

WATER RESOURCES ASSESSMENT FOR THE PEEL WATERSHED

**James Kenyon, Ducks Unlimited Canada
Gerry Whitley, Consultant**

**Prepared for the
Peel Watershed Planning Commission**

April 1, 2008

ABOUT THE AUTHORS

James Kenyon moved to the Yukon in April 2007 to accept a position with Ducks Unlimited Canada. Previous work took him throughout British Columbia and to Alberta working on numerous field studies with Ducks Unlimited Canada and the Canadian Wildlife Service among others. He attained his M.Sc from Simon Fraser University in 2005 after studying the colony dynamics of the Great Blue Heron. Between 2005 and 2007 he worked with the Canadian Wildlife Service in British Columbia examining conservation rankings of estuaries and marine waters as well as studying the distribution of pelagic seabirds. Since arriving in the Yukon he has had the opportunity to visit many areas of the territory including aerial surveys for waterfowl on the Peel Plateau.

Gerry Whitley has been interested in water quality since he arrived in the Yukon in 1969 to help start up the Anvil Mine in Faro. He joined Yukon Water Resources in 1975 as a water quality professional and has been a consultant since he retired 2001. Between 1980 and 1983 he led the Canada, Yukon and British Columbia study of the Yukon River Basin. Gerry has been fascinated by the Peel Basin throughout his career. He has sampled the rivers and streams in all seasons, endured the mosquitoes of Engineer creek and canoed the Wind River.

ACKNOWLEDGEMENTS

This report was commissioned on behalf of the Peel Watershed Planning Commission, with coordination by the PWPC Senior Planner, Brian Johnston. Data contributors and editors included:

Heather Jirousek (YTG – Department of Environment-Water Resources Branch)
Richard Janowicz (YTG – Department of Environment-Water Resources Branch)
Bob Truelson (YTG – Department of Environment-Water Quality Section)
Andrea Czarnecki (INAC – Water Resources Division)
Silvie Forest (Ducks Unlimited Canada – Edmonton)
Brian Johnston (PWPC)

We would like to thank all those who have assisted in the production of this report.

WATER RESOURCE ASSESSMENT

Overview

Several key points regarding water resources within the Peel Watershed Planning Region (PWPR) include:

- Water use (and deposit of waste into water) is regulated by the *Waters Act* (Yukon).
- Regulatory decisions will consider water/aquatic ecosystem objectives as identified in the transboundary agreements.
- Several wetlands have been identified for their importance to waterbirds including Chappie Lake, Turner Lakes, Tabor Lake, and Jackfish Creek.
- Major rivers within the watershed include the Peel, Bonnet Plume, Snake, Wind, Ogilvie, Blackstone, and Hart.
- Benchmark water quality is naturally poor.
- Water availability is limited, particularly in winter.
- Industrial requirements may be more than the potential supply of available water.

Use of water resources within the PWPR is subject to the *Waters Act* (Yukon). In addition, regulatory decisions regarding water use will consider the Yukon/Northwest Territories Transboundary Water Management Agreement (as part of the Mackenzie River Basin Transboundary Waters Master Agreement) between the Government of the Yukon Territory, Government of Canada and Government of the Northwest Territories as well as First Nation Final Agreements with affected First Nations. These agreements in general provide water/aquatic ecosystems objectives which seek to retain natural conditions while allowing for sustainable development and traditional use of water resources. Watershed integrity can be described as the maintenance of the quantity and quality of water flow. Maintaining this integrity is important to ensure the sustainability of aquatic ecosystems. Currently, the Peel Watershed is believed to be in relatively natural or pristine conditions.

The Peel Watershed Planning Region encompasses the Yukon Portion of the Peel River watershed. The Peel River watershed is comprised of 4 major river drainages: the Peel, Bonnet Plume, Snake, and Wind rivers. Additionally, the Hart, Blackstone, and Ogilvie rivers are large tributaries in the upper reaches of the Peel. Other important lakes and wetlands include Chappie Lake, Turner Lakes, Tabor Lake, Vittrekwa River, and Jackfish Creek.

The water resources of a region can be described via many attributes. Attributes include snow cover, permafrost, glaciers, water availability, and water properties such as chemistry and water quantity/quality. Water resources can also be described by its anthropogenic uses such as industrial needs and availability and how it responds to climate change.

Background

The Peel River watershed is made up of the Peel River along with its major tributaries: Bonnet Plume, Wind, Snake, Ogilvie, Blackstone, and Hart Rivers. Important wetland complexes, identified primarily for their use by waterbirds by the Wetlands Technical Committee, include Chappie Lake, Turner Lakes, Tabor Lake, and Jackfish Creek.

The Peel River watershed was described as ‘at the pioneer stage of development’ in 1965 (Department of Northern Affairs and National Resources 1965, page 18) and it remains so today despite the construction of the Dempster Highway. Water quantity and quality are believed to remain virtually unchanged from natural conditions.

The basin is covered with continuous permafrost and groundwater may be limited or nonexistent. Stream flow may be changing due to climate change but that is not yet clear from the record. Although modern water quality methods can detect human manufactured compounds carried by long range atmospheric transport, these compounds are at extremely low concentrations, similar to other northern rivers and lakes. Climate change could result in flow and quality changes which would not be observed in a monitoring record because it takes some years of data to demonstrate change and monitoring is limited. It is possible that traditional users would notice changes in flow or water quality before the monitoring network. Users could be the best monitors of change.

Water quality and quantity are usually judged by the suitability of the water for hydroelectric, industrial, or in-stream use. The suitability of water for subsistence use and sustaining aquatic life has also been examined. Since the waters of the basin are not used for any industrial purpose, water quality is unaltered and natural. However, due to the dynamic nature of the basin, waters of the basin are commonly turbid with high sediment loads. Water quality has been this way since before humans arrived in the region.

The rivers, streams and lakes are ice covered from freeze-up to break-up, approximately September to late-May or early-June. Water quality in winter is good, as it reflects the quality of the soils and gravels of the shallow aquifers. Water and sediments may contain metals immediately downstream of metal rich areas but only in small concentrations. Since storage of water in lakes and shallow aquifers is limited due to permafrost, flowing water may only be found in localized reaches and in the large rivers such as the Peel River. Limited water supply and cold water temperature are limitations on water use; however, water quality would be expected to be suitable for industrial use.

At breakup, the water quality situation changes dramatically. The Peel River flows through frozen soils which contribute sediment through erosion of river banks and through thawing of ground ice. The sediment concentration varies with the flow of water and the rate of thawing of the adjacent ground and is not predictable. Sediments carry the bulk of the substances and metals which are measured as water quality variables. The Peel River is notable for the high sediment concentrations which can occur during open water (summer) and the resulting poor water quality. Surface water may not be suitable for industrial or municipal uses without treatment.

Methods

Information regarding the water resources of the Peel River watershed came from a variety of sources. This included federal government agencies such as Department of Indian and Northern Affairs (or an equivalent department), Environment Canada including the Sustainable Development Branch and Inland Water Branch, Agriculture and Agri-Food Canada, and the Water Survey of Canada. Territorial agencies such as Yukon Environment have data on yearly snow depths, stream flow and water quality. Boards and committees with representatives from a variety of government departments, First Nations, and non-government organizations have data on water resources within the Peel River watershed including the Mackenzie River Basin Board and the Yukon Wetlands Technical Committee. Data was also found in reports to government by independent contractors and government employees. The Peel Watershed Planning Commission has data regarding the glacial history and has identified human interests in water and perceived issues. Data also exists within the primary scientific literature.

Discussion

Mackenzie River Basin Transboundary Waters Master Agreement

The Mackenzie River Basin Transboundary Waters Master Agreement is an agreement between the Government of Canada and the Alberta, British Columbia, Northwest Territories, Saskatchewan, and Yukon governments. There are five guiding principles of the Mackenzie River Basin Transboundary Waters Master Agreement: equitable use, prior consultation, use of resources in a sustainable manner, maintenance of ecological integrity, and harmony and cooperation in resolving issues. The Yukon-Northwest Territories Transboundary Water Management Agreement falls under the Master Agreement. Its purpose is to “cooperatively manage, protect, and conserve the ecological integrity of the aquatic ecosystem”. This agreement will lead to the development of ecological indicators that assess environmental stress, meet water quality objectives consistent with the Canadian Environmental Quality Guidelines (Canadian Council of Ministers of the Environment 1999), and have the interim water quantity objective of no change in flow rate caused by new human activity that could affect the aquatic ecosystem. Ecological indicators will be developed at a later date with the agreement being amended accordingly.

Yukon First Nations have water rights under Chapter 14 of the Umbrella Final Agreement (Minister of Indian Affairs and Northern Development 1993). Traditional uses are guaranteed although no changes in water quality, quantity, or rate of flow are allowed.

Watersheds

The Peel River watershed covers approximately 6.7 million hectares or 14% of the entire Yukon land base. The Peel River watershed is bounded in the west by the Richardson Mountains and Nahoni Range, the Selwyn and Wernecke Mountains in the south, the

Ogilvie Mountains in the southwest, and the Mackenzie Mountains in the east. The Ogilvie River drains the Nahoni Range and the western portion of the Ogilvie Mountains. The Ogilvie Mountains are also drained by the Blackstone River. The Wernecke Mountains are drained by both the Hart River in the west and the Wind River. The Bonnet Plume River drains the Selwyn Mountains west of the Bonnet Plume Range while portions of the Mackenzie Mountains are drained by the Snake River. The Richardson Mountains are drained by a series of small rivers including the Caribou, Trail, Road, and Vittrekwa Rivers flowing directly into the Peel River (*See Figure 1: Watershed map*).

Knowledge of water quantity and quality come from many sources including a 1965 report on hydroelectric potential, Water Survey of Canada hydrometric surveys, Mackenzie River Basin Study reports from 1981 and 2003, and a wide variety of scientific reports conducted since the early 1980's. Water quality is generally, but naturally, poor within the Peel River watershed. High water levels in summer lead to high sediment load in rivers due to bank erosion. Metal concentrations are naturally high but metals attach to sediment particles rendering them relatively harmless to aquatic plants and animals. Water flow of the Peel River at Fort McPherson is 28 million dam³ per year (http://www.wsc.ec.gc.ca/hydat/H2O/index_e.cfm?cname=main_e.cfm). Most water flow data is historical data from five stations throughout the Peel River watershed although two stations have been reactivated: one along the Peel River above Canyon Creek and the other on the Blackstone River near Chapman Lake.

Wetlands and Lakes

Wetlands are important for maintaining the hydrology of a watershed through the ability to mitigate effects of flooding, filtering sediment, preventing erosion, and storage and supply of surface water. The National Wetlands Working Group (1988) defined a wetland as "land that is saturated with water long enough to promote wetland or aquatic processes as indicated by poorly drained soils, hydrophytic vegetation and various kinds of biological activity which are adapted to a wet environment". This definition of wetlands has five classes of wetlands within it: bogs, fens, swamps, marshes, and shallow open water. Currently, no formal, spatially explicit wetland inventory exists for the Peel River watershed. In addition to lakes, all five wetland classes have been identified within the watershed (see Rosie 2005). Rosie (2005) describes the distribution of wetlands within the watershed, finding that wetlands are very common in the Fort McPherson Plain and Peel Plateau ecoregions but less so in the Eagle Plains and British-Richardson Mountains ecoregions. Rosie (2005) found that wetlands are abundant on the Fort McPherson Plain due to its low relief. Bogs and fens are most common, with fens being very extensive and including patterned fens which serve as drainage ways for the area, particularly around the Jackfish Creek area. Portions of the Peel Plateau ecoregion are similar to the Fort McPherson Plain with respect to types and expanse of wetlands. Marshes and swamps are common along creeks and rivers in all ecoregions, particularly the Peel River. Rosie (2005) found that type of soil, in particular glaciated moraine till or non-glaciated soils, and presence of permafrost can impact the type and extent of wetlands in an area.

Four wetland complexes have been identified by the Yukon Wetlands Technical Committee as important wetland sites: Chappie Lake, Jackfish Creek, Tabor Lakes, and Turner Lakes. All four wetland complexes were chosen due to their use by waterbirds, songbirds, gulls, and birds of prey. Chappie Lake is located between the Bonnet Plume and Wind rivers, Jackfish Creek is located along the Yukon-Northwest Territories border in the eastern portion of the Peel River watershed. Tabor Lakes is located along the Yukon-Northwest Territories border just east of the Peel River. Turner Lakes is located just west of the Peel River north of the confluence of the Peel and Snake Rivers. The use of these areas by waterbirds, particularly during the moulting period and migration, is due to its natural connection as a flight path for birds travelling to and from Alaska and the Mackenzie Valley.

Major rivers

The Peel River watershed consists of a number of major rivers in addition to the Peel River. These rivers include the Bonnet Plume, Blackstone, Hart, Ogilvie, Snake, and Wind Rivers. The Ogilvie, Blackstone and Hart Rivers comprise the upper reaches of the Peel River. Further downstream the Wind, then the Bonnet Plume, and then the Snake drain into the Peel River. In general, rivers flow north or eastward with the exception of the lower reaches of the Snake River which flows west to meet the Peel River. Many smaller rivers and creeks drain into each of these major rivers. The eastern slope of the Richardson Mountains are not drained by a major river but numerous smaller ones such as the Caribou, Trail, Road, and Vittrekwa Rivers flow directly into the Peel River. The winter precipitation is stored as snow with most of the annual runoff occurring during the snow melt between mid-May and mid-June. On main rivers, the peak flow occurs within one or two weeks of break-up.

Snow cover

Snow depths vary by basin within the Peel River watershed (*See Figure 2: Snow Depth map*). The Ogilvie, Hart, and Snake River drainages usually have less snow than the Peel River or forested areas of the Wernecke Mountains, but alpine areas have similar snow level (Russell et al 1993).

Environment Yukon (2007) prepares a snow survey three times annually after March 1, April 1 and May 1. It summarizes annual winter and meteorological conditions for Yukon. The Peel basin is described using the snow pack at Blackstone River 10MA-SC01, Ogilvie River 10MA-SC02, and Bonnet Plume Lake 10MB-SC01. The document predicts runoff volume and peak flows.

Permafrost

Rosie (2005) describes permafrost in relation to wetlands. Most wetlands have no permafrost under them with the exception of bogs and some swamps. Permafrost is critical to the cyclical nature of bog-fen complexes commonly observed on the Fort McPherson Plain and Peel Plateau. Janowicz (2007a,b) places the Peel Basin in a region of continuous permafrost. Continuous permafrost (defined as more than 90% coverage) prevents surface water from becoming groundwater. This northern hydrologic flow type is located within the northern portion of the discontinuous permafrost zones, and the

southern portion of the continuous permafrost zones, in an area which receives 300 to 400 mm of annual precipitation. Annual peak flow increases significantly with latitude as a result of the increasing dominance of the underlying permafrost which reduces the pathways to the stream channel. Conversely, annual minimum flows decrease with latitude due to lesser groundwater contributions to winter stream flow. Many smaller streams within the continuous permafrost zone are completely dominated by the underlying permafrost and have no observed flow during the latter part of the winter.

A developing trend for streams in the continuous permafrost zone is increased winter flow and for streams with no winter flow, the possibility of future winter flow. Similarly, spring peak flows may be reduced in future as infiltration increases through degrading permafrost. Permafrost can affect river hydrology and channel stability through increasing the proportion of surface runoff to total runoff, slowing bank erosion in the short term, and increasing the relative importance of block slumpages in channel migration (Mackenzie River Basin Study Report Supplement 2, 1981).

Glaciers

Western sections of the region were not glaciated but the Peel Plateau, Fort McPherson Plain and lower elevations within the Richardson Mountains were covered by the Laurentide ice sheet (Reid and Skinner 2008). The Mackenzie Mountains were heavily impacted by glaciation with a few alpine cirques remaining (Reid and Skinner 2008). There presently are glaciers in the headwater regions of the Peel (Bonnet Plume), but streamflow response due to glacier melt would be restricted to headwater regions only.

Water Properties

Chemistry

Schier et al. (1980) report on water quality studies on the Ogilvie River. Dissolved oxygen concentrations were depressed under ice cover in late winter coincident with the highest concentrations of basic cations. Both these results have subsequently been observed at many Yukon locations (Ref 8 in Schier et al. 1980). Dissolved oxygen may be depressed under ice and the opportunities for re-aeration would be limited. Substances with an oxygen demand should not be discharged to surface waters. The water of the Bonnet Plume River was hard (~270 mg/L) and contained relatively high sulphate concentrations (~116 mg/L) (Whitley et al. 1996). All metals were below CCME guidelines for aquatic life. Overall, water in the Peel River watershed has a high average pH of 8.2, an alkalinity 133 mg/L, conductivity 376 uS/cm, 230 mg/l total dissolved solids, calcium 49, Magnesium 15, sulphate 67 and hardness of 189 mg/L. These results indicate that the waters of the basin are hard to very hard and flow through rocks containing carbonates (EMAN-North, page 3-17). Engineer Creek is a significant source of metals, acid rock drainage and related water quality variables to the Ogilvie River (Kwong et al. 2008). Trace metal amounts, including zinc, peak during high flow periods of summer and when suspended sediment loads in the river are also high (Mackenzie River Basin Board 2003).

Water Quantity

Water flow of the Peel River at Fort McPherson averages 23 million dam^3 per year while other tributaries range in flow from just over 300,000 to 3 million dam^3 per year (Table 1). Most water flow data is historical data from five stations throughout the Peel River watershed although two stations have been reactivated: one along the Peel River above Canyon Creek and the other on the Blackstone River near Chapman Lake. Water flow is controlled by the mountainous terrain and permafrost (Energy, Mines and Resources Canada, Surveys and Mapping Branch 1985) with peak flows occurring after snow melt in late May/early June (Figure 1) (Smith et al. 2004). Timing and magnitude of water flow peaks varies between years (Figure 1). Secondary peaks can be attained due to summer rains (Smith et al. 2004). Annual precipitation is about 300 mm throughout the watershed with mountainous regions receiving slightly higher levels (Smith et al. 2004).

Table 1: Mean annual discharge at seven historical water monitoring stations throughout the Peel River watershed.

Name	Years	Area (km^2)	Mean total discharge (dam^3)
Peel River at Fort McPherson 10MC002	1969 to 2006	70800	23300000
Snake River near mouth 10MB003	1975 to 1995	8910	3150000
Snake River above Iron Creek 10MB001	1963 to 1967	2770	
Peel River above Canyon Creek 10MA001	1962 to 2006	26700	5960000
Ogilvie River at km 197.9 Dempster Highway 10MA002	1974 to 1996	5410	985000
Bonnet Plume River above Gillespie Creek 10MB004	1981 to 1994	3780	1860000
Blackstone River near Chapman Lake Airstrip 10MA003	1984 to 2006	1130	309000

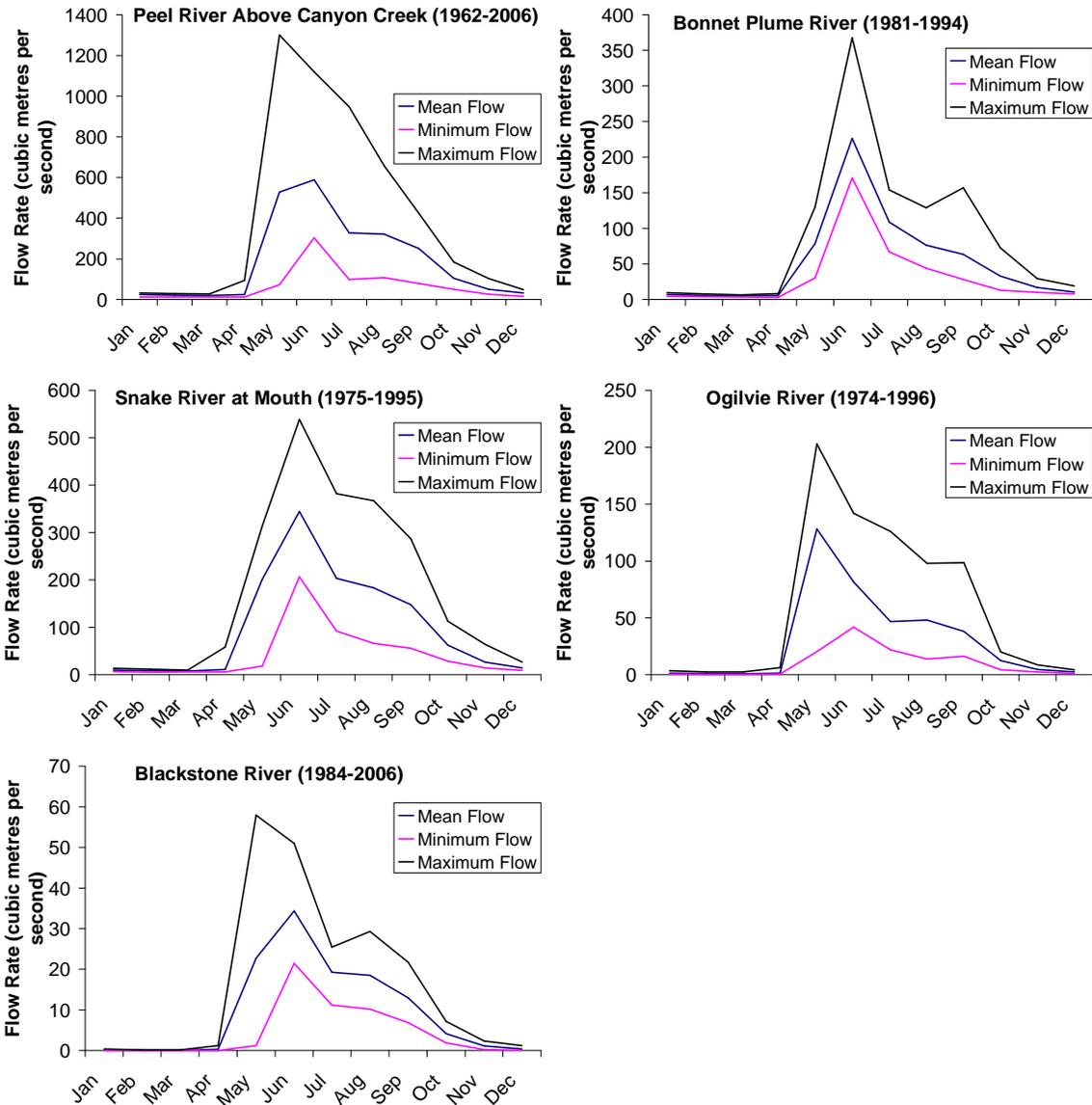


Figure 1: Monthly flow rates (m^3/s) at hydrometric stations within the Peel River watershed. Data from the Water Survey of Canada (http://www.wsc.ec.gc.ca/hydat/H2O/index_e.cfm?cname=main_e.cfm).

Water Quality

Water quality is naturally poor but is safe for drinking (after boiling for 5 minutes as per Health Canada) and aquatic life. There is no licenced water use or deposit of waste in the Yukon portion of the basin. The basin is subjected to atmospheric deposition of long range transport of pollutants (such as persistent organic pollutants) which remain at low levels. In the open water season, the Peel River and lower tributaries may contain high sediment levels due to erosion. Some streams in the upper watershed may contain locally elevated metals concentrations reflecting mineral deposits. Some total metals exceeded the Canadian Environment Quality Guideline values (Canadian Council of Ministers of

the Environment 1999) however as metals are attached to sediment particles they are unlikely to pose a hazard to aquatic life. Dissolved metal concentrations were significantly lower than total metal concentrations supporting the fact that metals are attached to particulate matter. All metals concentrations were within the historical range of water quality at Peel River above Fort McPherson (1980-2000).

Polycyclic aromatic hydrocarbons (PAHs) found in suspended sediment are in low levels and are likely natural given the known oil and gas reserves in the Peel Plateau (Czarnecki 2007). Some PAHs are associated with cancers and can affect the reproductive abilities of animals. The levels of PCBs found in July 2002 were very low and typical of long range transport. Water quality in the Peel River watershed is different in winter and summer. In winter, the ice cover separates the river from surface disturbance so generally suspended sediments and metals are low and dissolved substances are at a seasonal high (Hem 1985, Mackenzie River Basin Board 2003, EMAN-North 2005). In summer, water quality is dominated by erosion (bank erosion and channel scour). The associated parameters are colour, turbidity and total suspended solids (TSS) (Hem 1985, EMAN-North 2005). Suspended sediments can be very high following heavy summer rains.

Water availability

Water is available for industrial-level use mainly during the summer months (Figure 1). Flow rate of rivers declines to near zero during winter with large increases during summer months when it peaks shortly after ice melt. Other sources of water, other than river water, are limited as most lakes are shallow and ground water is scarce. Traditional water users take the natural variation in water quality and quantity into account in their seasonal use patterns. Traditional camps usually have an associated water source. Access to camps takes the variation of flow into account. Likewise, the traditional fishery is adapted to the natural water quality even though fish life may be limited by it. Past and present water use has been limited to tourism/recreation users, mining exploration teams and oil/gas exploration teams who take water for drilling and camp use. Personnel are aware of the natural conditions and have adapted to the local flow and quality issues. At present, the poor natural water quality is not limiting to consumption.

Future municipal/camp users will find that the difficulty of finding a winter water supply and the challenges of treating the more abundant summer water with variable quality to be major issues. Developers looking for an industrial water supply may find that water supply is limiting. Storage and recycling may be required to maintain operations year round. Lack of information on the fisheries resources, particularly over-wintering fish populations, will make water abstraction a critical issue for development planning.

Industrial requirements

Future industrial demand for water and water availability for industrial activity are unknown (Peel Watershed Planning Commission 2005). All industries would require water either for use in camps or in industrial activity. Industries may include hydroelectricity, oil/gas exploration and development, or mineral exploration and development.

Hydroelectric power

In 1965, the Department of Northern Affairs and National Resources, Water Resources Branch examined the feasibility of hydroelectric projects on northern Yukon rivers including the Peel River (Department of Northern Affairs and National Resources 1965). This report was part of the survey of the hydroelectric water resources of Canada and involved flow measurements, field surveys, aerial photography and office studies between 1962 and 1965.

The report discussed a diversion plan and non-diversion plans. The diversion plan dammed the Porcupine River to provide flow for power plants on the Rat River through the Bell-Rat Pass. The final stage of development would include the Peel River for flow by a dam at Aberdeen Canyon and diversion to the Porcupine River through Eagle Pass. This five stage project would produce 10 billion kWh of firm power annually.

Non-diversion projects on the Porcupine and Bonnet Plume rivers were discussed but the report concluded that the studies were incomplete. A storage project at Aberdeen Falls in conjunction with a run-of-river project at the Bonnet Plume site would produce 2.7 billion kilowatt hours (kWh) or 310 megawatts (MW) of firm energy annually. A kilowatt hour is the amount of energy equivalent to a power of one kilowatt running for one hour. The Yukon presently has maximum hydroelectric capacity of 76.3/60.3 MW (summer/winter) (Yukon Development Corp. 2001). Additional hydrologic data and studies would be required to define the hydroelectric potential of the basin and engineering feasibility using recent experience with northern systems.

The study discussed the lack of markets for the size of the power projects examined and mentioned the iron ore deposits as a potential future customer. The need for large reservoirs to compensate for the long winter low flow season and the need for bedrock dam foundation in permafrost shaped the design of the power projects. There is no discussion of other resources.

There are currently no plans for hydroelectric development within the Peel River watershed (Peel Watershed Planning Commission 2005).

Water exports

“Bulk removal” is usually used to describe the removal of significant quantities of water through tanker ships, pipelines or inter-basin diversion projects. Such removals have the potential, directly or cumulatively, to harm the health of the watershed.

In 1999, the federal government announced a strategy to prohibit bulk water removal out of all Canadian water basins, thereby ensuring the long-term security of Canada’s freshwater resources. Since that time, the federal government and virtually all the provinces have taken steps to ban bulk water removal.

The Yukon Government adopted the Department of Indian and Northern Affairs’ Policy Statement respecting the Prohibition of Bulk Removal from the Northwest Territories and Nunavut in December, 2003. This policy defines bulk water as any water transferred out

of a river basin in any individual container greater than 40 litres, or removal by any means that involves permanent out-of-basin transfer, whether by diversion, tanker or other mechanism.

Climate change impacts

Impacts of climate change are difficult to predict as the complexity of hydrologic changes make different responses possible (Price and Waddington 2000). Increases in mean air temperature may cause an increase in melting of permafrost resulting in the extensive peat plateau bogs to transform into fens (Rosie 2005). Jorgenson and Ostercamp (2005) suggest melting surface permafrost may lead to low lying areas with fine grained soils having lakes form and a transition of forested areas to bogs and fens, or in some cases becoming better drained. Up to 16 forms of permafrost degradation have been identified, all causing some type of alteration to hydrology and occurring at various spatial scales (Jorgenson and Ostercamp 2005). Warmer temperatures may lead to an increase in winter flow in streams causing a reduction in the magnitude of spring peak water flow. Glaciers within the Peel River watershed are within a transitional zone where advancement or retreat is possible depending upon a number of factors including elevation and proximity to an ocean (Brugman et al. 1997).

Literature Cited

Brugman, M.M., P. Raistrick, and A. Pietroniro. 1997. Glacier related impacts of doubling atmospheric carbon dioxide concentrations on British Columbia and Yukon. In Responding to global climate change in British Columbia and Yukon. Eds E. Taylor and B. Taylor. Aquatic and Atmospheric Sciences Division, Environment Canada, Pacific and Yukon Region, and the Air Resources Branch, British Columbia Ministry of Environment, Lands, and Parks. 363 pp.

Canadian Council of Ministers of the Environment. 1999. Canadian environmental quality guidelines. Canadian Council of Ministers of the Environment, Winnipeg.

Czarnecki, A. 2007. Peel Watershed Sampling Program, Water Resources Division, Indian and Northern Affairs Canada, Yellowknife NWT. http://nwt-tno.inac-ainc.gc.ca/pdf/wr/Peel_poster_eng.pdf

Department of Northern Affairs and National Resources. 1965. Report on hydro-electric power resources of the Porcupine, Peel, and Rat River region Yukon and Northwest Territories. Department of Northern Affairs and National Resources, Water Resources Branch. 90 pages. Yukon EMR Library TK1427.N6C3.

EMAN-North. 2005. Northern Waters: A Guide to Designing and Conducting Water Quality Monitoring in Northern Canada. Northern Ecological Monitoring and Assessment Network (EMAN-North).

Energy, Mines and Resources Canada, Surveys and Mapping Branch. 1985. Canada - drainage basins, The National Atlas of Canada, 5th ed., scale 1:7 500 000. Environment Canada, Inland Waters Branch, Ottawa.

Environment Yukon. 2007. Yukon Snow Survey Bulletin and Water Supply Forecast. Environmental Programs Branch, Water Resources Section, Department of Environment. Whitehorse, Yukon.

Hem, J.D. 1985. Study and Interpretation of the Chemical Characteristics of Natural Water, Third Edition. U.S. Geological Survey Water-Supply Paper 2254.

Janowicz, J.R. 2007a. Apparent recent trends in hydrologic response in permafrost regions in Northwest Canada. Submitted to Nordic Hydrology.

Janowicz, J.R. 2007b. Increasing winter base flow conditions apparent in permafrost regions of Northwest Canada. 16th International Northern Research Basins Symposium and Workshop, Petrozavodsk, Russia, 27 Aug.-2 Sept. 2007.

Jorgenson, M.T. and T.E. Ostercamp. 2005. Response of boreal ecosystems to varying modes of permafrost degradation. Canadian Journal of Forest Research 35:2100-2111.

Kwong, Y.T. J, G. Whitley, and P. Roach. 2008; Natural acid rock drainage associated with black shale in the Yukon Territory, Canada; Submitted for publication to Applied Geochemistry.

Mackenzie River Basin Study Report Supplement 2: Alluvial Ecosystems.1981.

Mackenzie River Basin Board. 2003. Mackenzie River Basin State of the Ecosystem Report 2003, Section 5 Peel Sub-basin. Pages 133 to 138.

Minister of Indian Affairs and Northern Development. 1993. Umbrella final agreement: Council for Yukon Indians. Minister of Public Works and Government Services Canada, Ottawa, Ontario.

National Wetlands Working Group. 1988. Wetlands of Canada. Ecological Land Classification Series. No. 24. Sustainable Development Branch. Environment Canada, Ottawa, Ontario and Polyscience Publications Inc., Montreal, Quebec, 452pp.

Peel Watershed Planning Commission. 2005. Issues and interests report. Peel Watershed Planning Commission, Whitehorse, YT. 24pp.

Price, J.S. and J.M. Waddington. 2000. Advances in Canadian wetland hydrology and biogeochemistry. Hydrological Processes 14:1579-1589.

Reid, D. and S. Skinner. 2008. Conservation priorities assessment report. Peel Watershed Planning Commission, Whitehorse, YT. 103pp.

Rosie, R. 2005. Wetlands of the Peel River watershed. 15pp.

Russell, D.E., A.M. Martell, and W.A.C. Nixon. 1993. Range ecology of the Porcupine Caribou Herd in Canada. Rangifer Special Issue No. 8. 168pp.

Schier, H., Erlebach, W; Albright, L. 1980; Variations in Water quality during winter in Two Yukon Rivers with Emphasis on Dissolved Oxygen Concentration. Water Research Vol 14, No 9, p 1345-1351, September, 1980. 9 Fig, 2 Tab, 7 Ref. (abstract in file).

Smith, C.A.S, J.C. Meikle, and C.F. Roots (editors). 2004. Ecoregions of the Yukon Territory: biophysical properties of Yukon landscapes. Agriculture and Agri-Food Canada, PARC Technical Bulletin No. 04-01, Summerland, British Columbia, 313pp.

Whitley, G., P. Whitfield, B. Slater, and D. Sherstone. 1996. A Synoptic Study of Water Quality in the Bonnet Plume River Implications for a Management Plan. Notes for a conference presentation.

Yukon Development Corporation. 2001. The Power of Water: The story of hydro power in the Yukon. 22pp.

Figure 1. Watersheds

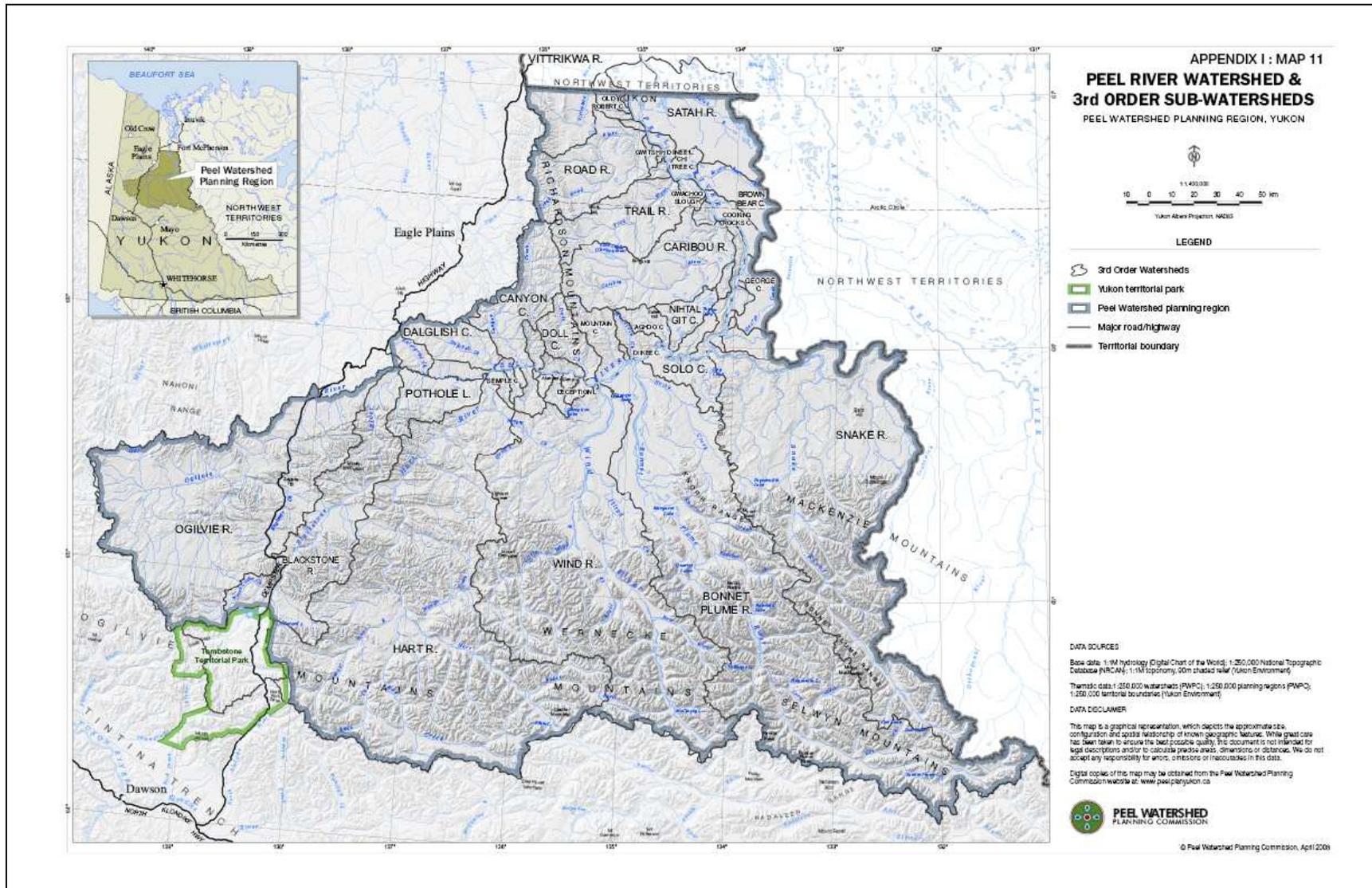


Figure 2. Snow Depth

