populus tremuloides* Michx.), white spruce (*Picea glauca* (Moench) Voss) and balsam poplar (*Populus balsamifera* L.) (Mitchell and Prepas, 1990). The topography of the drainage basin is level to gently rolling. The soils are predominantly orthic grey luvisols (Mitchell and Prepas, 1990).

Pigeon Lake has a surface area of 96.7 km^2 (Table 1), which represents about 52% of the drainage area. The lake has a mean depth of 6.2 m and a maximum depth of 9.1 m (Table 1). A detailed bathymetry map is shown in Figure 2. A study of 30 Alberta lakes showed that lakes with large drainage areas compared to lake area generally have more algal growth than lakes with smaller drainage basins (Alberta Environment, 1989); however, Pigeon Lake, with its relatively small drainage area, has a large amount of algae growth. This suggests that the lake is exposed to elevated nutrient concentrations from the surrounding landscape.

Table 2. Physical parameters of Pigeon Lake (Mitchell and Prepas, 1990).

Variable	Value
Elevation (m) [a]	849.48
Surface Area (km^2) [a]	96.7
Volume (m^3) [a]	603×10^6
Maximum depth (m) [a]	9.1
Mean depth (m) [a]	6.2
Shoreline length (km) [b]	46
Mean annual lake evaporation (mm)	664
Mean annual precipitation (mm)	534
Mean annual inflow (m^3) [c]	17.0×10^6
Mean residence time (yr) [c]	>100
Sill elevation (m)	849.8

[a] On date of sounding (1961), [b] Energy Mines and Resources Canada (1974) in Mitchell and Prepas (1990), [c] excluding groundwater inflow.

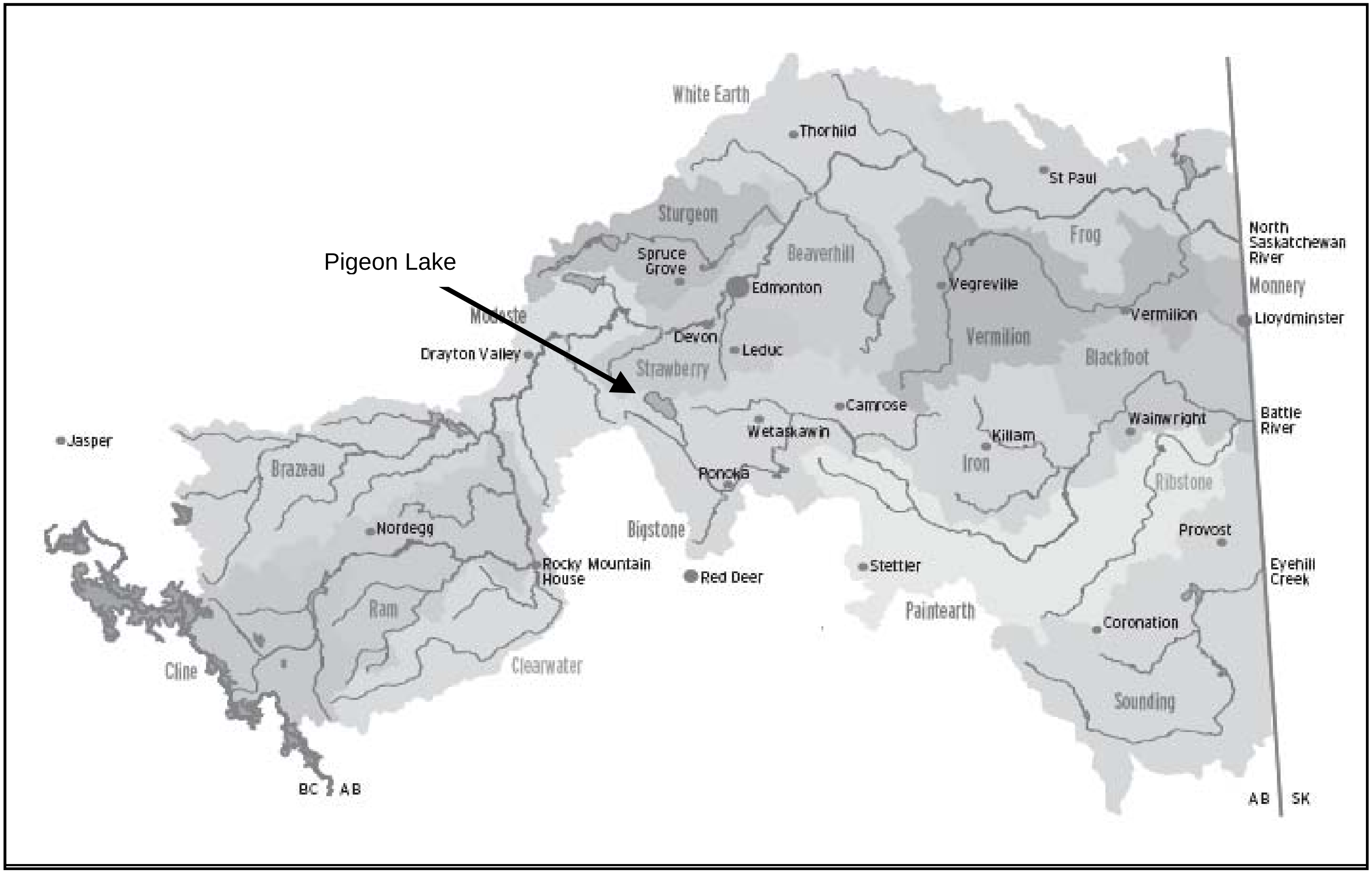

Figure 1. Location of Pigeon Lake in the North Saskatchewan Watershed (North Saskatchewan Watershed Alliance, 2006).

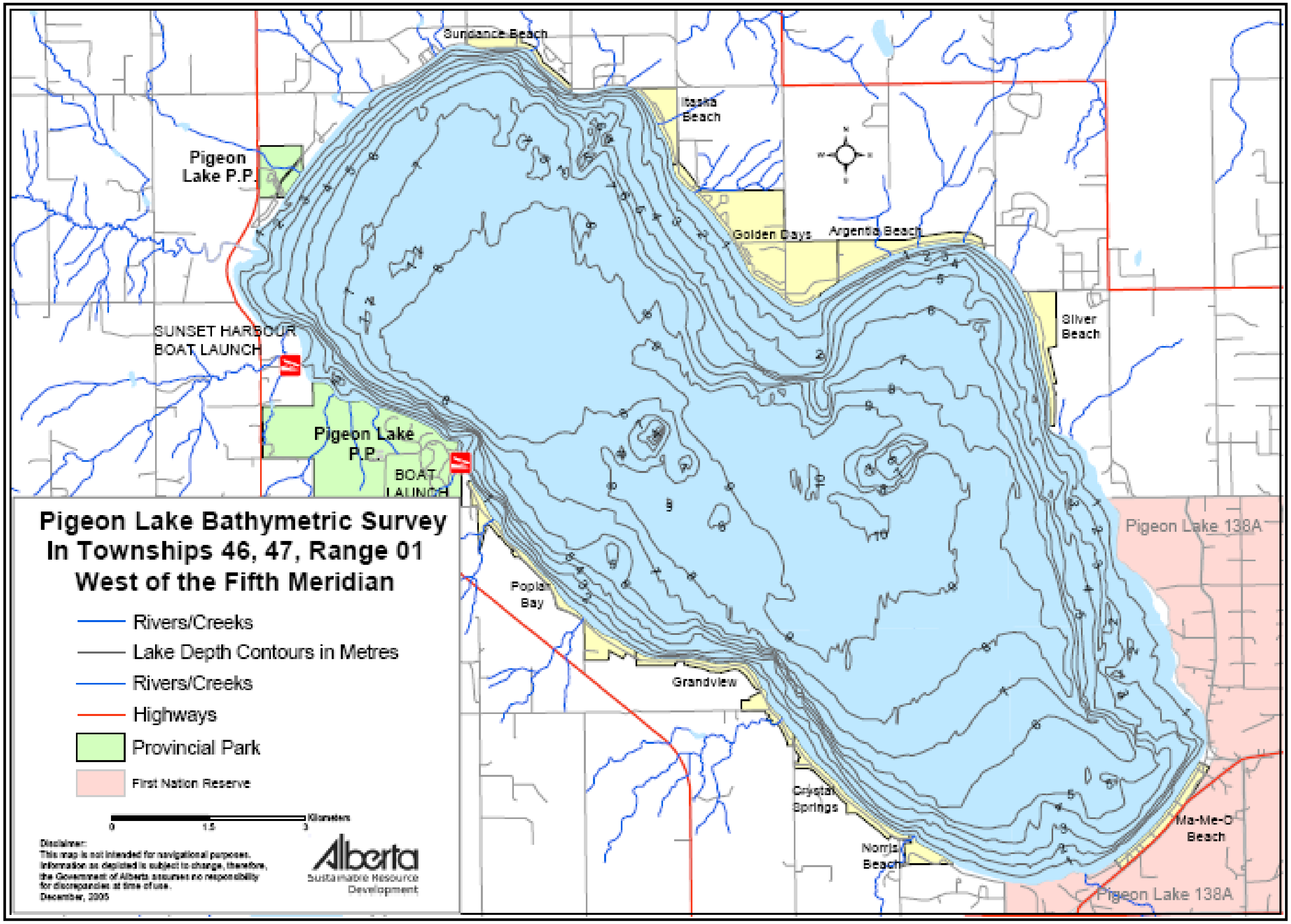

Figure 2. Bathymetry of Pigeon Lake (Alberta Sustainable Resource Development, 2003).

4.2 Climate

In 2006, the mean annual temperature at the nearest weather station (Edmonton International Airport) was 3.3°C, with a mean monthly maximum temperature of 25.4°C (July) and a mean monthly minimum temperature of -15.9°C (November). The area received 338.2 mm of rain and 149.5 cm of snow for a total annual precipitation of 473.5 mm (Environment Canada, 2007). The Climate Normals for 1971-2000 from the nearest weather station (Edmonton International Airport) are shown in Table 3.

Table 3. Climate Normals at the Edmonton International Airport from 1971-2000 (Environment Canada, 2004).

Variables	Value
Mean annual temperature (°C)	2.4
Mean annual maximum temperature (°C)	8.5
Mean annual minimum temperature (°C)	-3.8
Rainfall (mm)	374.8
Snowfall (cm)	121.4
Total Precipitation (mm)	482.7

4.3 Topography, Soils and Geology

The topography of the Pigeon Lake watershed is mostly level to undulating (0-5% slope) and gently rolling (5-9% slope; 80% of the watershed has slope <10%). There are areas of low-lying marshland along the northwest shoreline, while the topography is hillier to the north and northeast (Pigeon Lake Study Group, 1975). Surficial deposits are primarily glacial till that originated from the Paskapoo Formation (Lindsay et al., 1968).

The dominant soils are well drained, orthic and dark grey luvisols of the Benalto and Breton Series that developed on the glacial till. Pockets of poorly drained organic and gleysolic soils are also present, particularly near the lake shore (Alberta Agriculture and Food, 2007). At the southeast end of the lake near Pigeon Lake Creek, well drained orthic dark grey chernozemic soils have developed on alluvial/aeolian material (Mitchell and Prepas, 1990; Alberta Agriculture and Food, 2007).

The soils in the watershed are mainly of Class III and IV, which means they have low fertility (low in nitrogen, phosphorus, sulfur and organic matter) and are limited to fair for irrigation. Thus, these soils have limited agricultural use. Some areas in the watershed have Class VI soils, which are limited for forage crops and are not feasible for improvement practices (Kovats, 1966).

4.4 Hydrology and Lake Levels

Water flows into Pigeon Lake via several intermittent streams that drain the west and northwestern portions of the watershed. In a water balance study developed using data from 1965-1980, it was estimated that land run-off contributed 18 x 10^6 m^3 of water to the lake each year (Evans, 1981). Precipitation was estimated to contribute another 50 x 10^6 m^3 of water annually. Lake evaporation was estimated to be 60 x 10^6 m^3 per year (Evans, 1981). The main outflow for the lake is Pigeon Lake Creek, which flows south into the Battle River. The inferred outflow from the creek is 8 x 10^6 m^3 per year (Northwest Hydraulic Consultants, 1981). Water in Pigeon Lake has a very long residence time (>100 years). Therefore, any unusual inflow simply raises the water level (Pigeon Lake Study Group, 1975). The lake has a mean annual maximum elevation above sea level (a.s.l.) of 850.04 m and a mean annual minimum elevation a.s.l. of 849.76 m (Evans, 1981).

In 1914, a weir was installed on Pigeon Lake Creek to prevent flooding of hay fields downstream. The wooden control structure had a sill level of 850 m a.s.l. (Mitchell and Prepas, 1990). In 1939/40, the structure was rebuilt to a fixed sill level of 849.78 m a.s.l. This structure was often clogged with sand and required frequent cleaning to avoid the accumulation of brush in the channel and maintain water flow out of the lake. From 1965-1972, lake levels rarely rose above the sill, consequently there was no outflow from lake. In 1974, high water levels (850.6 m) created a public demand for lake stabilization at a level that would maximize recreational benefits (Evans, 1981). A study was undertaken in 1980/81 to determine the feasibility of regulating Pigeon Lake water levels using the weir instead of relying on outflow from the creek. In 1981, the lake water level was lowered by 0.4 m to 850.2 m a.s.l after the outlet was cleared and the creek was dredged and maintained (Evans, 1981). In 1986, the weir was replaced with a two-bay structure with two stop logs and a Denil II fish ladder. The weir maintains the lake water level at an elevation of 849.95 m a.s.l. (Mitchell and Prepas, 1990). Over the years, the water level in Pigeon Lake has fluctuated by about 1.0-1.5 m (max. 850.71 m in 1948, min. 849.33 m in 1968) (Evans, 1981), which is typical for lakes in central Alberta (Evans, 1981; Mitchell and Prepas, 1990) (Figure 3).

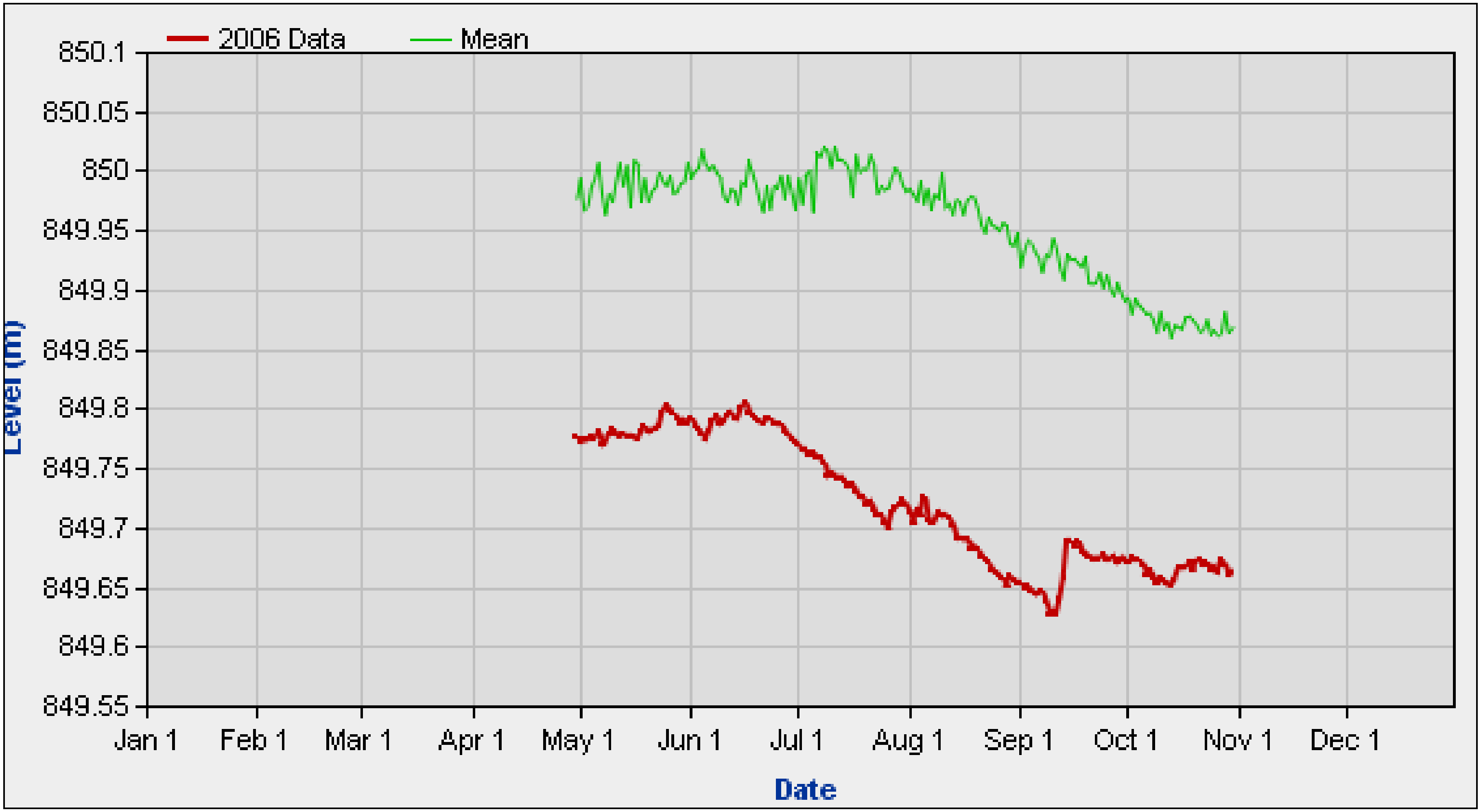

Figure 3. Mean (1972-2006) and 2006 water levels at Pigeon Lake (Environment Canada, 2007).

4.5 Water Withdrawals and Consumption

Permits have been issued by Alberta Environment for individuals and organizations to:

- Divert surface water from a tributary to Pigeon Lake;
- Construct, operate and maintain a storm water management facility for the purpose of collecting and draining storm water into Pigeon Lake and an unnamed tributary of Pigeon Lake; and
- Carry out silt and vegetation removal for beach enhancement work.

Water diversions do not exceed 6200 m^3 per year per permit and require the individual or organization to comply with strict conditions laid out by Alberta Environment.

5.0 Water and Sediment Quality

5.1 Water Quality

Pigeon Lake has water quality data dating back to 1972. The University of Alberta conducted water quality testing from 1973-1975, and Alberta Environment sampled the lake in 1971-1972, then from 1983-2006. In 1982, a water quality study was commissioned by the Battle River Regional Planning Commission, and in 1988, and a volunteer citizens monitoring program was initiated by Alberta Environment. Lilley Environmental Consulting and Earle (1998) conducted a water quality assessment and drafted a “Pigeon Lake Watershed management Plan”, which was subsequently adopted by the Counties of Leduc and Wataskiwin and several summer villages on Pigeon Lake in 2000. The Alberta Lake Management Society (ALMS) sampled Pigeon Lake in 2001, and Aquality Environmental Consulting Ltd. sampled the lake for caffeine in 2006 and for nutrient concentrations following an algal bloom in the summer of 2007.

Table 4. Major ions and related water quality variables for Pigeon Lake. (Alberta Environment unpublished data, Naquadat station 01AL05FA1500). Most variables are in mg/L unless otherwise indicated.

Variables	Mean
pH (range)	8.2-8.6
Total alkalinity ($CaCO_3$)	152
Specific conductivity (µS/cm)	283
Total dissolved solids (calculated)	155
Total hardness (calcium carbonate, $CaCO_3$)	107
Bicarbonate (HCO_3^-)	179
Carbonate (CO_3^{2-})	<4
Magnesium (Mg^{2+})	10
Calcium(Ca^{2+})	26
Sodium (Na^+)	16
Potassium (K^+)	5
Chlorine (Cl^-)	<1
Sulphate (SO_4^{2-})	<5

Pigeon Lake is a well-buffered, freshwater lake, with bicarbonate (HCO_3^-) and calcium (Ca^{2+}) moderating the acidity of the lake water (Table 4).
Due to the large size and shallow depth of Pigeon Lake, the water mixes from the lake surface to the bottom on windy days during most of the open-water period. As a result, the water temperature is generally uniform (Bidgood, 1972), and dissolved oxygen concentrations remain relatively stable throughout the water column up to a depth of 8 m. Only at a depth greater than 8 m does the water column become devoid of oxygen (Figure 4). In addition, dissolved oxygen may be depleted near the lake bottom by late winter; however, winterkill of fish is unlikely, because there is sufficient dissolved oxygen in the upper portions of the water column. Similarly, water temperature is relatively constant throughout the water column (Figure 4), and the lake does not stratify, i.e., no thermocline forms that separates warmer water near the surface from colder water at greater depths.

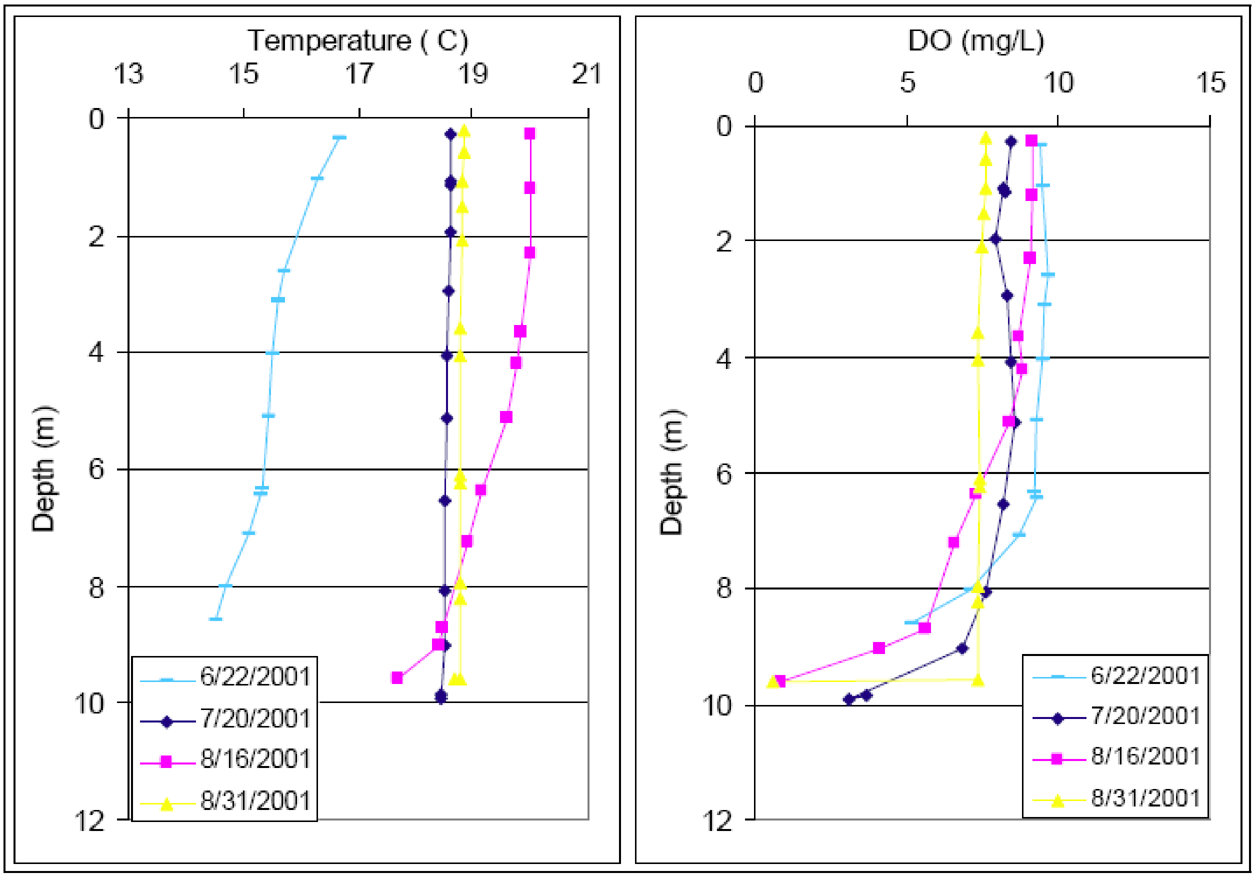

Figure 4. Temperature and dissolved oxygen concentrations at various depths in Pigeon Lake (McEachern et al., 2001).

Pigeon Lake is mesotrophic to mildly eutrophic, with total phosphorus concentrations ranging from 29-35 µg/L (Table 5). There is considerable annual variation in mean concentrations of total phosphorus and chlorophyll *a*, an indicator of algal productivity. Total phosphorus and chlorophyll *a* concentrations have been shown to increase during summer to peak levels in late August. This pattern is typical of shallow lakes in Alberta. Due to wind action and rapid mixing of the water column, total phosphorus concentrations generally remain constant throughout the water column (Aquality Environmental Consulting Ltd., unpublished data). The internal supply of phosphorus likely maintains summer algal populations in the lake and reduces water clarity. Increasing concentrations of phosphorus in the water column ("eutrophication") can lead to algal blooms. The long retention time of the lake exacerbates the problem due to the lack of flushing with fresh inflow water, trapping the nutrients within the lake and causing accumulation over time.

Table 5. Surface water nutrient and chlorophyll *a* concentrations and Secchi depth for Pigeon Lake (Alberta Environment unpublished data, Naquadat station 01AL05FA1500). All units are µg/L unless otherwise indicated.

Variables	1983	1984	2007[c]
	Mean	Mean	Mean
Total phosphorus	29	35	33
Total Kjeldahl nitrogen	910 [a]	---	1100
Iron	---	<20 [b]	---
Chlorophyll *a*	11.6	14.1	26.6
Secchi depth (m)	2.9	2.0	---

[a] n = 1, [b] n = 4, [c] Aquality.

Table 6. Theoretical total external phosphorus loading to Pigeon Lake (Alberta Environment, 1989). The largest sources of phosphorus are indicated by bold text.

Sources		Phosphorus (kg/yr)	Percent of total
Watershed	Forest/brush	900	16
	Agricultural/cleared	**1702**	**30**
	Residential/cottage	770	14
Sewage [a]		133	2
Precipitation/dustfall		**2127**	**38**
	Total	5632	100
Annual areal loading (g/m^2 of lake surface) 0.06			

[a] unmeasured, assumed that 4% of all sewage effluent from residences and camps entered the lake (see Mitchell, 1982).

Agricultural practices (30% of the total external phosphorus supply to Pigeon Lake) have been shown to increase nutrient concentrations in aquatic ecosystems and may have contributed to the algal bloom in Pigeon Lake in 2007 (Pigeon Lake Watershed Association, 2007). Phosphorus loss from agriculture can come from point and diffuse sources. Point sources include waste water from farms and dairies and seepage from manure stores. Diffuse sources relate to individual fields, where soil erosion, surface runoff, and drainage represent the major pathways of phosphorus transport into aquatic ecosystems (Daniel et al., 1998).

In addition, the transport of soil particles by wind is currently recognized as one of the major contemporary environmental problems (see Niemeyer et al., 1999), particularly in regions where clay and silt form a major component of surficial soil deposits, such as on the Boreal Plain in central Alberta. Apart from naturally occurring wind erosion, agricultural tillage practices also re-distribute soil particles and nutrients; however, unlike wind erosion events, dust production due to tillage extends over much longer periods, normally in the order of weeks. Thus, the amounts of soil released from fields by tillage can be considerable. Dust storms re-distribute fine soil particles along with chemically bound nutrients, such as nitrates, phosphates, and cations (positively charged ions, e.g., sodium, potassium, and calcium), pesticides and fertilizer, and microorganisms (e.g., fungi, bacteria, viruses). The concentrations of nutrients, pesticides, and fertilizers can be up to ten times greater in dust than in topsoil (Fritz, 1993), and their deposition into aquatic ecosystems can cause significant negative impacts, including the proliferation of algae and the subsequent formation of algal blooms.

Fecal coliform bacteria are of concern, particular from a human health perspective. Fecal coliforms include the genera that originate in human feces, such as *Escherichia*, as well as genera that are not of fecal origin, such as *Enterobacter*, *Klebsiella* and *Citrobacter*. When levels are elevated, there may be an elevated risk of waterborne gastroenteritis. The presence of these bacteria in aquatic environments may indicate that the water has been contaminated with the fecal material of humans or animals, e.g., cattle, sheep, etc. Fecal coliform bacteria can enter aquatic systems through direct discharge of waste from mammals and birds, from agricultural and storm runoff, and from untreated human sewage. The recreational water quality guideline for indicator bacteria is 200 fecal coliforms, or 200 *E. coli*, per 100 ml of sample (CCME 2007). Thus, fecal coliform counts in Pigeon Lake are well below the Health Canada and CCME guideline recommendations, and only those at Ma-Me-O Beach approached critical levels (the 180 CFU value was measured in early September 2006) (Table 7).

Table 7. Means and ranges (where available) fecal coliform concentrations (as colony-forming units = CFU) per 100 mL water sample in Pigeon Lake in 2006. The CCME and Health Canada Recreational Guidelines are 200 CFU/100 mL.

Locations	Mean	Low	High
Crystal Springs	50	---	---
Grandview	15	10	20
Ma-Me-O Beach	104	10	180
Mulhurst Bay	60	---	---
Poplar Bay	20	---	---
Silver Beach	13	10	20

5.2 Sediment Quality

The sediments of Pigeon Lake consist primarily of silt and clay, which are fine-grained minerals, with sand comprising only a minor component (Table 8). Most of the carbon is in organic form (97.6%). From an elemental perspective, aluminum, iron and calcium are most abundant, but a number of other metals and non-metals are present in the sediment as well. The elemental composition of the sediments in Pigeon Lake is characteristic of the underlying geologic formation, the Paskapoo Formation (a sedimentary rock unit comprised dominantly of shale and sandstone). Sediment composition plays a significant role in determining nutrient availability in lake water. For example, phosphorus is readily adsorbed (chemically bound) to clay particles in sediments. Similarly, iron and aluminum can bind with phosphorus and precipitate it out of the water column. In both cases, the phosphorus becomes biounavailable, i.e., unavailable to plants or algae for growth (Wetzel, 2001). Neither clay nor iron or aluminum concentrations in sediments of Pigeon Lake decrease phosphorus concentrations sufficiently to limit growth of algae and plants, as is shown by the frequency of algal blooms and the mesotrophic to mildly eutrophic status of the lake (Table 5).

Table 8. Mean physical and chemical composition of sediments in Pigeon Lake compared to the CCME Interim Sediment Quality Guidelines (Anderson, 2003). All units in µg/g unless otherwise indicated. Parameters in excess of the CCME Guidelines are indicated in red.

Variables	Mean	CCME Sediment Quality Guideline (Interim)
Sand (%)	4.3	
Clay (%)	47.7	
Silt (%)	48.0	
Total carbon (mg/g)	165.0	
Total inorganic carbon (mg/g)	3.6	
Total organic carbon (mg/g)	161.0	
Mercury (Hg) *	0.082	0.17
Silver (Ag)	0.3	-
Aluminum (Al)	43562	-
Arsenic (As)	6.1	5.9
Boron (B)	72.7	-
Barium (Ba)	583.3	-
Bismuth (Bi)	0.33	-
Cadmium (Cd)	0.38	0.6
Calcium (Ca)	16809	-
Chlorine (Cl)	1493	-
Chromium (Cr)	44.0	37.3
Cobalt (Co)	8.6	-
Copper (Cu)	22.6	35.7
Lithium (Li)	20.8	-
Manganese (Mn)	810.3	-
Molybdenum (Mb)	1.26	-
Nickel (Ni)	29.5	-
Lead (Pb)	21.3	35
Antimony (Sb)	0.91	-
Selenium (Se)	1.2	-
Strontium (Sr)	146.7	-
Thorium (Th)	8.7	-
Titanium (Ti)	2288	-
Thallium (Tl)	0.44	-
Uranium (U)	2.91	-
Vanadium (V)	72.9	-
Zinc (Zn)	80.4	123
Iron (Fe)	28516	-

The sediments of Pigeon Lake also contain several hydrocarbons (Table 9), which are common in crude oil, form during the combustion of organic matter, or form during the manufacturing or degradation of synthetic materials (e.g, plastics). Several of these are considered carcinogenic (causing cancer), mutagenic (causing mutations) and/or teratogenic (causing birth defects). Concentrations of these hydrocarbons in Pigeon Lake are below the CCME Sediment Quality Guidelines and pose no risk to humans or animals. Many of these hydrocarbons are water soluble and have short half-lives in aquatic ecosystems, i.e., they degrade rapidly through photolysis or microbial activities. Others have low solubility in water and leaching from landfills into sediments/soils is generally slow.

Table 9. Mean hydrocarbon concentrations in sediments in Pigeon Lake (Anderson, 2003). All units are ng/g unless otherwise indicated.

Variables	Mean	CCME Sediment Quality Guideline (Interim)
Fluorene	0.42	21.2
Phenanthrene	2.30	41.9
Pyrene	1.59	53.0
Fluoranthene	1.84	111
7-Isopropyl-1-methylphenanthrene (Retene)	2.93	-
Benzo(c)phenanthrene	0.53	-
Indeno(1,2,3-c,d)pyrene	0.86	-
Benzo(g,h,I,)perylene *	0.66	-
Dibenzo(a,l)pyrene *	0.84	-
Butylbenzylphthalate	0.16	-
Di-N-butylphthalate	0.97	-
Diethylphthalate *	0.08	-
Di-N-octylphthalate	0.17	-
Bis(2-ethylhexyl)phthalate	1.50	-

n = 3, * n = 1, 1 ng = 1 x 10^{-9} g.

5.3 Fisheries

Pigeon Lake has been managed for commercial, recreational and domestic fisheries (Mitchell and Prepas, 1990). Fish species present in Pigeon Lake include walleye (*Stizostedion vitreum* Mitchill), lake whitefish (*Coregonus clupeaformis* Mitchill), northern pike (*Esox lucius* L.), yellow perch (*Perca flavescens* Mitchill), white sucker (*Catostomus commersoni* Lacepède), burbot (*Lota lota* L.), spottail shiner (*Notropis hudsonius* Clinton), emerald shiner *(Notropis atherinoides* Rafinesque), trout-perch (*Percopsis omiscomaycus* Walbaum) and Iowa darter (*Etheostoma exile* Girard).

Fish populations in Pigeon Lake have fluctuated dramatically over the past century. Human settlement around the lake, increased fishing pressures, and over-fishing during World War II caused lake whitefish, walleye and northern pike populations to collapse. Fish populations have also suffered from habitat loss due to aquatic vegetation removal and shoreline modification and development. Whitefish populations were able to recover; however, walleye were extirpated from the lake by the 1960s. Pike population numbers remain low to this day as a result of the impacts on habitat (Buchwald, 1994).

In the 1990s, walleye were successfully re-introduced to Pigeon Lake. Reintroducing these predators has changed the dynamics of the lake's fish populations, affecting the number, size and fish species available for commercial and recreational anglers. These changes resulted in conflicts between the lake's recreational fishers, who prefer walleye, and commercial fishers, who favour whitefish (ASRD, 2008). More detailed analyses of specific fish species population dynamics are treated in the following sections.

5.3.1 Walleye

Walleye were reported in commercial catches until 1963-64, after which natural populations were extirpated from the lake (Patterson, 2004). From 1979-1984 and from 1994-1999, Pigeon Lake was stocked with 143,000 walleye fingerlings (Boag and Jacobson, 1993) and 18.4 million walleye fry and fingerlings, respectively (Patterson, 2003). Despite stocking efforts, the walleye age distribution remained unstable (Patterson, 2004; Watkins, 2004). Currently, only two age classes support the walleye fishery, indicating poor recruitment (Watkins, 2004). In 2003, index netting surveys determined that 2% of walleye in Pigeon Lake were born naturally and that the rest were stocked. By 2007, the percentage of naturally-born walleye had recovered and increased to 35% (Winkel, 2008).

During 2001-2004, anglers reported catching many large walleye. The reason for these artificially large catch sizes was the lack of competition stocked fish encountered when they first entered Pigeon Lake. With little or no competition, a large proportion of the stocked fish population was able to grow large. These large fish, however, have pretty much disappeared. There are now more medium and small-sized fish and fewer large fish. This trend in the size and numbers of fish is in line with the current management strategy, which aims to produce a quality fishery with a good catch rate for medium-sized fish (ASRD, 2008).

From 2003-2005, there was a decline in the condition of the walleye due an exceedence of the walleye population in Pigeon Lake. Consequently, overall fish size declined; however, since 2005, the condition of walleye in Pigeon Lake has improved and is now comparable to other walleye populations in Alberta (ASRD 2008). In 2006 and 2007, special walleye licenses were issued for Pigeon Lake and two other lakes. Anglers were allowed to keep two large (> 50 cm), three medium (43-50 cm) or three small (< 43 cm) walleye per license. There were about 9,000 licenses available for Pigeon Lake. A similar scheme has been implemented for 2008.

5.3.2 Northern Pike

Creel surveys in 1999 indicated low densities of northern pike. The pike population was classified as stable-recreational (collapsed), and a 63 cm size limit and a three-fish limit were imposed (Patterson, 2004). A 2003 creel survey and test fishery found the population of northern pike to have extremely low densities and little to no recruitment. It was determined that the population was on the verge of collapsing, and the bag limit was reduced from three to one fish (size limit remained at 63 cm) (Patterson, 2004). Northern pike numbers remain low in Pigeon Lake to date (Winkel, 2008). In addition to fishing pressure, one of the main reasons for low pike numbers is the loss of important habitat caused by extensive shoreline development around the lake. Optimum spawning habitats for northern pike are lacustrine marshes with dense beds of submerged aquatic vegetation (Kraft and Shirvell, 1974).

5.3.3 Lake Whitefish

Lake Whitefish have been commercially fished since the 1918. A collapse and recovery of the fishery was reported in the 1940s (Kraft and Shirvell, 1974). Since then, progressively smaller fish have been harvested and net size regulations have decreased twice to maintain the economic viability of the fishery (Bidgood, 1972; Allan, 1974; Kraft and Shirvell, 1974). In 2001, the commercial whitefish fishery was suspended after the walleye tolerance quota had been exceeded by 272% in 2000 (Watkins, 2004). With the closure of the commercial fishery and the increased walleye population, the dynamics of the whitefish population have again changed; there is now large sized lake whitefish in Pigeon Lake in high numbers (Cooper, 2008), similar to the sizes present prior to the collapse during the 1940s.

Whitefish spawn on boulder, rubble and sand substrata, which occur on 16.6% of the bottom of the lake (Figure 5). Proper spawning substrate is critical to ensure adequate oxygen transfer to the eggs (Casselman and Lewis, 1996; Soulsby et al., 2001). For example, excessive sedimentation by fine-grained sediment particles reduces oxygen transport to developing eggs and can reduce offspring vitality or cause egg mortality prior to hatching. Spawning occurs most frequently on the south-east and southern littoral zones, with minor spawning on the north-east shore. Spawning occurs over a wide temperature range, starting in late September and ending in late January.

5.3.4 Fish Habitat

Habitat loss was first recognized as a major factor in pike declines in the 1960s as cottage numbers and shoreline properties increased steadily from 1950-1966 (from 250 to 845 cottages, an increase from 6 to nearly 25 cottages per km of shoreline) (Bidgood, 1972), which led to the removal of emergent macrophytes and the subsequent destruction of crucial spawning and recruitment habitat for northern pike. Predatory fish species, such as northern pike, are important in controlling prey fish species, which feed on zooplankton, which in turn feed on algae. In the absence of fish or when fish populations are declining and/or vulnerable, zooplankton populations can increase due to reduced predation. These zooplankton can then consume larger quantities of algae, which decreases water column turbidity resulting in a clearer water column. Conversely, in the presence of fish, zooplankton is preyed upon, which increases the density of algae and consequently increases the turbidity of the water column (Jeppesen et al., 1997). Thus, the health and diversity of the fish community is important in maintaining zooplankton populations and hence water clarity (Rodriguez et al., 1993), particularly in lakes that do not freeze to the bottom in the winter months, such as Pigeon Lake.

More cottagers, residential and recreational property owners have increased fishing pressure on northern pike and walleye populations. The decrease in these populations has increased intraspecific competition among whitefish and interspecific competition with other prey species (Bidgood, 1972).

5.3.5 Fisheries Management Plan

In 2001, ASRD responded to the emerging fisheries management issues resulting from the developing walleye population by setting up the Pigeon Lake Fisheries Management Advisory Committee, consisting of representatives from First Nations, recreational fishers, commercial fishers, the local community and government staff. The Advisory Committee was given the task of developing a fisheries management plan for Pigeon Lake.

Public consultations were held in 2002 and 2003, and the management plan was finalized in May 2003. The management plan provides an overview of Pigeon Lake and its fisheries, including:

- The current condition of fish populations in the lake;
- Fish management issues;
- Principles for guiding future management of the fishery;
- Specific recommendations for managing fish stocks; and
- Fish allocations for First Nations, recreational and commercial fisheries.

The management plan can be viewed at:

http://www.srd.gov.ab.ca/fieldoffices/prairies/fisheriesmanagement/reportspublications.aspx.

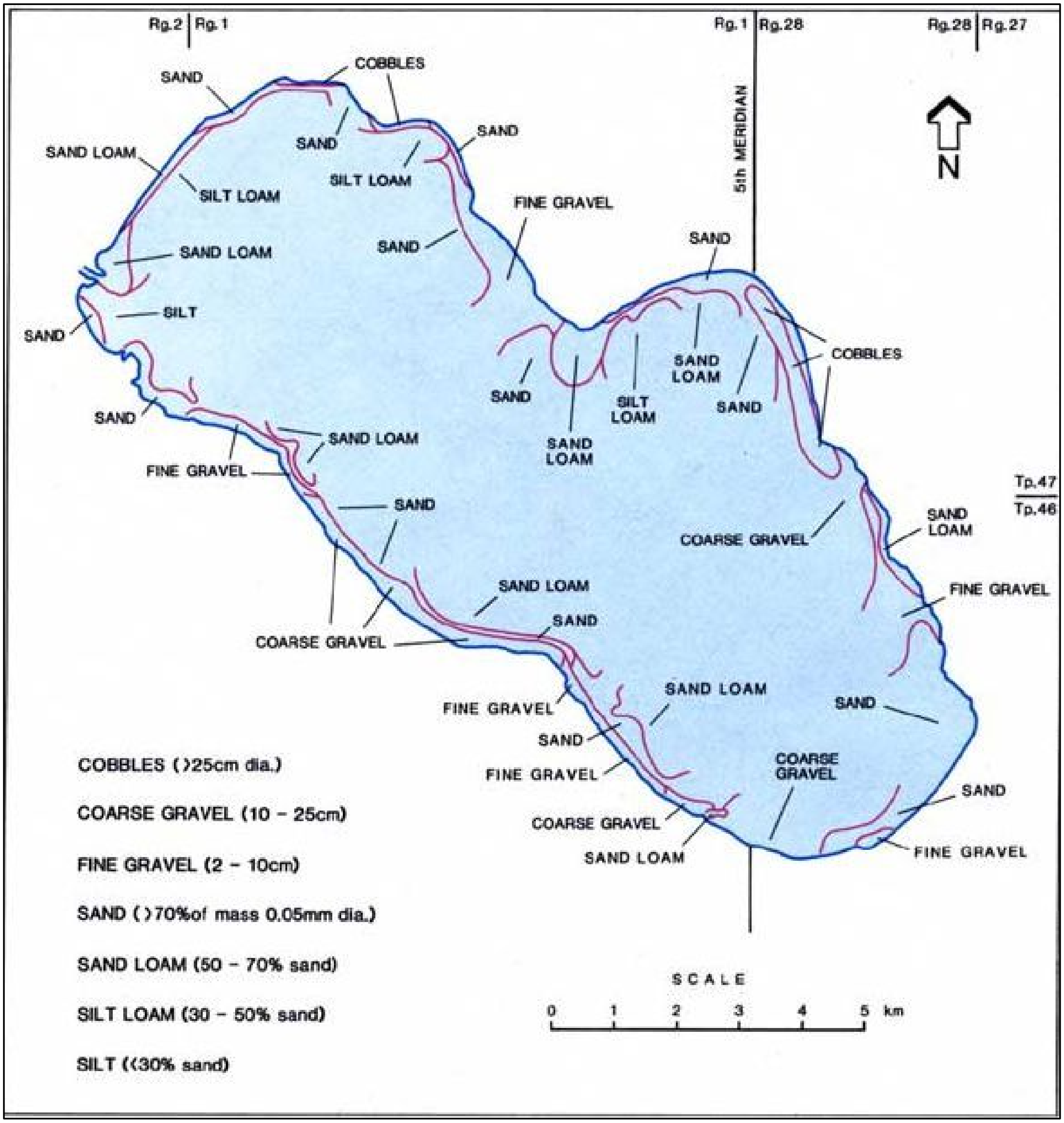

Figure 5. Distribution of littoral sediments and shoreline characteristics of Pigeon Lake (Pigeon Lake Study Group, 1975; Haag and Noton, 1981).

5.4 Vegetation and Cyanophytes

Plant cover in 1981 was generally low along most of the shoreline at depths less than 1.5 m and was highest where fine sediments accumulated (Haag and Noton, 1981). The most frequently occurring species were northern watermilfoil (*Myriophyllum exalbescens* Fern.), stonewort (*Chara* sp.) and Richardson pondweed (*Potamogeton richardsonii* (Benn.) Rydb.) (Figure 6). Northern watermilfoil was most abundant in areas of low turbulence, and it occurs at slightly greater depths than Richardson pondweed. Also abundant was widgeon grass (*Ruppia cirrhosa* (Petag.) Grande), despite its predilection for more saline environments. The dominant emergent species in lacustrine marshes was common great bulrush (*Scirpus validus* Vahl.). Its distribution is limited by substrate type and most prevalent in areas of low cottage density (Haag and Noton, 1981).

The densest submersed aquatic plant communities occur along the north-west and east-central shores (>75% cover), although virtually the entire shore of Pigeon lake has submersed aquatic plant cover of 30-75%, with only the south shore having <30% submersed aquatic plant cover (Figure 6). Macrophyte removal around the littoral areas has occurred with the use of aquatic herbicides and/or mechanical means (Bidgood, 1972).

Aquatic vegetation performs a number of crucial ecosystem functions, including water purification; nutrient recycling; physical link between water and air for many invertebrates, e.g. larvae and nymphs of caddis flies, mayflies, chironomids, which are food for fish and have aquatic larval stages and aerial adults; refugia for zooplankton, which graze phytoplankton and keep water clear; cover for many invertebrates, many of which are food for fish; cover for fish; spawning areas and sites of egg-deposition for many fish species, including pike; food source (living and dying); and affect water flow patterns.

Numerous previous studies have shown that the reduction in extent or destruction of aquatic plant stands has significantly reduced the health and diversity of fish, waterfowl, waterbird, and invertebrate species (e.g., Carpenter and Lodge, 1985; Carpenter and McCreary, 1986; review in Petr 2000). In addition, water quality is significantly impaired, often resulting in decreased sedimentation (i.e., more turbid water), increased nutrient loading from run-off and increased shoreline erosion through unimpeded wave action (Hargeby et al., 1994; review in Petr 2000). Thus, the maintenance of aquatic vegetation stands is important in maintaining wildlife habitat and water quality.

Cyanobacteria, also known as Cyanophyta or blue-green algae, are an important primary producer in many aquatic and terrestrial ecosystems. An algal bloom, most often associated with elevated concentrations of nutrients in the water column, is a rapid increase in the population of cyanobacteria in an aquatic system. Favourable light conditions and water temperatures and the absence of grazing zooplankton species, such as *Daphnia*, facilitate the proliferation of cyanobacterial cells and subsequent expansion of a bloom. Typically only one or a few cyanobacteria species are involved in a bloom. In recent years, cyanobacteria belonging mainly to *Anabaena* and *Lyngbya* have been responsible for blooms and deteriorating water quality in Pigeon Lake. Their fast growth and reproductive rates provide them with a competitive advantage over algal species in the same habitat. Blooms usually develop in nutrient-rich lakes during the summer months when the water is warm and slightly to moderately alkaline; however, variations in air and water temperatures, total sunlight and wind velocity also influence bloom development. Because these factors vary from year to year, blooms cannot be accurately predicted. Blooms may not occur every year in a given lake, or they may not develop at the same time or with similar intensity each year. Furthermore, the species responsible for the bloom may differ.

5.5 Invertebrates

Copepods were abundant throughout the open-water period, particularly from May-June. The most common copepod was *Diacyclops thomasi* S.A. Forbes. *Diaptomus* sp. was also common. Cladocerans were less numerous, with the highest numbers occurring in midsummer (Bidgood, 1972). One species of *Daphnia* was dominant, and another cladoceran, the large *Leptodora kindtii* Focke, was also present. These invertebrates represent a major food source for small-bodies fish in Pigeon Lake (Kraft and Shirvell, 1974). Sand, silt and rubble substrates in Pigeon Lake yielded abundant benthic invertebrates, with *Hyalella azteca* Saussure, an amphipod, being dominant in early spring (March) and occurring mainly on sandy substrates (3-m deep). In contrast, midge larvae (Chironomidae) predominated on silt substrates in late summer (August) (Bidgood, 1972).

Zooplankton, such as cladocerans and crustaceans, play a functionally important role in aquatic systems by consuming algae and bacteria then re-releasing nutrients or serving as prey for larger invertebrates and/or fish (Hillbricht-Ilkowska, 1977). The relationship between fish and invertebrate populations and the resultant influence on water clarity through the control of algal populations has been addressed above.

5.6 Wildlife

Pigeon Lake provides poor waterfowl habitat, because shallow, marshy areas are scarce. However, the lake is an important staging area for waterfowl during fall migration (Hardy Associates Ltd., 1983). Nesting colonies of gulls and terns have been reported, and a Great Blue Heron colony in Pigeon Lake Provincial Park contained 16 active nests in 1987. Deer (e.g., whitetail deer [*Odocoileus virginianus* Zimmermann]), moose (*Alces alces* L.), beaver (*Castor canadensis* Kuhl), muskrat (*Ondatra zibethicus* L.) and mink (*Neovison vison* Schreber) in addition to 135 bird species, including exotic upland game species, have been reported in the Battle River watershed, including the vicinity of Pigeon Lake (Pigeon Lake Study Group, 1975). For example, the least flycatcher (*Empidonax minimus* Baird), house wren (*Troglodytes aedon* Vieillot), ovenbird (*Seiurus aurocapillus* L.), red-eyed (*Vireo olivaceus* L), blue-headed (*Vireo solitarius* Wilson) and warbling vireos (*Vireo gilvus* Vieillot), Baltimore oriole (*Icterus galbula* L.), rose-breasted grosbeak (*Pheucticus ludovicianus* L.), yellow-bellied sapsucker (*Sphyrapicus varius* L.), magnolia warbler (*Dendroica magnolia* Wilson), white-throated sparrow (*Zonotrichia albicollis* Gmelin), pileated woodpecker (*Dryocopus pileatus* L.) and northern goshawk (*Accipiter gentilis* L.) are common in the Dry Mixedwood Subregion and have been spotted around Pigeon Lake.

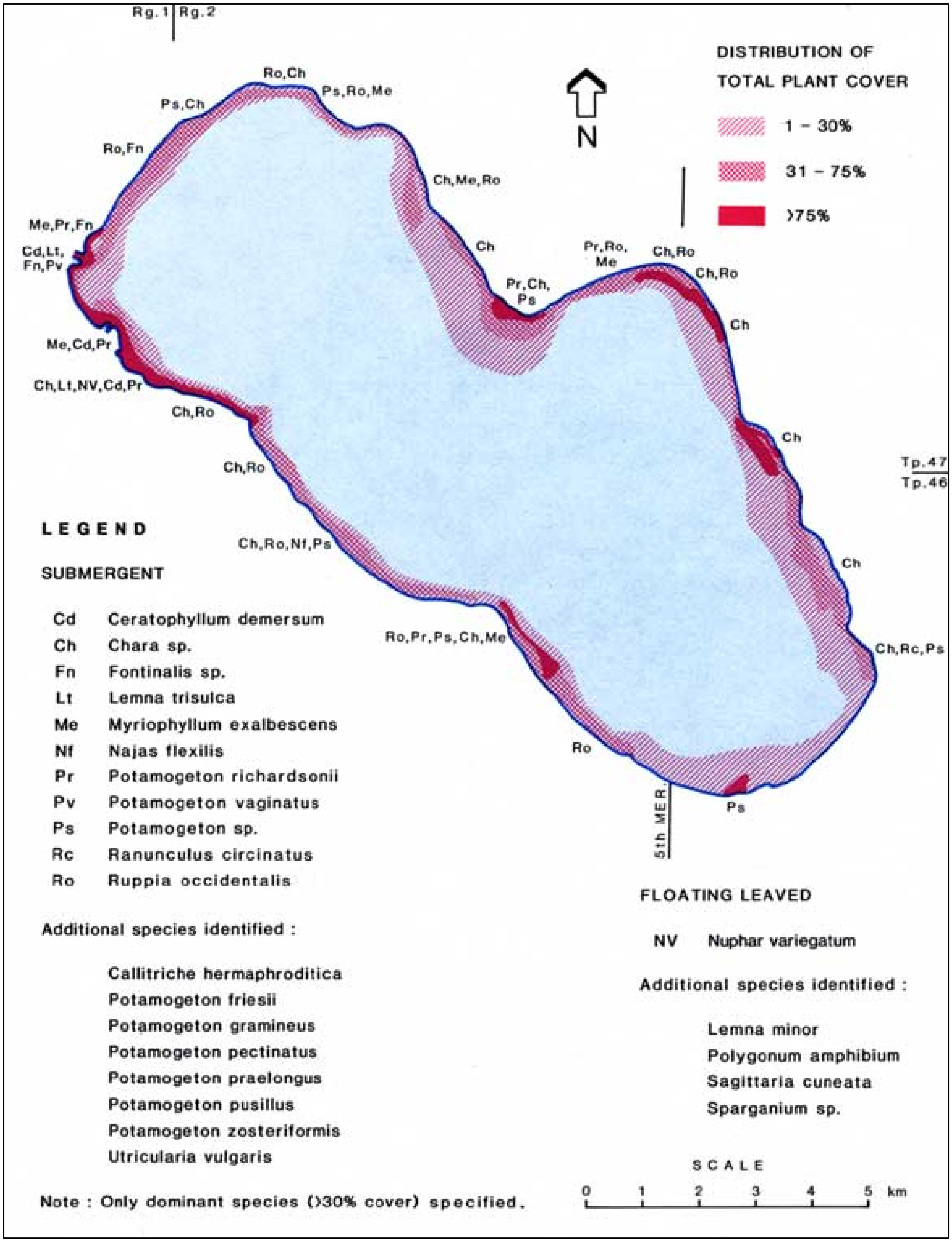

Figure 6. Distribution of floating and submersed macrophytes in Pigeon Lake (Haag and Noton, 1981).

6.0 Land Cover and Land Use

6.1 Residential Developments

In the 1960's, there were only four summer villages (Ma-Me-O Beach, Silver Beach, Itaska Beach and Crystal Springs) (Provincial Planning and Advisory Board, 1959) (Figure 7). Pigeon Lake Provincial Park was established on the north-west shore of the lake on May 26, 1967, and Ma-Me-O Beach Provincial Park, the smallest provincial park in Alberta (4 acres), was created on the south shore of Pigeon Lake on October 18, 1949. In 1967, the lakeshore of Pigeon Lake was developed as follows: developed residential land - 22%; undeveloped subdivided land - 7%; agricultural land - 3%; organizational camps - 5%; privately-owned undeveloped land - 37%; public park blocks and strips - 9.3%; undeveloped crown land - 3.7%; Indian Reserve - 13%. Since then, pressure from residential and agricultural developments has steadily increased along the shoreline and in the watershed.

As of 1985, there were over 2300 private cottages, 10 summer villages (mainly active in the summer), and 9 hamlets established on its shores (Battle River Regional management Commission 1985). Among the communities dotting the lake contour, the most prominent ones are Mulhurst Bay, Golden Days, Ma-Me-O Beach, Grandview, Crystal Springs, Mulhurst and Sundance Beach with smaller populations at Poplar Bay, Argentia Beach, Silver Beach, Norris Beach and Itaska Beach (Table 10). Populations of the summer villages in particular can increase from less than 100 in the winter months to over 2000 during the summer months.

Table 11. Population demographics of communities on the shore of Pigeon Lake (Statistics Canada, 2006).

Community	Population	Number of dwellings
Mulhurst Bay*	313	417
Golden Days	207	274
Ma-Me-O Beach	155	232
Grandview	127	184
Crystal Springs	112	124
Mulhurst*	108	159
Sundance Beach	102	124
Poplar Bay	84	145
Argentia Beach	52	90
Silver Beach	47	35
Norris Beach	40	76
Itaska Beach	35	70

* Community statistics based on Industry Canada (2006).

6.2 Recreational Use

Pigeon Lake offers a large array of recreational opportunities and facilities to residents and visitors. These include swimming, summer and winter sport fishing, boating (sailing, kayaking, power boating), wind surfing, wildlife viewing, hiking, and cross-country skiing. Local facilities include summer camps (Camp Muskepetoon, Camp Wohelo, Covenant Bay Bible Camp, Mulhurst Lutheran Camp and St. Basil's Camp), a youth hostel, three golf courses, dog sled tours, beaches and provincial and private day-use areas and campgrounds.

The two largest recreational facilities and activities that would increase the seasonal population of the Pigeon Lake area are Pigeon Lake Provincial Park and the three area golf courses. Pigeon Lake Provincial Park (including Zeiner campground) has 410 overnight camp sites and 143 group camp sites, which attract about 90,000-100,000 visitors (50,000-60,000 campers) throughout the year, making it one of the top-ten visited provincial parks in Alberta (Alberta Tourism, Parks and Recreation, 1998-2004). The three golf courses in the vicinity of Pigeon Lake attract up to an additional 100,000-120,000 golfers and guests from May-October (no exact data available; estimate based on May-October season [5 months], 10-minute tee-off intervals [vary from 8-15 minutes], full foursomes, booked to capacity daily [based on conversations with golf course managers]). Other recreational activities and facilities attract substantially fewer visitors throughout the year, e.g., summer camps, hikers, wind-surfers and skiers, and cause a smaller increase in the total population of the Pigeon lake area.

Together, recreational activities increase the population in the vicinity of Pigeon Lake about 200 to 220-fold compared to the permanent population of the ten largest communities on the lake (about 1000, Table 11).

It can be seen from a comparison of Figures 7 and 8 that development has increased substantially around the lake from 1987 to 2000, especially on the northern shore of the lake.

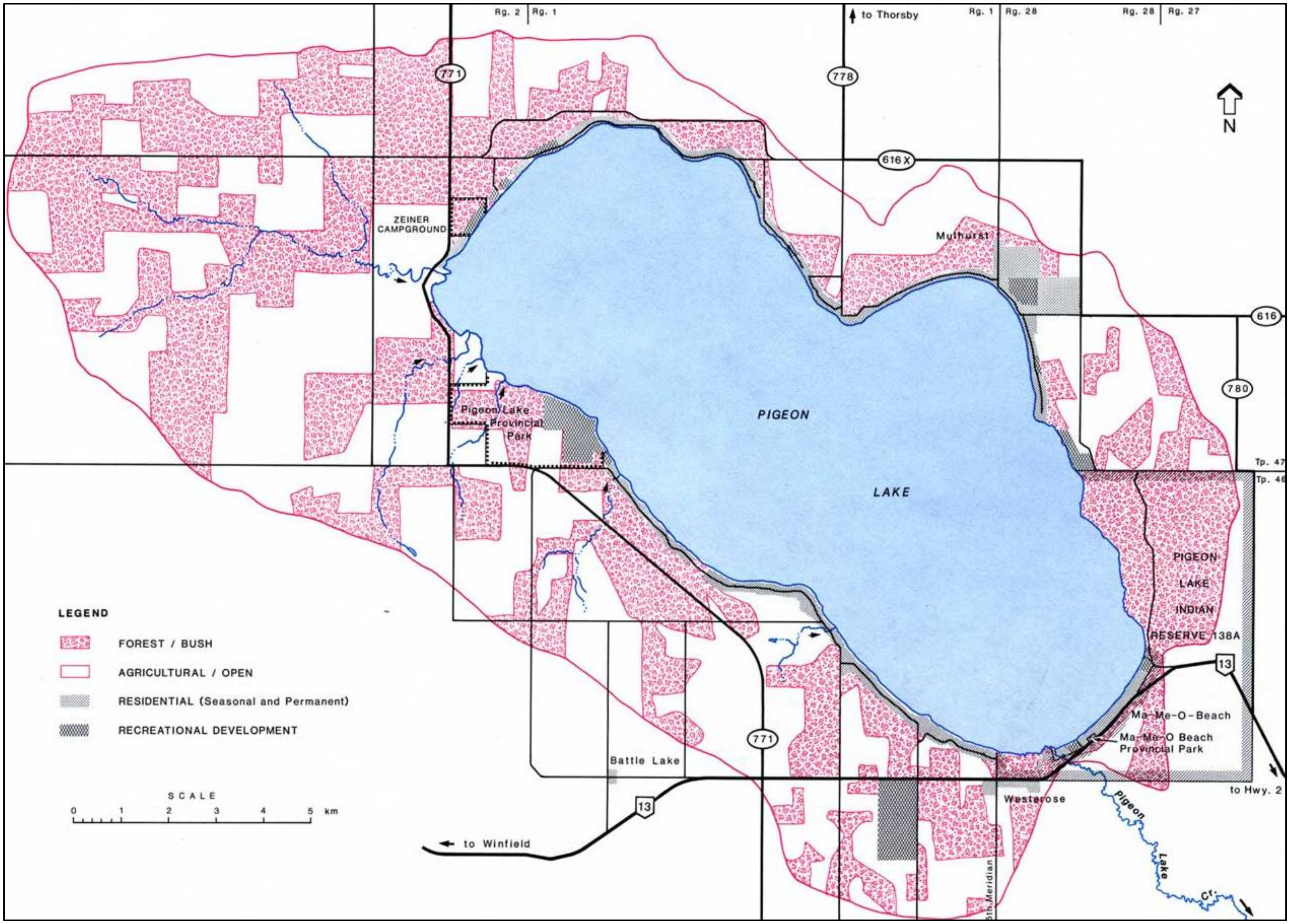

Figure 7. Landscape features of the drainage basin of Pigeon Lake (Alberta Environment, n.d.; Energy Mines and Resources Canada, 1974; updated with 1987 aerial photos).

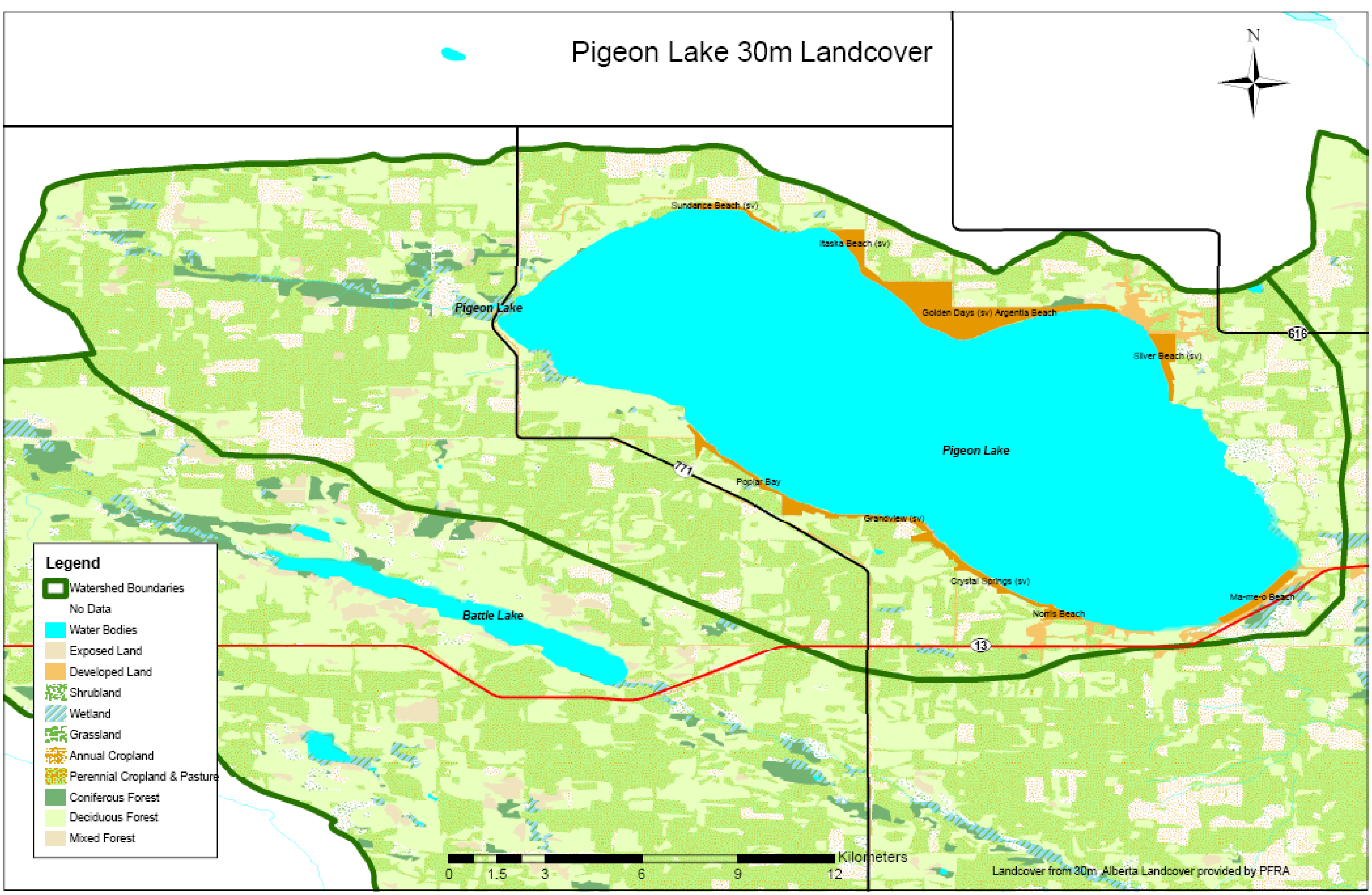

Figure 8. Land use and land cover in the Pigeon Lake watershed, 2000. Map provided by PFRA, 2008.

6.3 Agricultural Development

By 1968, the majority of land sections in the Pigeon Lake watershed were partially cultivated for cattle, dairy, and grain production (10-120 acres) (Lindsay et al., 1968). While cattle farms are prevalent in the Battle River watershed, total production of manure on cattle farms near Pigeon Lake is among the lowest in the entire watershed (about 0.7-2.0 t/ha) (Figure 8). On average, there were 117 cattle per farm and 371 pigs per farm in 2001 (Statistics Canada, 2007).

Wheat, barley, and oat are among the most important cereal crops along with canola, alfalfa, and other herbs (Statistics Canada, 2007). There are no specific data available for agricultural operations in the immediate vicinity of Pigeon Lake.

Table 12. Agricultural demographics for Census Division 11 (include Leduc and Wetaskiwin Counties) and Wetaskiwin County in 2001 (Statistics Canada, 2007).

Variables	Statistic
Farm and farm operator statistics (Wetaskiwin County)	
Total population	25,565
Total number of operators	1,950
Total number of farms	1,317
Total area of farms (ha)	275,317
Farm use in Census Division 11	
Wheat production (acres/farm)	260
Barley production (acres/farm)	179
Oat production (acres/farm)	73
Cattle (head/farm)	117
Pigs (head/farm)	371

6.4 Natural Resource Developments

Oil and gas industries represent the major natural resources developments. Since the discovery of oil in Alberta in 1914 in Turner Valley near Calgary, oil exploration continues to spread across the province. Oil was discovered near Pigeon Lake in February 1947 by Imperial Oil Ltd., who drilled the Leduc #1 well in a field 15 km west of Leduc. After the Leduc discovery, numerous American and British oil companies came to Alberta and further exploration in the late 1940s and 1950s uncovered additional oil fields. As of 2005, the oil well density is variable near Pigeon Lake, ranging from less than 10 wells to up to 100 oil wells quarter section (Alberta Agriculture, Food and Rural Development, 2001).

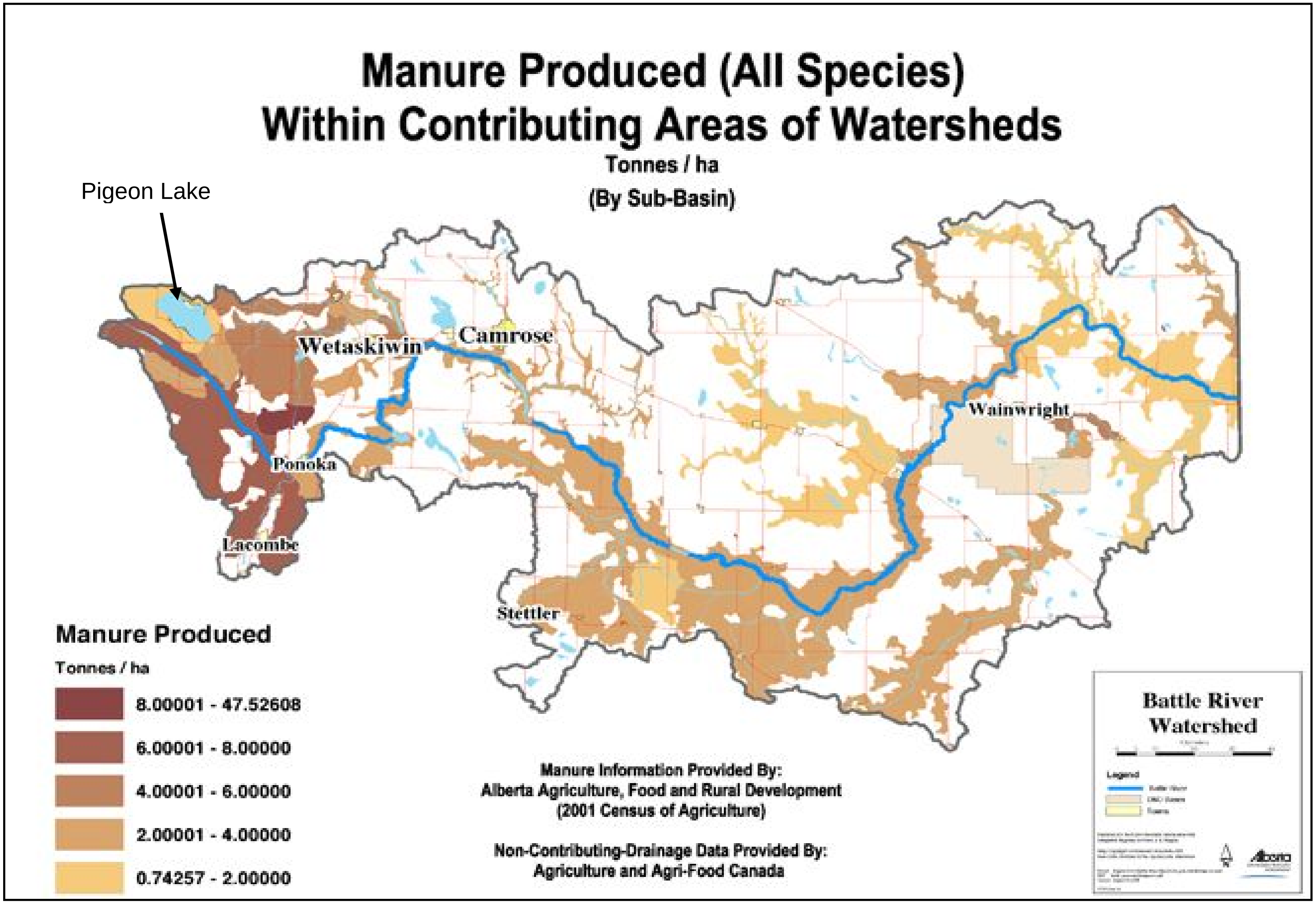

Figure 9. Manure produced in the Battle River Watershed (Alberta Agriculture, Food and Rural Development, 2001).

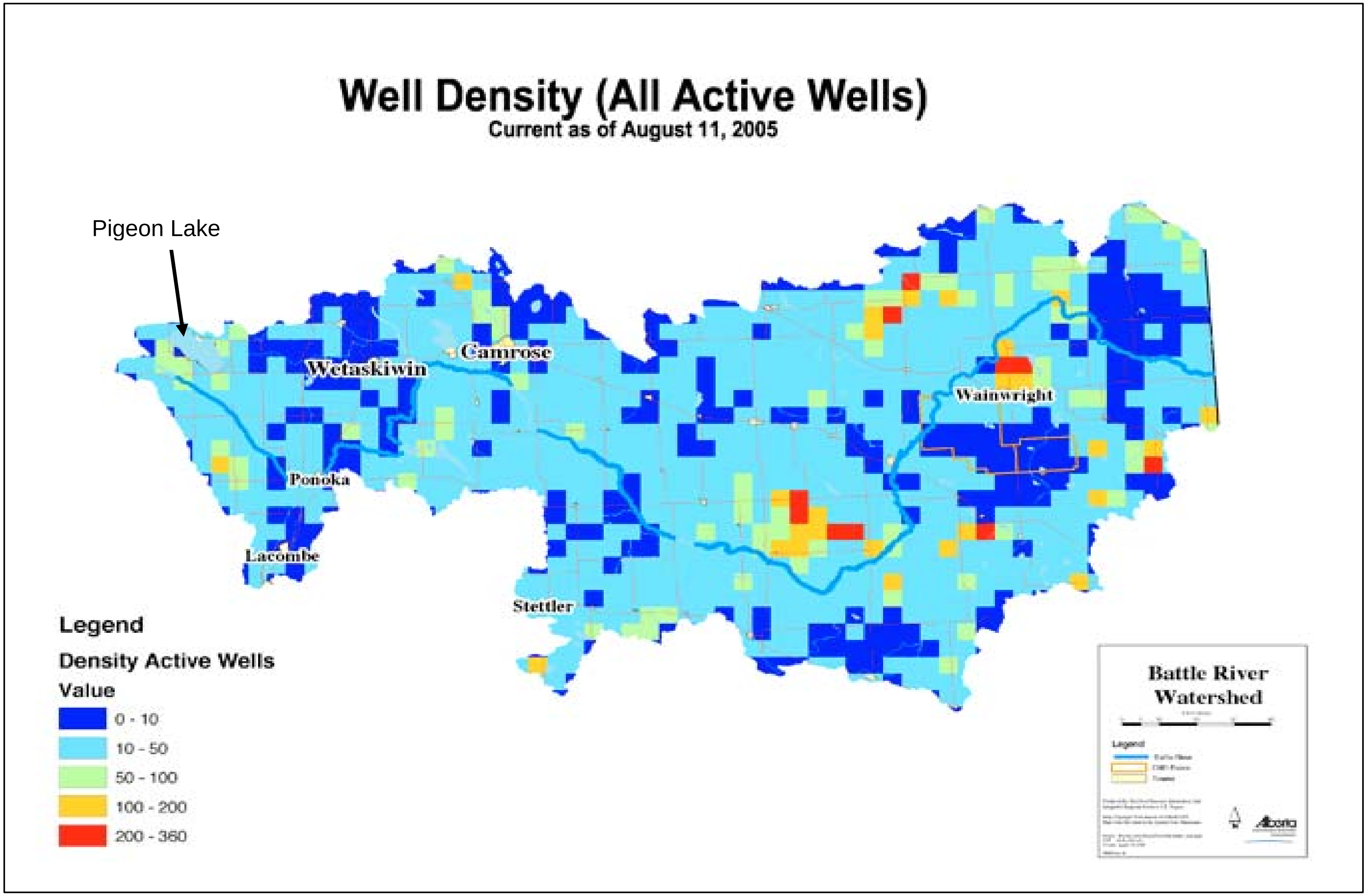

Figure 10. Oil well density in the Battle River Watershed (Alberta Agriculture, Food and Rural Development, 2001).

7.0 Conclusions

External and internal nutrient inputs are a concern to the health of Pigeon Lake. Land use practices, sewage and manure management around the lake should be managed to minimize further nutrient loadings to the lake. Another concern is the lack of healthy and functional riparian area around the lake, and the potential loss of wetlands.

When present, riparian areas act as a very effective filter for removal of excess nutrients due to surface runoff. If external loads could be controlled, this would certainly help control in-lake nutrient levels and subsequently control the formation of algal blooms. Some interim lake restoration options may be considered but may prove to be cost prohibitive and may only provide a short term solution. For example, phosphorus may be immobilized via increased water column aeration, water column circulation or the addition of chemical immobilizers (e.g., iron, calcium and aluminum salts). However, most of these approaches only provide short-term relief from elevated phosphorus concentrations and associated cyanobacterial blooms and/or may have adverse or unknown short- and long-term effects on aquatic organisms, such as fish, invertebrates, or vegetation. In addition, they may be cost prohibitive depending on dosages of chemical immobilizers and application frequencies required.

The frequency and intensity of algal blooms can also be reduced by an effectively managed fishery in a lake. Fish recruitment shows high interannual variability, whereby episodes of high recruitment cascade through lake food webs, inducing fluctuations in lower trophic levels at time scales of years to decades (a “trophic cascade”), i.e., algal biomass can increase substantially in years with low fish recruitment due to increasing algal grazer populations, e.g., water fleas (*Daphnia* spp.), which have not been preyed upon by fish. Conversely, high fish recruitment can reduce algal grazer populations and lead to algal blooms.

8.0 Recommendations

Recommendations for this watershed fall into the following four categories:

1. <u>Planning</u> – This is an ongoing, regulatory approach which will include the watershed management planning process, and the municipal process (intermunicipal development plans, bylaws, others).

2. <u>Stewardship</u> – This is ongoing as well, and requires community involvement. Components of this step are education and awareness, use of cottage owner BMP’s provided by organizations such as Living by Water and ALMS, better animal husbandry and agricultural land use practices, nutrient and manure management and others.

3. <u>Reclamation and restoration</u> – This is the most invasive of all of the steps. This would involve activities such as riparian restoration, replanting and restoration of critical lacustrine marsh areas and riparian vegetation and others.

4. <u>Data gaps</u> – Significant data gaps will need to be filled to move forward with a Watershed Management Plan. These gaps include drained wetland inventories, an updated and measured nutrient budget for the lake and riparian health assessments.

Planning is a slow process but will be the most effective method to help preserve the health of the Pigeon Lake watershed. The main areas of concern that have been noted are listed in Table 11, along with the corresponding parties responsible for addressing these priorities.

Based on the increase in nutrient levels in Pigeon Lake and the prolific algal blooms in 2006 and 2007, we recommend that the following steps be taken to help identify some potential sources of nutrient loading to the lake:

- Use aerial videography shoreline assessment data from 2002 to identify primary areas of riparian habitat loss and update the aerial survey with current information;
- Identify the subdivisions that still use septic tanks and research the frequency of tank cleaning and methods of disposal, particularly in the Ma-Me-O Beach area;
- Complete groundwater analysis to determine nutrient levels and movement in shallow groundwater around the lake;
- Continue annual water quality monitoring program with Alberta Environment or the Alberta Lake Management Society and ensure the lake is sampled in winter, spring and summer;
- Continue bacterial testing with the David Thompson Health Authority to determine fecal coliform levels and possibly parasite levels;
- Work with Municipalities to establish adequate riparian setbacks for all new developments;
- Educate the public regarding fertilizer and pesticide use;
- Examine surrounding agricultural land use and gathering of livestock statistics for the area;
- Develop best management practices for land use;
- Enforce removal of aquatic vegetation and bed and shore modification laws;
- Update of the nutrient budget for lake, and
- Complete a drained wetland inventory to identify critical lost wetland areas.

Table 13. Priority areas of concern and associated responsibilities.

Priority Areas (Highest to Lowest Concern)	Lead Role	Contributors
Water quality of the lake	Provincial and Federal Governments, Alberta Environment	PLWA, ALMS
Cottage development and associated land use; land use bylaws, ASP, IDP	Municipalities and SV's, Provincial government	PLWA
Sewage inputs and concerns over lake recreational use	Municipal Government Municipal Affairs, Alberta Public Health	PLWA
Education and Awareness	PLWA	Alberta Environment, NGO's
Improving land use practices	Municipal Government, Producers and General Public	All Municipalities, PLWA

9.0 Stewardship Opportunities

This report should be used by landowners, stakeholders, municipalities and governments as a basis for future watershed management planning and for the implementation of BMPs. All regulatory agencies have a role to play in watershed management planning, and the Pigeon Lake Watershed Association must work closely with Alberta Environment to ensure success. Financial and technical support will be required from project partners. Local support and behavioural changes that are needed to benefit water quality will come through communicating with and educating local residents and producers.

The surrounding Counties and municipalities must be made aware of the importance of preserving watershed health, either through public consultation or advisement from the PLWA. Important points to make would include the extensive costs associated with infrastructure and/or restoration to improve water quality, the loss of tax revenues from individuals no longer interested in living next to a "polluted" lake, the public health risks associated with toxic algal blooms and the subsequent loss of recreational value of the lake, among others. These effects would be extremely detrimental to the local economy due to the popularity of the lake.

Municipalities have a significant role to play in the protection and preservation of watershed health in many ways, including:

- Enforcement of environmental Bylaws and increased bylaw presence;
- Creation of environmentally conscious Area Structure Plans and Municipal Development Plans with adequate environmental reserves;
- Harmonizing development bylaws with surrounding municipalities and ensuring the highest standards are used;
- Regular and scheduled review and revision of bylaws as required;

- Support watershed management planning activities, including staffing resources, establishing/maintaining ratepayer buy-in, continued education and awareness programs, newsletters and newspaper articles, and establishing a progressive approach with developers and realtors;
- Consider wider environmental reserves, municipal reserves, and minimum setbacks from water bodies where possible;
- Stormwater management and low impact development initiatives for new developments, retrofitting options for older developments;
- Control/prohibit development in sloped areas due to the potential for stormwater runoff;
- Encouraging the use of Environmental Farm Plans and Homesite Assessments; and
- Begin private sewage inspections.

Cottage owners have many options available to them for helping to restore the health of the lake and watershed. Groups such as Living by Water and ALMS (among others) have many programs available for assisting cottage owners with improving their land use practices, from how to better manage vegetation to fertilizing practices and water management. A list of stewardship groups can be found on the Alberta Stewardship Network website at: www.ab.stewardshipcanada.ca.

On a community basis, initiatives such as shoreline cleanup days should be initiated by the Counties or by the PLWA, and participation in program like Alberta Water Quality Awareness Day and Farm WaterWatch should be promoted. Partnerships can be formed with the Alberta Fish and Game Association, Water's Edge Resource Group, the West Central Conservation Group, Alberta Riparian Management Society, Ducks Unlimited Canada, the Alberta Conservation Association and the Living By Water Project to host open houses, lake awareness days, riparian and wetland restoration sites, and other opportunities to increase the level of education and awareness in the Pigeon Lake watershed residents and stakeholders.

Associated with water quality improvement would be restoration and protection of wetlands and riparian areas, sewage and stormwater best management practices, nutrient management in residential areas, changes to the land use bylaws and IDP to further protect sensitive areas and limit development and public education and outreach regarding watershed health and beneficial land use practices. A recommendation for future management initiatives would be to implement a long term, annual sampling program for Pigeon Lake in order to monitor lake water quality and as a performance measure for watershed restoration programs. Sources of fecal contamination should be identified and quantified with methods such as microbial source tracking.

A generic land use bylaw has been drafted by the Bow River Basin Council and is freely available for municipalities to review and adopt. It can be downloaded from the BRBC website (www.brbc.ab.ca). Other forward-thinking initiatives have been undertaken by Lac La Biche County, such as the adoption of the Riparian Setback Matrix Model into their planning documents. The model and guidance for use can be found on the County website: http://www.laclabichecounty.com/Planning/planning.aspx.

10.0 Future Strategies

In the near future, the PLWA should continue on the watershed management planning process to address some of the issues faced in the Pigeon Lake watershed. To proceed effectively, a watershed advisory committee (WAC) should be formed, followed by ad-hoc technical advisory committees (TACs) as required. The WAC will need to formalize their mandate, include all involved municipalities and stakeholders and identify grants or other funding and in-kind assistance in order to complete the watershed management plan and associated implementation activities.

Planning initiatives with the two Counties and all Summer Villages should be undertaken to harmonize legislation to protect watershed health. Outreach and education programs should focus on nutrient management best management practices for the agricultural and recreational cottage communities. Several data gaps should be filled, as listed above. Environmental Farm Planning should be undertaken on a large scale and this will likely involve a significant commitment from county agricultural fieldmen. The watershed management plan for Pigeon Lake should be linked with the larger planning initiatives in the Battle River Basin in order to ensure consistency and harmony among plans.

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