State of Aquatic Knowledge for the Hay River Basin

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EXECUTIVE SUMMARY

This *State of Aquatic Knowledge for the Hay River Basin* report summarizes information about the basin setting, aquatic environment (groundwater, surface water flows, water quality, and organisms that depend on the river), trends over time, and current and future human activities that could affect basin and river health. The data gathered reflects the level of information that was accessed through literature searches and various government databases of current human activities. To support long-term management of the Hay River Basin, knowledge and data gaps are identified and recommendations are made for future monitoring programs, strategies, objectives, and additional database or file searches.

The Hay River Basin is a transboundary watershed, with its headwaters in British Columbia (BC) and Alberta (AB), and its terminus at Great Slave Lake, in the Northwest Territories (NWT). The basin area (51,700 km^2) is divided among AB (77% of the area), BC (17%) and the NWT (6%). While each jurisdiction individually has policies and processes to protect the aquatic environment, management of a transboundary river like the Hay requires cooperation and an integrated approach among the three jurisdictions. The Mackenzie River Basin Transboundary Waters Master Agreement and associated Bilateral Water Management Agreements between the jurisdictions provide the framework for integrated management of the basin.

The AB-NWT Bilateral Water Management Agreement assigns a Risk Informed Management Class 3 for water quality and quantity in the Hay River Basin on the basis of land development and/or activities, high traditional use, existing annual trends in water quality, and use as a community drinking water supply.

By considering the existing aquatic knowledge, the types of development, stressors, and effects that may occur in the future, along with gaps in monitoring data and programs, this report provides a knowledge base for integrated management and monitoring activities in the basin, by the individual jurisdictions and jointly for transboundary considerations.

Environmental Setting

The Hay River is 1,114 km long and flows generally northeast from the foothills of the Rocky Mountains to Great Slave Lake in the NWT. The Chinchaga and Kotcho rivers are major tributaries. There are three sub-basins: the Upper Hay, Chinchaga, and Lower Hay. The basin is situated within the boreal forest and is home to many terrestrial and aquatic wildlife species. Wetlands and low-lying land cover about 30% of the basin area. Notable physiographic features include the Hay-Zama Lake wetland complex in Alberta (an internationally-recognized Ramsar 'wetland of importance') and two large waterfalls (Alexandra and Louise Falls) in the NWT that provide spectacular recreational and aesthetic opportunities.

The Hay River Basin is mainly situated within the traditional territories of the Dene Tha' First Nation, in AB and BC, the Fort Nelson First Nation in BC, and the Dehcho First Nations, Kátł'odeeche First Nation, and Northwest Territory Métis Nation in the NWT. Aboriginal peoples have carried out traditional, cultural, and subsistence activities within the Hay River Basin for many generations.

The population of the basin is estimated at 5,897 people (2011 census), with the Town of Hay River, NWT, the largest community. There is one other municipal community in the NWT (Enterprise), eight in AB (Rainbow Lake, Zama City, Chateh, Indian Cabins, Steen River, Slavey Creek, Lutose, and Meander River), and none in BC. Various development and land use activities, such as oil and gas, forestry, and agriculture occur throughout the Hay River Basin.

Hydrologic Conditions

Water Survey of Canada produces flow data at six hydrometric stations in the Hay River Basin. There is year-round daily monitoring for two stations ('Hay River at Hay River' since 1963 and 'Chinchaga near High Level' since 1981) and seasonal data at the other four stations. Annual discharge of the Hay River into Great Slave Lake is estimated at about 3.6 billion cubic metres (m^3). There have been no notable changes in total yearly flow over the past 40 years, although flows vary greatly on a seasonal and annual basis, and there is a pattern of slightly increased winter baseflow in the Lower Hay sub-basin. Flow typically peaks in May. Extensive data analysis was not carried out to understand whether there are trends in the sub-basins, especially the Upper Hay, related to water withdrawals for industries (mainly oil and gas sector), changes in land cover, or climate change. Additional analysis and monitoring of additional stations are recommended.

A review of river morphology and flow path was conducted to provide baseline information and to comment on evolution of the river flow path over the last 50 to 60 years. A review of historical and current aerial imagery at seven representative sites along the Hay River indicates there has been no significant change in morphology over that time period, although there are localized examples of erosion and small landslides typical of large rivers.

Hydrogeologic Conditions

There are three monitoring wells in AB (two in the Upper Hay and one in the Lower Hay) that have been monitored for groundwater level and quality since 1989. Seasonal patterns and an influence from surface waters are evident for two wells (Upper Hay), but less so for the Lower Hay well. There is no other consistent or continuous monitoring of transboundary groundwater in the Mackenzie River Basin, including the Hay River Basin, at this time. Registered water wells are listed in the AB Water Well Information Database and BC Ground Water Wells and Aquifer Database. There are 1,254 registered water wells in the basin (1,220 in AB and 34 in BC), 74% of which are for the commercial/industrial sector (mainly oil and gas). About half the known water well records are for completion at less than 30 m below ground surface and three-quarters are completed to less than 150 m below ground surface. With the exception of the NWT Office of the Regulator of Oil and Gas Operations (for wells drilled through sedimentary rock to a depth greater than

150 m), there is no central registry for well data in the NWT and no consistent monitoring of transboundary groundwater conditions. Also, there are incomplete well records in BC because reporting was voluntary before 2015. Recommendations are made to address these gaps.

Water Quality

Environment Canada and the Government of the NWT monitor water quality of the Hay River at a station on the AB-NWT border (HR-BORDER) in the Lower Hay sub-basin for general parameters, nutrients, metals, and organic contaminants in surface water, centrifuge water, and suspended sediment. The long-term dataset began in 1988. There is also a program using permeable membrane devices (PMDs) at the Town of Hay River to monitor hydrocarbons in water. The long term monitoring data were used to develop interim triggers that identify conditions outside the normal (median) and extreme (90th percentile) range as part of the Bilateral Water Management Agreement.

Hay River water has naturally elevated levels of organic carbon and colour (related to abundant wetlands in the basin) and suspended sediment (typical of low gradient northern rivers). Water is hard and slightly alkaline in pH. Under ice, dissolved oxygen levels are often below the Canadian Council of Ministers of Environment water quality guidelines (CCME WQGs) for protection of aquatic life. River water is naturally mesotrophic to eutrophic, based on nitrogen and phosphorus levels, respectively. Many metals meet CCME WQGs, except for total iron (60% of samples), cadmium (23%), copper (15%), zinc (4%) and, on one occasion each, total arsenic, chromium, and lead. The exceptions are mainly associated with the particulate fraction and spring freshet, when total suspended solids and turbidity are elevated.

Organic contaminants such as polychlorinated biphenyls (PCBs) and pesticides are present in low concentrations, well below guidelines, and likely come from long-range atmospheric transport.

Polycyclic aromatic hydrocarbons (PAHs) are present in water and suspended sediment, at levels below water and sediment guidelines, and not considered a risk to aquatic biota. The PAH levels are, in general, lower in the Hay than the Slave River , where there are vast natural oil reserves and intense oil sands developments; however, overall, PAH levels in both rivers are low. Detectable PAHs in the Hay River reflect mainly petrogenic (petroleum) sources and likely come mainly from sources in the basin and, pyrogenic sources (associated with combustion), from local sources and long range atmospheric transport. Naphthenic acids (associated with petroleum sources) are also present. The existing PAH data could be explored further to identify potential hydrocarbon sources in the basin.

Long term trends were identified for chloride (decreasing during the open water season) and total iron (decreasing on an annual basis); potential trends for other parameters were identified, with the recommendation that caution be used in interpretation, given either the relatively low number of data points available for analysis or high proportion of values at less than detection.

There are little or no monitoring data for individual sub-basins, and recommendations are made to address these gaps.

Aquatic Biota

The Hay River Basin provides extensive aquatic habitat values for fish and wildlife, including an estimated 26 fish, 81 bird, 4 amphibian, and 12 aquatic mammal species. Species of commercial, recreational, and subsistence interest include lake whitefish, walleye, burbot, northern pike, longnose sucker, white sucker, inconnu, and lake trout. Low dissolved oxygen concentrations during winter may limit available overwintering habitat for fish in some parts of the basin, especially if resident fish are unable to move to suitable overwintering habitat. Numerous wetlands provide habitat for migratory birds and other wildlife; the most extensive are the Hay-Zama Lakes wetland complex (recognized internationally as a Ramsar wetland of importance and nationally as an Important Bird Area). Many of the aquatic wildlife species also have significant cultural value for local Indigenous people (e.g., furbearers for trapping, moose and waterfowl as a food source).

Levels of metals, PAHs, and other contaminants in fish tissue were measured in the late 1980s and early 1990s in the Hay River within the NWT. Mercury concentrations in walleye and northern pike muscle exceeded the Health Canada advisory level for subsistence or frequent consumers but were below the advisory level for the commercial sale of fish.

There is very little information about other aspects of aquatic ecosystems (benthic invertebrates, plankton, macrophytes). In 2015, the benthic community in the Hay River at the Town of Hay River was sampled using the CABIN protocol, which will provide a baseline for future monitoring. There are few reports for aquatic biota in the basin and no long-term monitoring of aquatic health of the Hay River. Where available, the data indicate undisturbed conditions in lakes, streams, and rivers of the basin (e.g., abundant mayflies, stoneflies, and caddisflies typical of clean water and riffle conditions in streams).

Recommendations are made to address the data gaps.

Water Use and Allocation

Surface water and groundwater allocations are recorded by the BC, AB, and NWT governments, and managed through permits. Allocation (2015 data) was highest in the Upper Hay sub-basin (>80% of the entire basin allocation, mostly occurring in one licence in Alberta, from Rainbow Lake) and lowest for the Chinchaga sub-basin (less than1% for the entire basin, roughly split between BC and AB). One active withdrawal licence was identified in the NWT portion of the basin, for the oil and gas sector. The oil and gas sector accounts for 71% each of surface water and groundwater allocation for the entire basin, with the remainder used by agriculture, commercial, forestry, and municipal sectors. Total surface water allocation in the basin represents 0.18% of the average annual surface water volume available, or 3.85% of the available average winter low flow (January to March). Recommendations are made to refine the understanding of allocation versus actual use of water and seasonal usage patterns, and to fill other data gaps.

Development Activities

The oil and gas sector (mostly gas) is the main development pressure in the basin, and is most active in BC (Upper Hay and Chinchaga sub-basins) and AB (Upper Hay, Chinchaga, Lower Hay sub-basins). There are oil reserves and extraction activities in the Hay-Zama area (Upper Hay sub-basin). Forestry is the second most active sector, mainly in the Upper Hay sub-basin (AB and BC), with some forestry also in the Chinchaga (AB and BC) and Lower Hay (NWT) sub-basins. There is little activity from transportation, agriculture, municipal, and mining sectors in the basin. Local development pressure in the NWT is low compared to BC and AB.

Sources of greenhouse gases within the Hay River Basin are small: a 2013 inventory of emission sources for large facilities identified five gas plants and one co-generation power plant, which together contribute less than 0.5% of emissions in Canada.

Trends in mean annual temperature and ice conditions were examined to assess sensitivity of the basin to global increases in greenhouse gas emissions. There has been an increase of almost 1°C over the last 69 years at the Town of Hay River, NWT and 2°C over the last 37 years at High Level, AB. Late winter ice thickness and time of ice-break-up have been monitored at the Town of Hay River. Ice thickness monitoring began in 2007, and no trend has been identified to date. Timing for ice break-up has been reported sporadically since 1904 and consistently since 2008; there is no obvious trend for timing of break-up, although local knowledge holders indicated ice thickness has decreased and break-up occurs one to two weeks earlier than in the 1970s.

Summary

Flowing through three jurisdictions, the Hay River Basin provides important habitat for numerous terrestrial and aquatic wildlife species, and is used by several First Nations for traditional, cultural, and subsistence activities. Residents of 10 communities call the Hay River Basin home. Existing data show little change in surface water flow or groundwater levels over the data record, though some trends have been identified for water quality and there are naturally-occurring exceedances of CCME WQG for some metals. Levels of organic contaminants in water are well below applicable guidelines. Human development activities have been ongoing in the basin since the early 1900s and, at present, the most substantial development activity is in the oil and gas sector, followed by forestry.

Available data on the existing state of aquatic knowledge have been collected sporadically or opportunistically over time (e.g., aquatic biota), inconsistently between jurisdictions (e.g., water use/allocation, development activities), or continuously (mainly for water quality and hydrology). As a result, limited data are available to provide baseline monitoring to assess potential changes in the aquatic environment throughout the basin, whether from local human development, long-range transport of contaminants, or climate change. Several

recommendations are made to address these data gaps to assist current transboundary water management and monitoring activities.

Abbreviations and Acronyms

AANDC	Aboriginal Affairs and Northern Development Canada
AEP	Alberta Environment and Parks
AESRD	Alberta Environment and Sustainable Resource Development
ATPRC	Alberta Tourism, Parks, Recreation and Culture
BWMA	Bilateral Water Management Agreement
CABIN	Canadian Aquatic Biomonitoring Network
CCME	Canadian Council of Ministers of the Environment
CN	Canadian National
CO_2	carbon dioxide
DDT	dichlorodiphenyltrichloroethane
DFO	Fisheries and Oceans Canada
DLUPC	Dehcho Land Use Planning Committee
DO	dissolved oxygen
DOC	dissolved organic carbon
dw	dry weight
EPEA	*Environmental Protection and Enhancement Act*
ESWG	Ecological Stratification Working Group
GC	Government of Canada
GHG	greenhouse gas
GNWT	Government of the Northwest Territories
GOWN	Groundwater Observation Well Network

HR-BORDER	Hay River Border (water chemistry station)
INAC	Indigenous and Northern Affairs Canada
ISQG	interim sediment quality guidelines
LUZ	land use zone
NTU	nephelometric turbidity units
NWT	Northwest Territories
PAH	polycyclic aromatic hydrocarbons
PBDE	polybrominated diphenyl ethers
PCB	polychlorinated biphenyl
PEL	probable effects level
PFC	perfluorinated compounds
PMD	polyethylene membrane devices
RMZ	Resource Management Zone
TDS	total dissolved solids
TOC	total organic carbon
TSS	total suspended solids
WQG	water quality guideline
WSC	Water Survey of Canada

FOREWORD

This *State of Aquatic Knowledge for the Hay River Basin* report summarizes information about the basin setting, aquatic environment (groundwater, surface water flows, water quality, and organisms that depend on the river), trends over time, and current and future human activities that could affect basin and river health. To support long-term management of the Hay River Basin, knowledge and data gaps are identified and recommendations are made for future monitoring programs, strategies, and objectives.

The Hay River Basin is a transboundary watershed, with its headwaters in British Columbia and Alberta, and its terminus at Great Slave Lake, in the Northwest Territories. While each jurisdiction individually has policies and processes to protect the aquatic environment, management of a transboundary river like the Hay requires cooperation and an integrated approach among the governments in the Northwest Territories, Alberta, and British Columbia. The Mackenzie River Basin Transboundary Waters Master Agreement and associated Bilateral Water Management Agreements between the jurisdictions provide the framework for integrated management of the basin.

By considering the existing aquatic knowledge, the types of development, stressors, and effects that may occur in the future, along with gaps in monitoring data and programs, this report provides a basis for integrated management and monitoring activities in the basin, by the individual jurisdictions and jointly for transboundary considerations.

Development of this report was led by the Government of the Northwest Territories, Department of Environment and Natural Resources, and the Government of Alberta, Environment and Parks, who engaged Stantec Consulting Ltd. to prepare the report. The report reflects collaboration and input from the following people:

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- Katrina Stipec, Government of British Columbia, Ministry of Environment
- Chad Sherburne, Government of Alberta, Environment and Parks
- Peter Redvers, Kátł'odeeche First Nation
- Ross Potter, Town of Hay River
- George Low, Aboriginal Aquatic Resource and Oceans Management Program

This report has largely been compiled from scientific data, studies, and reports, and publicly available information on development activities, and traditional land use and human history in the Hay River Basin (e.g., land use plans, regulatory applications). Efforts were made to obtain the most recent development information for the basin; however, it is noted that additional information may exist, given some data accessibility issues, and the evolving nature of development activities in the basin.

Further, Traditional Ecological Knowledge or Traditional Land Use information of the Indigenous peoples in the Hay River Basin has not been integrated into the report. The Dene Tha' First Nations of Alberta and British Columbia, the Dehcho First Nations of the Northwest Territories, and the Northwest Territories Métis Nation all have a long history within the Hay River Basin and represent an important source of Traditional Ecological Knowledge and Traditional Land Use information, which can support, expand, and strengthen the compiled scientific data, and assist in development of a more comprehensive assessment.

TRANSBOUNDARY AGREEMENT

In 1997, the governments of Canada, British Columbia, Alberta, Saskatchewan, Yukon, and the Northwest Territories, signed the Mackenzie River Basin Transboundary Waters Master Agreement. The Master Agreement made provisions for establishment of Bilateral Water Management Agreements (BWMA) between provinces and territories, and founded "common principles for the cooperative management of the aquatic ecosystem of the Mackenzie River Basin" (MRBB 2009). In accordance with the Master Agreement, the Governments of Alberta and the Northwest Territories signed a BWMA for transboundary waters within the Mackenzie River Basin in March 2015. The Hay River is one of the transboundary waterbodies within the Alberta-Northwest Territories BWMA. Negotiations for an Alberta-British Columbia BWMA are currently underway, within which the Hay River will be included as a transboundary waterbody.

The Alberta-Northwest Territories (AB-NWT) BWMA is guided by "risk-informed management", an approach that requires an understanding of the risks to, and uses of, a waterbody to guide the identification and implementation of management actions (AB-NWT 2015). From risk-informed management, waterbodies are evaluated and classified based on use and intensity of development, nature and intensity of risks (MRBB 2015), and downstream water needs (AB-NWT 2015). The Hay River is categorized as a "Class 3" transboundary waterbody due to the level of development within the basin, high levels of traditional use, presence of community drinking water supplies, and identified temporal trends in winter water quantity/flow (AB-NWT 2015). Under the BWMA, all transboundary waterbodies rated as Class 2 or higher shall have Learning Plans developed to summarize existing aquatic ecosystem conditions in the transboundary watershed, existing and potential water uses and pressures, risks and receptors, and recommendations for setting transboundary triggers and objectives. This *State of Aquatic Knowledge* report is intended to contribute to the Learning Plan for the Hay River Basin, which is necessary to move forward with management plans and actions.

1.0 ENVIRONMENTAL SETTING

The Hay River Basin is a transboundary watershed that spans parts of British Columbia, Alberta, and the Northwest Territories (Figure 1-1). The Hay River is 1,114 km long and flows generally northeast from the foothills of the Rocky Mountains to Great Slave Lake in the Northwest Territories. The basin covers an area of approximately 51,400 square kilometres (km^2) (Environment Canada 2015a) and consists of three sub-basins. The Hay River Basin is situated within Canada's boreal forest, and is home to many terrestrial and aquatic wildlife species. Notable physiographic features include the Hay-Zama Lake wetland complex in Alberta (an internationally-recognized Ramsar "wetland of importance") and two large waterfalls (Alexandra and Louise Falls) in the Northwest Territories that provide spectacular recreational and aesthetic opportunities. The Dene Tha' First Nations of Alberta and British Columbia, the Fort Nelson First Nation of British Columbia, and the Dehcho First Nations, Kátł'odeeche First Nation, and Northwest Territory Métis Nation of the Northwest Territories have carried out traditional, cultural, and subsistence activities within the Hay River Basin for many generations. A variety of development and land use activities, such as forestry and oil and gas, also occurs throughout the Hay River Basin.

This section describes the environmental setting (location and physical features, geology and geomorphology, climate, soils and vegetation, and human history) of the Hay River Basin, to provide context for subsequent sections of this report.

1.1 LOCATION AND PHYSICAL FEATURES

Lying between latitudes 57° and 61° north, and between longitudes 115° and 121° west, the Hay River Basin spans approximately 490 km on a north-south axis and 250 km on an east-west axis. As shown in Figure 1-1, the Hay River Basin (approximately 51,400 km^2) is a transboundary watershed that spans three jurisdictions: Alberta, with 77% of the basin's area (39,500 km^2); British Columbia, with 17% (8,800 km^2); and the Northwest Territories, with 6% (3,100 km^2). The headwaters of the mainstem of the Hay River lie within Alberta, south of the Hay-Zama wetland complex (Figure 1-1). From its headwaters, the mainstem flows west into British Columbia and loops back into Alberta, flowing east through the Hay-Zama wetland complex. The Hay River is joined by the Chinchaga River about 24 km downstream of the Hay-Zama Lake wetland complex. From here, the river flows north, continuing into the Northwest Territories, and discharges into Great Slave Lake. The Lower Hay sub-basin begins at the confluence of the Hay and Chinchaga Rivers. Many lakes, small rivers, and streams form tributaries of the Hay River. Major tributaries include the Kotcho River in the Upper Hay sub-basin of British Columbia (which drains Kotcho Lake and is joined by the Shekilie River) and the Chinchaga River (which is the primary tributary draining the Chinchaga sub-basin and largely lies within Alberta).

Annual discharge of the Hay River into Great Slave Lake, at the Town of Hay River in the Northwest Territories, is estimated at approximately 3.6 billion cubic metres (m^3) (Environment Canada 2015a).

Elevation of the Hay River Basin drops 450 m (1,476 ft.) between headwaters to mouth (Government of the Northwest Territories and Government of Canada [GNWT and GC] 1984; Kovachis 2011; Google Earth Pro 2016) (Figure 1-2). The headwaters in British Columbia (Upper Hay sub-basin) are at an elevation of about 640 m above sea level (masl) (2,100 feet) and the headwaters in Alberta (Chinchaga sub-basin) are higher, at 750 masl (2,460 feet). These are the steepest areas of the basin. The two rivers join in Alberta at an elevation of 360 masl (1,180 ft.) and flow through the lowlands of the Lower Hay sub-basin, with a small drop in elevation to the Alberta/Northwest Territories border (at 330 masl [1,080 ft.]) and a larger drop to Great Slave Lake (at 160 masl [525 ft.]), associated with the Alexandra and Louise waterfalls.

The Hay River Basin is located within the Taiga Plains and Boreal Plains ecozones, in Canada's boreal forest (Figure 1-3 and Figure 1-4). Lands within the Taiga Plains ecozone are generally low-lying plains, level to gently rolling, with large and deep river valleys (Ecological Stratification Working Group [ESWG] 1995). The majority of the Hay River Basin lies within the Hay River Lowlands ecoregion of the Taiga Plains ecozone, typically consisting of gentle topography, with about 30% of the area covered by poorly drained fens and bogs (ESWG 1995). The higher elevation headwater areas of the Upper Hay sub-basin in British Columbia and the majority of the northern border of the basin lie within the Northern Alberta Uplands ecoregion of the Taiga Plains ecozone, characterized by uplands with steep slopes and undulating to rolling topography (ESWG 1995).

The Boreal Plains ecozone typically consists of level to gently rolling plains (ESWG 1995). A small southern portion of the Upper Hay sub-basin and the upper portion of the Chinchaga sub-basin lie within the Clear Hills Upland ecoregion of the Boreal Plains ecozone. The Clear Hills Upland ecoregion is typified by uplands with steep slopes, rolling plateaus, and gently undulating valleys (ESWG 1995).

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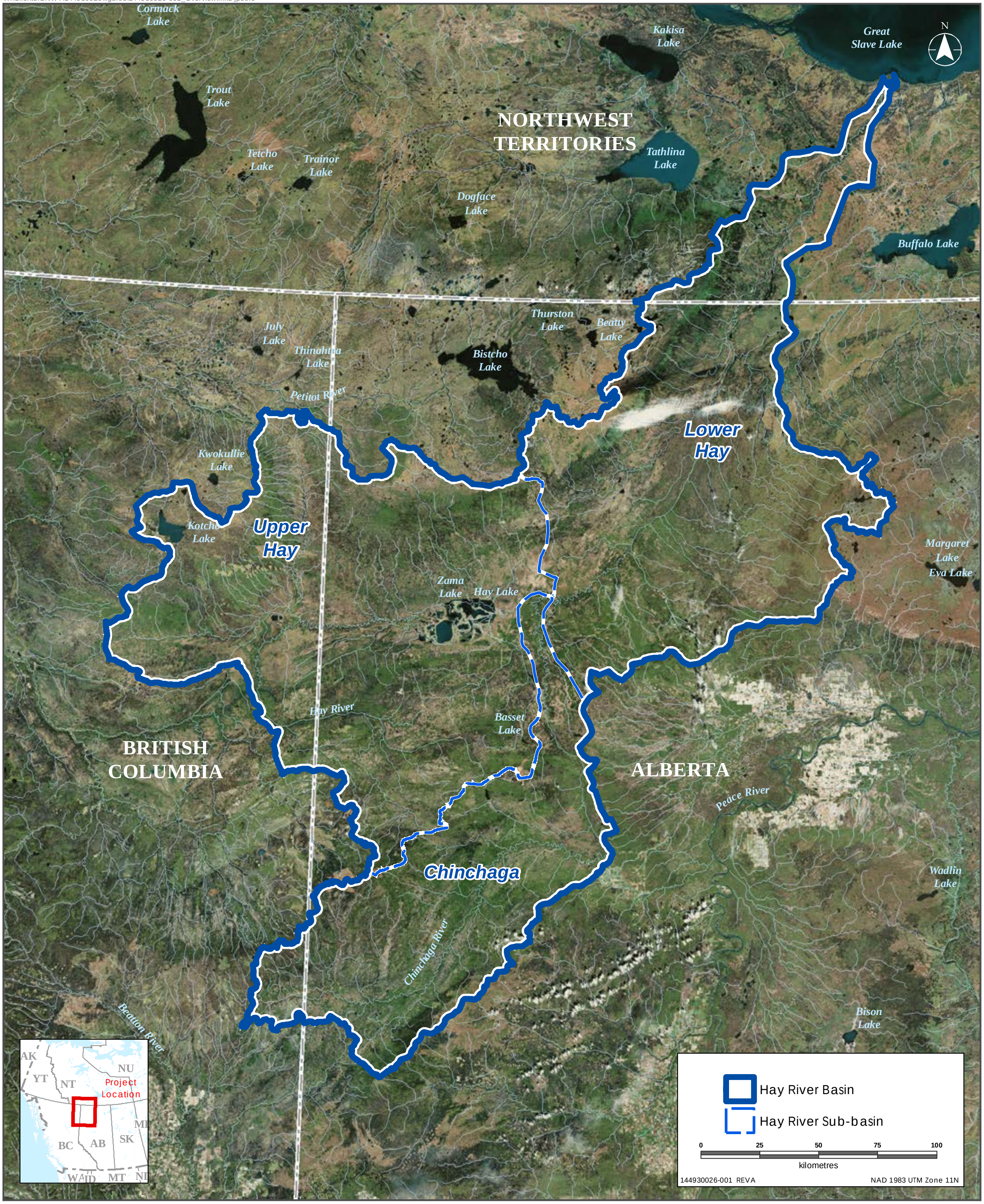

Sources: Base Data - Government of Canada; Thematic Data - Government of Canada, Stantec

Disclaimer: This map is for illustrative purposes to support this Stantec project; questions can be directed to the issuing agency.

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Overview of Hay River Basin and Sub-basins

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Figure 1-1

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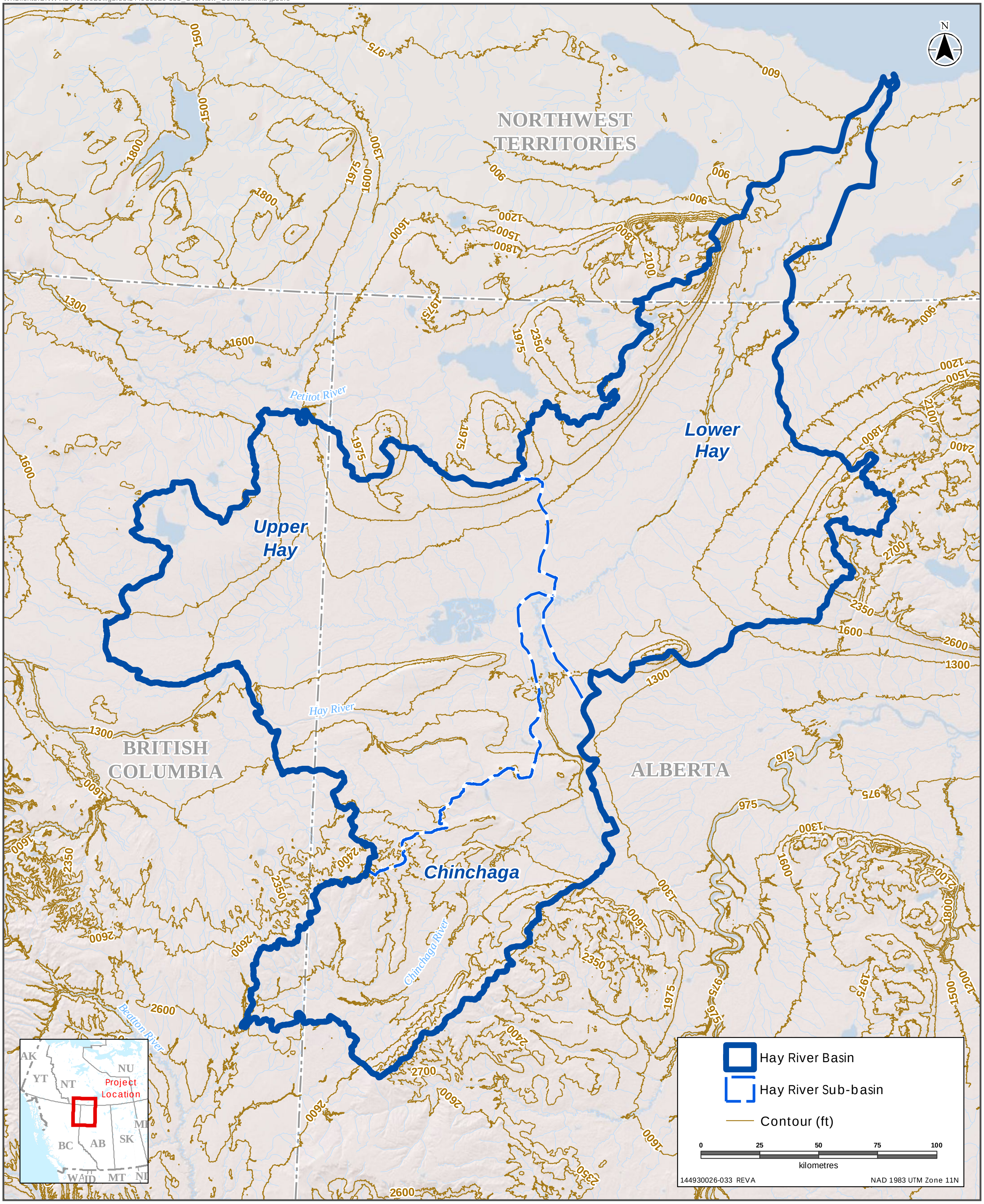

Sources: Base Data - Government of Canada; Thematic Data - Government of Canada, Stantec

Disclaimer: This map is for illustrative purposes to support this Stantec project; questions can be directed to the issuing agency.

Overview of Hay River Basin and Sub-basins with Elevation Contours

Stantec

Figure 1-2

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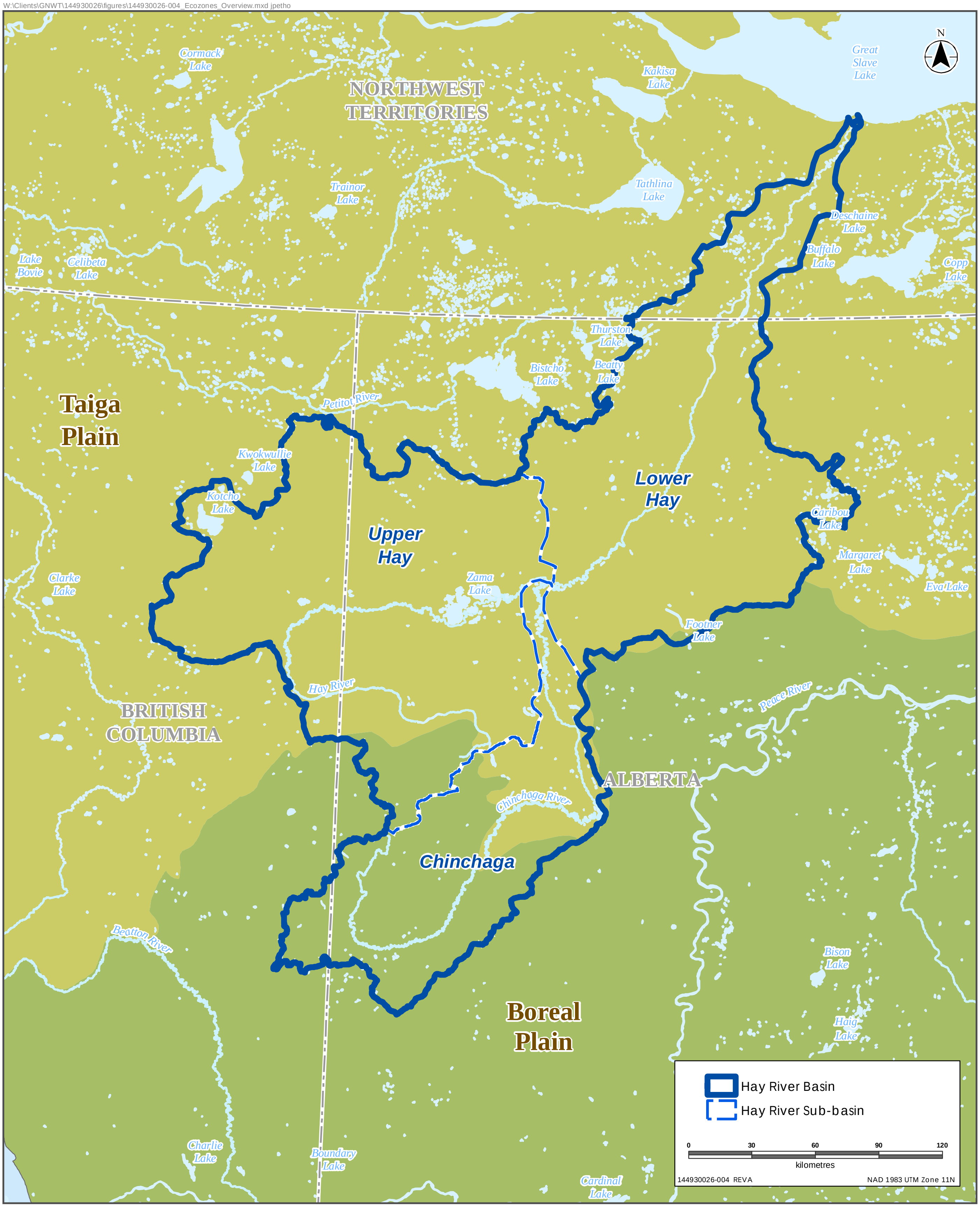

Sources: Base Data - Government of Canada; Thematic Data - Government of Canada, Stantec

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Hay River Basin and Sub-basins: Ecozones

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Figure 1-3

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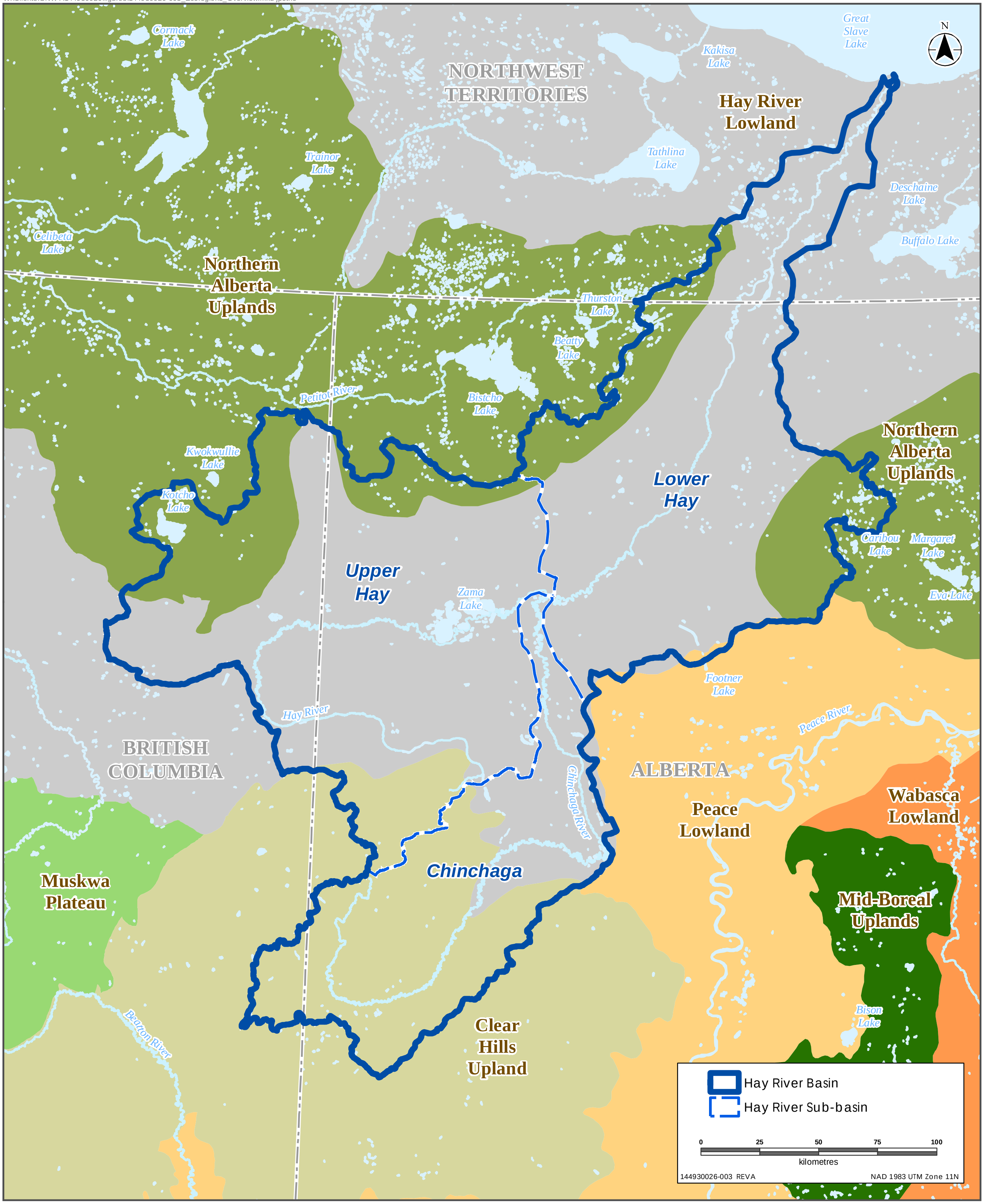

Sources: Base Data - Government of Canada; Thematic Data - Government of Canada, Stantec

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Hay River Basin and Sub-basins: Ecoregions

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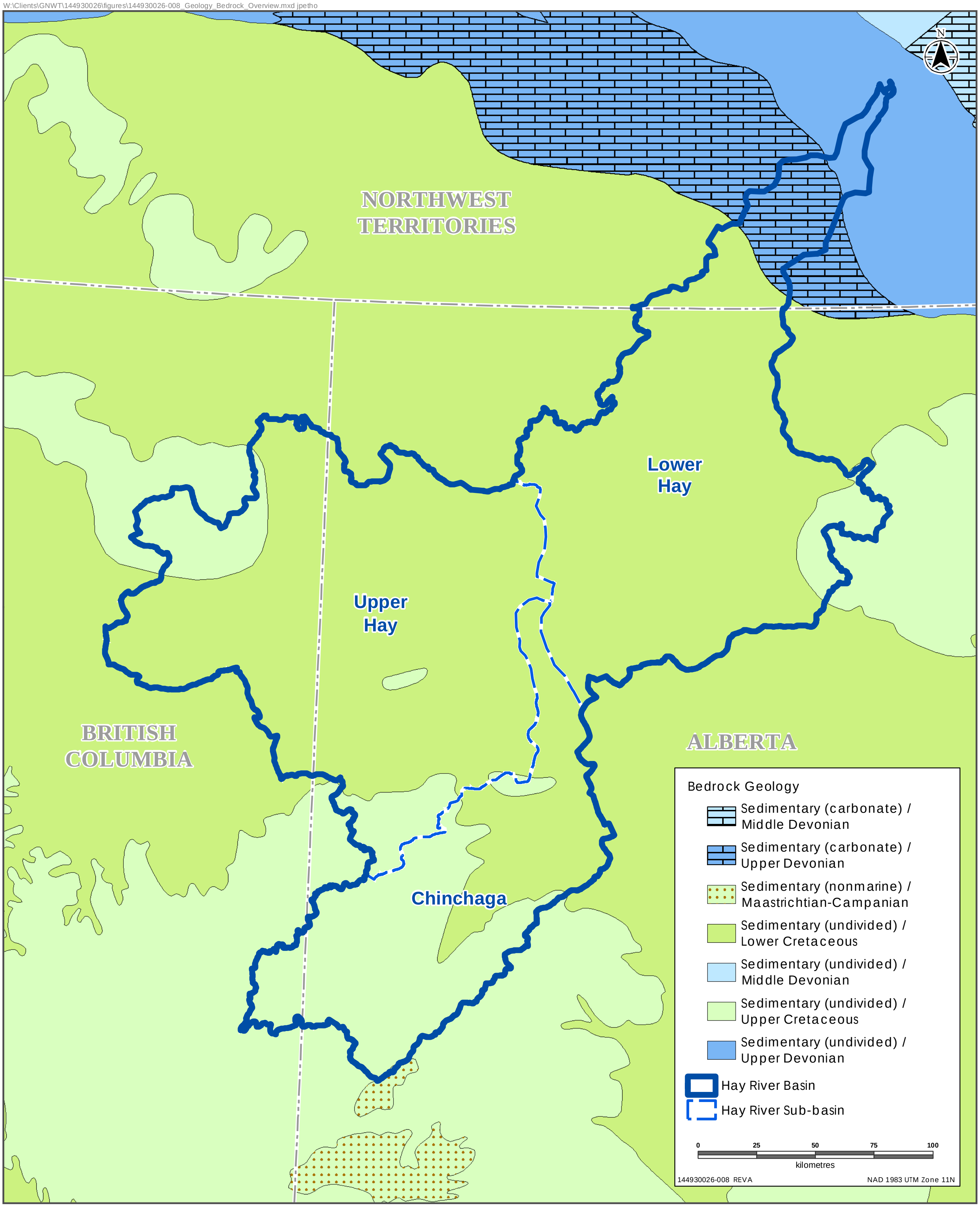
Figure 1-4

1.2 GEOLOGY AND GEOMORPHOLOGY

The Hay River Basin is a mature drainage system and is thought to have had a similar branching appearance over the past 2.58 million years, as it was mostly unchanged during the last glaciation (Prest 1970). Bedrock geology refers to the solid rock underlying most of the earth's surface, formed from the cooling of molten lava, deposition and compression of sediments, or through changes in temperature, pressure, and force. Surficial geology refers to the unconsolidated (loose) deposits of sediments that lie on top of bedrock materials. Over time, surficial deposits are laid down by several geologic processes including glacial (e.g., melting of ice, glacial melt channels); lacustrine (settling out in non-flowing water, lakes); fluvial (settling out from flowing water, rivers and streams); colluvial (from run-off/erosion and downslope movement by gravity); and, eolian (transported by wind).

Bedrock materials underlying most of the Hay River Basin are composed of sedimentary rocks, mainly shale and sandstone, which originate from the Lower Cretaceous period (145 to 100 million years ago) (Figure 1-5). The southern, western, and eastern extremities of the basin contain undivided sedimentary shale and sandstone from the Upper Cretaceous period (100 to 66 million years ago), whereas the northern extremity contains sedimentary sandstone, limestone, shale, and dolomite from the Upper Devonian period (419 to 358 million years ago) (Natural Resources Canada 1996; GNWT and GC 1984; ESWG 1995).

The landscape and surficial geology of the Hay River Basin was influenced by the most recent glaciation as well as by post-glacial processes. A simplified map of the surficial geology in the Hay River basin area is presented in Figure 1-6. During the Late Wisconsin glaciation (24,000 to 12,000 years before present), the area was covered by the Laurentide Ice Sheet, a 2 to 3 km thick ice-sheet which extended over most of Canada, including the Hay River Basin (Klassen 1989; Dyke et al. 2002). The ice deposited blankets and veneers of till deposits, which are most predominant in the Upper Hay and in the Chinchaga sub-basins (Figure 1-6). As the ice sheet melted, large accumulations of meltwater resulted in the formation of glacial lakes, the largest one in the area being Glacial Lake McConnell, which extended from the present Great Bear Lake, in the Northwest Territories, south to Lake Athabasca in northeastern Alberta. From these former, now inexistent glacial lakes, extensive blankets of fine-grained glaciolacustrine silt and clays have accumulated in low-lying portions of the Hay River Basin (e.g., in the Lower Hay sub-basin) while much coarser, sandy to gravelly deposits have accumulated along former shoreline positions near Great Slave Lake in the Lower Hay sub-basin (Natural Resources Canada 1995) (Figure 1-6). Glacial meltwater eroded a number of channels in the area, but deposited relatively small amounts of material.



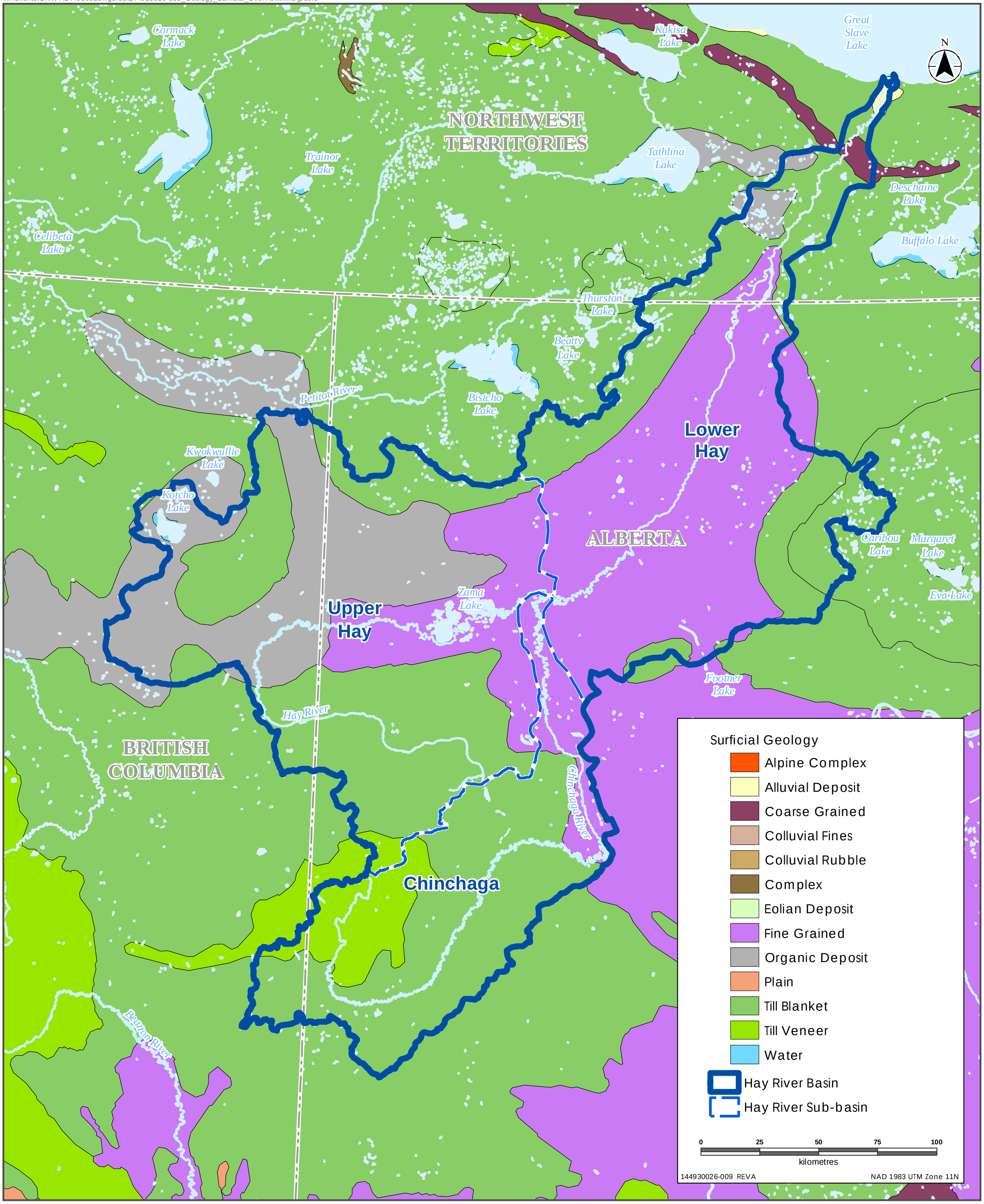
Sources: Base Data - Government of Canada; Thematic Data - Government of Canada, Stantec

Disclaimer: This map is for illustrative purposes to support this Stantec project; questions can be directed to the issuing agency.

Hay River Watershed and Sub-basins: Bedrock Geology

Stantec

Figure 1-5



Sources: Base Data - Government of Canada; Thematic Data - Government of Canada, Stantec

Disclaimer: This map is for illustrative purposes to support this Stantec project; questions can be directed to the issuing agency.

Hay River Watershed and Sub-basins:
Surficial Geology

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Figure 1-6

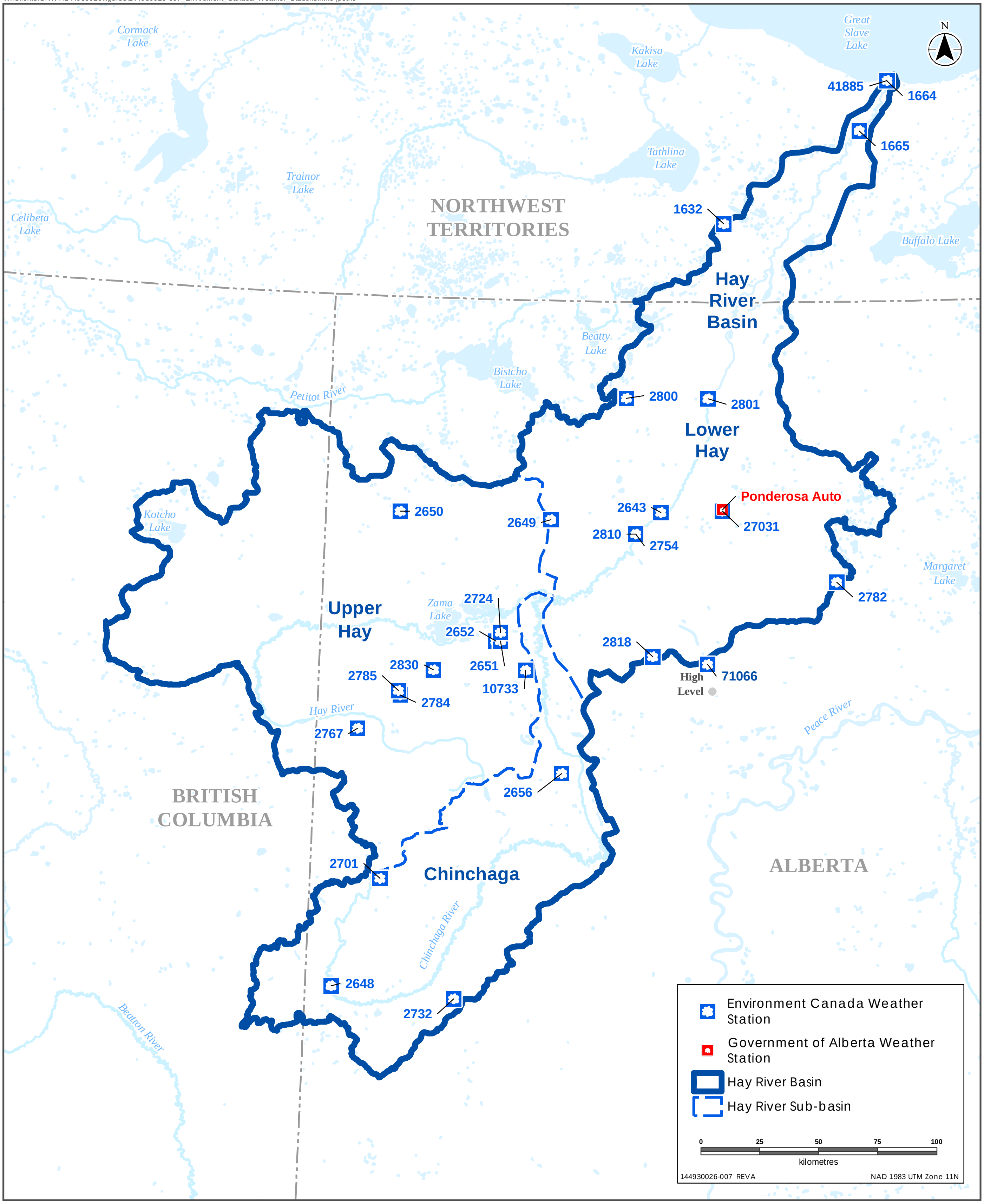
Colluvial deposits are locally significant along hill slopes, flanks of glacial meltwater channels, and steep river valley side slopes. Fluvial deposits are present along various rivers and streams, especially along the Hay River floodplain at Great Slave Lake. Eolian deposits, transported by wind, are found locally and are generally associated to the reworking of fine-grained glaciolacustrine and fluvial deposits. These deposits are present in the basin but are relatively small and are not shown on Figure 1-6. Organic deposits are widespread throughout the Hay River Basin. Vast peat bogs and fens have accumulated over the glacial and non-glacial deposits, especially over poorly drained glaciolacustrine, lacustrine and morainal deposits.

Permafrost, or permanently frozen ground, occurs sporadically in the Hay River Basin. It generally has low ice content and is often maintained in areas overlain by organic soils (GNWT and GC 1984; ESWG 1995). Generally, the presence of permafrost increases from south to north: there is permafrost at the Town of Hay River, up to 10 m thick under an active layer 2 to 3 m thick, but permafrost becomes increasingly sporadic south of the Town of Hay River (GNWT and GC 1984).

1.3 CLIMATE

The climate in the Hay River Basin is defined as sub-humid boreal, with a mean annual temperature varying between -0.5°C and -2.5°C and mean annual precipitation ranging between 350 and 600 mm (Strong et al. 1989, ESWG 1995). Summers are typically brief and cool, with temperatures averaging 13°C, and winters are long and cold, with temperatures averaging -17.5°C to -20°C. The southern portion of the Hay River Basin, within the Clear Hills Upland ecoregion of the Boreal Plain ecozone, is influenced by Chinooks during the winter.

Environment and Climate Change Canada (Environment Canada) has monitored up to 26 weather stations in the Hay River Basin sporadically over the past 54 years (Figure 1-7). The Government of Alberta monitors one station ("Ponderosa Auto") and reports weather data through the AgroClimatic Information Service (Alberta Agriculture and Forestry 2016a); the station appears to have been active since 2005. Environment Canada data collection began in 1961 at the weather station in Assumption, Alberta (ID 2651), however monitoring at this station, and most other stations, was terminated by 1990. Temperature data are not available for winter months for most stations. The Hay River station (ID 41885), near the Town of Hay River in the Northwest Territories, is the most northern station of the Hay River Basin, and is currently the only station within the basin with recent climate data (i.e., climate normals for the period 1981 to 2010; Environment Canada 2015b), and is active today. The weather station at High Level, Alberta (ID 71066) is also active, although outside of the basin (about 14 km south of the Lower Hay sub-basin). Data for the High Level station were included in this review to provide information about climate conditions further south in the Hay River Basin in Alberta.



Sources: Base Data - Natural Earth Thematic Data - Government of Canada (Environment Canada). (2013), Government of Alberta.

Disclaimer: This map is for illustrative purposes to support this Stantec project; questions can be directed to the issuing agency.

Weather Stations in the Hay River Basin

Figure 1-7

Data on climate normals, calculated for the period 1981 to 2010, are provided for daily mean, minimum, and maximum monthly temperatures, and monthly precipitation at the Hay River (Table 1-1Table 1-1) and High Level (Table 1-2) weather stations (Environment Canada 2015b). Extreme minimum and maximum temperature data are also provided. Climate normal data for the two stations reflect a mean annual temperature below 0°C (Table 1-1 and Table 1-2). Temperatures are slightly warmer at High Level than at Hay River during several months of the year. The coldest month is typically January, with temperatures averaging -21.8°C in Hay River and -20.4°C in High Level, while the warmest month is typically July, with temperatures averaging 16.1°C in Hay River and 16.5°C in High Level. Total annual precipitation is slightly higher at High Level (372.1 mm) than at Hay River (336.4 mm). August is the wettest month in Hay River (58.7 mm), while July is the wettest month in High Level (66.2 mm). The average frost-free period is 101 days, and ranges from 84 to 116 days (Environment Canada 2015a).

Table 1-1 Climate Normals at the Environment Canada Weather Station in Hay River, Northwest Territories; 1981–2010

Month	Temperature (°C)[1]							Precip. (mm)[3]
	Daily			Extreme[2]				
	Min	Max	Mean	Min	Year of Min	Max	Year of Max	
January	-26.2	-17.3	-21.8	-47.8	1962	10.7	1985	16.4
February	-24.9	-14.2	-19.6	-48.3	1947	13.9	1968	14.3
March	-19.8	-7.8	-13.8	-44.4	1945	15.6	1944	14.4
April	-8.1	2.9	-2.7	-38.8	1954	26.0	2010	12.6
May	0.0	10.7	5.4	-20.5	2002	33.3	1948	23.3
June	7.0	18	12.5	-5.6	1951	34.0	1989	31.9
July	10.9	21.2	16.1	0.7	2009	35.0	1975	43
August	9.5	19.6	14.6	-1.1	1948	36.7	1981	58.7
September	4.1	13.2	8.7	-11.7	1974	30.0	1951	44.6
October	-3.2	4.1	0.5	-24.3	1984	25.4	2003	35.7
November	-15.4	-7.7	-11.6	-40.8	1985	15.0	1949	24.8
December	-23.1	-14.4	-18.8	-47.2	1946	12.2	1944	16.8
Annual Average	**-7.4**	**2.4**	**-2.5**	—	—	—	—	—
Annual Total	—	—	—	—	—	—	—	**336.4**

NOTES:

[1] Temperature normals for period 1981 to 2010; Min = minimum monthly temperature; Max = maximum monthly temperature; Mean = mean monthly temperature

[2] Extreme minimum and maximum temperature provided for entire period of station operation

[3] Precip. = precipitation normals, in millimetres (mm)

SOURCE: Environment Canada 2015b

Table 1-2 Climate Normals at the Environment Canada Weather Station in High Level, Alberta; 1981–2010

Month	Temperature (°C)[1]							Precip. (mm)[3]
	Daily			Extreme[2]				
	Min	Max	Mean	Min	Year of Min	Max	Year of Max	
January	-25.8	-15.0	-20.4	-50.6	1972	11.3	2003	19.5
February	-23.3	-10.4	-16.9	-46.1	1975	14.6	1992	17.5
March	-16.4	-2.4	-9.4	-45.0	1976	17.4	2004	18.2
April	-4.7	8.7	2.0	-32.2	1972	30.2	1977	14.7
May	2	16.2	9.1	-13.7	2002	33.9	1971	35.8
June	7.3	21.3	14.3	-3.6	1982	31.5	1982	51.3
July	9.9	23.0	16.5	-0.2	1985	34.4	1975	66.2
August	7.6	21.1	14.4	-4.4	1982	35.2	1981	43.3
September	1.9	14.8	8.4	-13.9	1974	30.2	1988	31.6
October	-4.6	5.3	0.4	-36.3	1984	25.2	1987	30.6
November	-16.8	-7.7	-12.3	-43.4	1985	15.0	1978	24.5
December	-23.5	-12.8	-18.2	-47.2	1971	14.2	1999	18.8
Annual Average	**-7.2**	**5.2**	**-1.0**	—	—	—	—	—
Annual Total	—	—	—	—	—	—	—	**372.1**

NOTES:

[1] Temperature normals for period 1981 to 2010; Min = minimum monthly temperature; Max = maximum monthly temperature; Mean = mean monthly temperature

[2] Extreme minimum and maximum temperature provided for entire period of station operation.

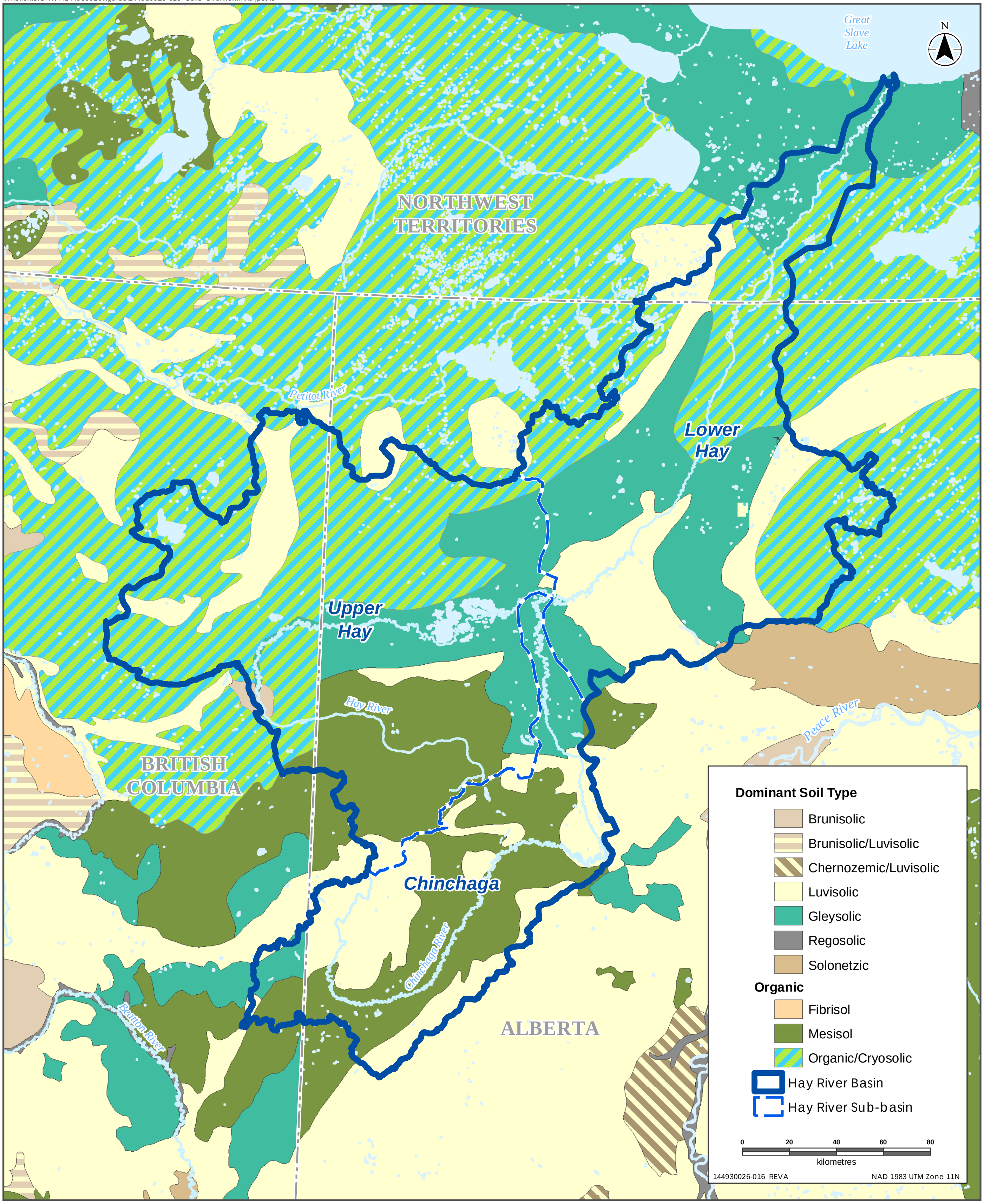
[3] Precip. = precipitation normals, in millimetres (mm).

SOURCE: Environment Canada 2015b

1.4 SOILS AND VEGETATION

There are three major types of soils in the Hay River Basin: organic, luvisolic, and gleysolic (Clayton et al., 1977), varying among the sub-basins and reflecting the topography (Figure 1-8):

- Chinchaga sub-basin contains mainly organic soils (typical in lowland areas and wetlands)
- Upper Hay sub-basin contains primarily organic soils (typical in lowland areas and wetlands) in the western half and gleysolic soils in the eastern half (reflecting lowland saturated conditions)
- Lower Hay sub-basin contains mainly gleysolic and organic soils (reflecting lowland conditions), with some areas of luvisolic soils (reflecting upland areas)



Sources: Base Data - Government of Canada; Thematic Data - Government of Canada

Disclaimer: This map is for illustrative purposes to support this Stantec project; questions can be directed to the issuing agency.

Hay River Basin and Sub-basins:
Overview of Dominant Soil Types

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Figure 1-8

As evident in Figure 1-8, there is a discrepancy at the Alberta-British Columbia border in the soil base data used to map soil types in the Hay River Basin. Data on soils types were obtained on a national scale as the Soil Landscapes of Canada from Agriculture and Agri-Food Canada, and this discrepancy was unfortunately an inherent feature of the dataset.

A variety of factors interact in soil formation, including parent material (i.e., surficial geology), level of water saturation and drainage, vegetation presence and organic matter content, topography, and climate. In Canada, soils are classified primarily based on soil formation processes which, in turn, affect soil properties and provide an indication of overall environmental conditions at a particular location (Soil Classification Working Group 1998). For example, luvisolic soils are typically found in forested areas and at upland sites and have poor to moderate drainage due to the presence of fine-grained material (e.g., clay) (ESWG 1995; Soil Classification Working Group 1998; North/South Consultants Inc. 2007). Gleysolic soils are a mineral soil that is typically found in lowland areas, and form during intermittent or extended periods of water saturation with a lack of oxygen (ESWG 1995; Soil Classification Working Group 1998; North/South Consultants Inc. 2007). Organic soils are also typically found in lowland areas or depressions, are largely formed from organic materials, and form during extended periods of high water saturation (Soil Classification Working Group 1998). Both gleysolic and organic soils are frequently associated with wetlands (Bedard-Haughn 2010).

In the Hay River Basin, two sub-types of organic soils occur: mesisols and organic/cryosols. Organic mesisols are at an intermediate stage of decomposition and formation, compared to other organic soils (i.e., fibrisols, which are at an early stage of decomposition with readily identifiable plant material, and humisols, which are at an advanced stage of decomposition) (Soil Classification Working Group 1998). Organic/cryosol soils are frequently associated with permafrost and frozen ground (within 1 m of the ground surface) for the majority of the year (Soil Classification Working Group 1998).

Soils can affect the chemistry of water that comes into contact with it through surface or shallow sub-surface flow. Water chemistry can be altered by the dissolving of salts, nutrients, metals, or other constituents that are bound to soil particles and then released to water, or conversely, by uptake of these constituents from water by vegetation (e.g., through root systems), or by binding to soil particles (e.g., settling out). The extent to which these processes occur depends on soil characteristics, including mineral and vegetation/organic content. Water chemistry is influenced by soil chemistry, which in turn is largely influenced by the soil parent materials (e.g., amount of calcium, organic material) (Acton and Gregorich 1995). Because of the wide range of parent materials across Canada, the various soil types and sub-types can affect water chemistry differently and site-specific conditions need to be considered. Within the Hay River Basin, the most obvious link between soils and water quality is the high proportion of organic and gleysolic soils associated with the abundant wetlands in the basin, which contribute to the elevated concentrations of total and dissolved organic carbon in river water (Hatfield 2009). Further work is needed to link the soil types to chemical composition of surrounding waterbodies (Mitchell and Prepas 1990).

The extensive wetlands in the Hay-Zama Lake wetland complex of the Upper Hay sub-basin in Alberta result from a combination of the low relief, poor drainage, and soil materials. Soil materials, such as the clay and fine silt that are deposited in this lowland, further prevent the widening of river channels and contribute to water retention and maintenance of the wetlands (GNWT and GC 1984). In addition, the presence of long meandering reaches in the Hay River lowlands suggests the river has reached a level of maturity and can be considered a "graded stream" (GNWT and GC 1984), or a river that is balanced between erosion and deposition, with minimal changes in channel profile.

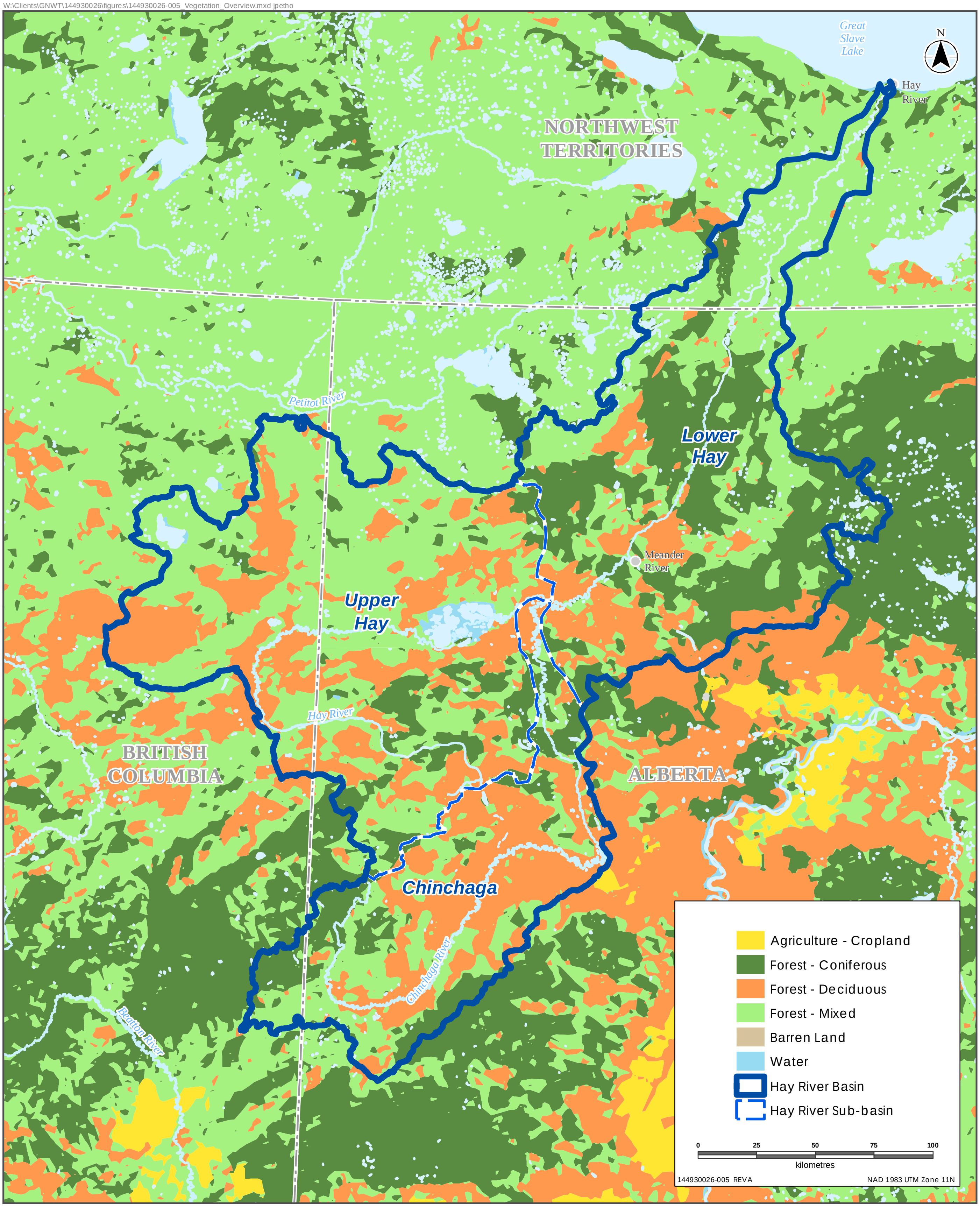
Vegetation in the basin consists primarily of mixedwood (22,743 km^2), deciduous (15,320 km^2), and coniferous (12,795 km^2) forests (Government of Canada 2015). Broad categories of vegetation are shown in Figure 1-9. Forest cover varies among the three sub-basins (Table 1-3):

- Mainly mixedwood forests (54% by sub-basin area) in the Upper Hay sub-basin
- Mainly deciduous forests (47% by area) in the Chinchaga sub-basin
- Mainly mixedwood and coniferous forests (42% each by area) in the Lower Hay sub-basin

Table 1-3 Dominant Forest Cover Types in the Hay River Basin

Forest Type	Dominant Tree Species	% Area of Sub-basin			Total % Area of Hay River Basin
		Upper Hay (21,260 km^2)	Chinchaga (11,070 km^2)	Lower Hay (19,060 km^2)	
Mixedwood	aspen, black spruce	54	31	42	44
Deciduous	aspen	33	47	16	30
Coniferous	black spruce	11	23	42	25
Other	water	2	0	<1	1
SOURCE: calculated from Government of Canada (2015)					

These boreal forests contain predominantly aspen (*Populus tremuloides*) and black spruce (*Picea mariana*). Other tree species present include balsam poplar (*Populus balsamifera*), white spruce (*Picea glauca*), lodgepole pine (*Pinus contorta*), jack pine (*Pinus banksiana*), and willow (*Salix* spp.) (GNWT and GC 1984; ESWG 1995). Coniferous forests in the northern part of the Lower Hay sub-basin contain predominantly white spruce and jack pine. In contrast, coniferous forests in the Upper Hay sub-basin in British Columbia, the eastern part of the Lower Hay sub-basin, and southern portion of the Chinchaga sub-basin contain stands of black spruce, white spruce, and lodgepole pine (GNWT and GC 1984).



Sources: Base Data - Government of Canada; Thematic Data - Government of Canada, Stantec

Disclaimer: This map is for illustrative purposes to support this Stantec project; questions can be directed to the issuing agency.

Hay River Basin and Sub-basins: Overview of Dominant Vegetation Types

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Figure 1-9

The Hay-Zama Lake wetland complex, in the Upper Hay sub-basin of Alberta, is characterized by grassland prairie vegetation, in contrast to the typical boreal forest vegetation elsewhere in the Hay River Basin (GNWT and GC 1984; Alberta Tourism, Parks, Recreation and Culture [ATPRC] 2007). Vegetation in areas where the water table is near the soil surface includes cattail (*Typha* spp.) and bulrush (*Cyperaceae*). In frequently flooded areas, sedges and grasses are predominant; in less frequently flooded areas, willows and other shrubs are common (GNWT and GC 1984; ATPRC 2007).

1.5 HUMAN HISTORY

1.5.1 Communities

There are 10 municipal communities in the Hay River Basin, 2 in the Northwest Territories (Hay River and Enterprise), and 8 in Alberta (Indian Cabins, Steen River, Slavey Creek, Lutose, Meander River, Rainbow Lake, Zama City, and Chateh [also known as Assumption]). There are no communities within the basin in British Columbia (Figure 1-10).

The population of the Hay River Basin (estimated at 5,897 people, based on communities with population counts in the 2011 census; Statistics Canada 2015) is spread out and reflects a density of less than two people per square kilometre (Aboriginal Affairs and Northern Development Canada [AANDC] 2014). Based on 2011 census data, population size ranges from 87 (Enterprise) to 3,606 people (Table 1-4). In Alberta, total population density in the Hay River Basin is not known, as there are no estimates for several small communities (populations in Indian Cabins, Steen River, Slavey Creek, Lutose, and Meander River were not recorded individually in the 2011 census). All Alberta communities within the Hay River Basin are included within the Mackenzie County census, with an overall population of 10,927 people, which includes communities within the Buffalo and Peace River basins, outside of the Hay River Basin.

Table 1-4 Communities and Human Populations within the Hay River Basin

Community		Population
Northwest Territories	Hay River (includes the West Point First Nation)	3,606
	Kátł'odeeche First Nation (Hay River Reserve No. 1)	292
	Enterprise	87
Alberta	Rainbow Lake	870
	Zama City	93
	Chateh (Assumption)	949
	Indian Cabins, Steen River, Slavey Creek, Lutose, and Meander River	Unavailable
SOURCE: Statistics Canada 2015		

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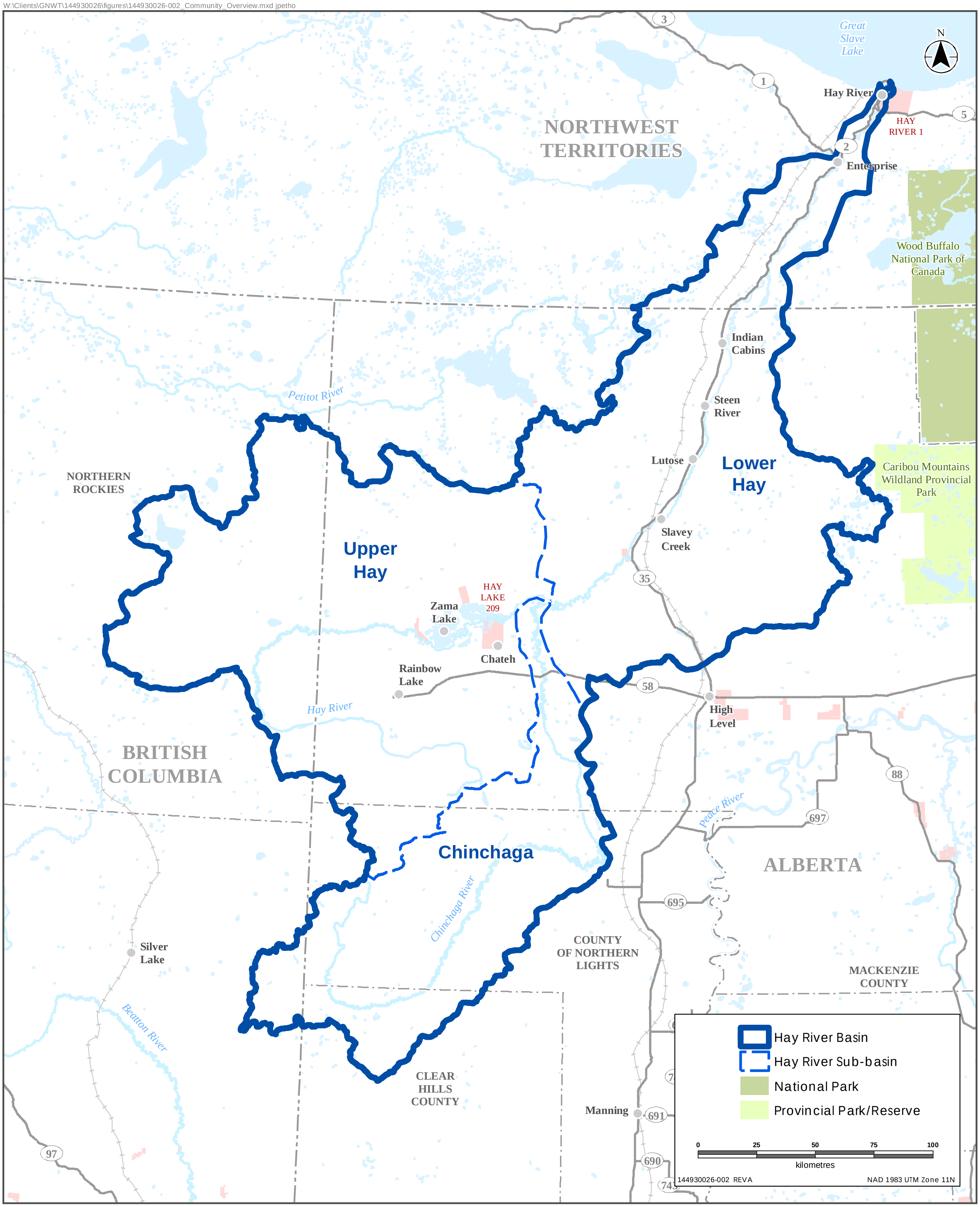

Sources: Base Data - Government of Canada; Thematic Data - Government of Canada, Stantec

Disclaimer: This map is for illustrative purposes to support this Stantec project; questions can be directed to the issuing agency.

Hay River Basin and Sub-basins: Overview of Counties, Communities, and Transportation

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Figure 1-10

Over the past decade, populations have declined in some communities. This includes the Town of Hay River (a 2.5% reduction, from 3,822 in 2004, to 3,725 in 2015; Northwest Territories Bureau of Statistics 2015) and the community of Rainbow Lake (a 9.8% reduction, from 965 in 2006, to 870 in 2011; Statistics Canada 2012). However, the population projection for the Town of Hay River includes a 10% increase between 2011 and 2031 (Northwest Territories Bureau of Statistics 2012). Population trends or projections for other communities in the basin are unavailable.

1.5.2 Traditional Use and History

The Hay River Basin has long supported the traditional lifestyle of the Aboriginal people that live there. Typical traditional activities consist of hunting, trapping, fishing, gathering berries and medicinal plants, and travelling.

The Hay River Basin is mainly situated within the traditional territories of the Dene Tha' First Nation, in Alberta and British Columbia, and the Dehcho First Nations, Kátł'odeeche First Nation, and Northwest Territory Métis Nation in the Northwest Territories. The Hay-Zama Lake wetland complex is part of the Dene Tha' traditional territory and has long been recognized by the Dene Tha' for its ecological importance (ATPRC 2007). The western end of the Upper Hay sub-basin and the Chinchaga sub-basin in British Columbia has also been used by the Fort Nelson First Nation and Acho Dene Koe (Fort Liard) First Nation (Dehcho Land Use Planning Committee [DLUPC] 2006; Government of British Columbia 2007; Calliou Group 2009; Stevenson 2011), although it is also considered part of the traditional territory of the Dene Tha' First Nation (AANDC 2015; British Columbia Ministry of Education 2016).

Four Dene Tha' First Nation reserves (Hay Lake No. 209, Zama Lake No. 210, Amber River No. 211 and the Upper Hay River No. 212) and two Dene Tha' First Nation communities (Chateh and Meander River) are located within the Alberta portion of the Hay River Basin (AANDC 2015). The Dene Tha' First Nation is a signatory of Treaty 8, speak Athapaskan, and are characterized by Cree, Beaver, and Slavey cultures (Dene Tha' 2016).

Prior to the 1900s, the Dene Tha' people were nomadic. At the beginning of the 20th century they began to settle, and established a settlement near the Hay-Zama Lake wetland complex called Habay (ATPRC 2007). In 1962, a flood forced the Habay settlement to be re-located to a new area, Chateh, formerly called Assumption (ATPRC 2007).

In British Columbia, there are no First Nation communities or reserves within the Upper Hay and Chinchaga sub-basins. However, the Dene Tha' First Nation still use areas of the Upper Hay sub-basin for traditional activities and there are known burial, ceremonial, and sacred sites, as well as camping areas and traditional cabins (LGL Limited 2003; Government of British Columbia 2007; Calliou Group 2009).

In the Northwest Territories, the Lower Hay sub-basin is situated within the traditional territory of the Dehcho First Nations, Kátł'odeeche First Nation, and the Northwest Territory Métis Nation. There are two First Nation communities: West Point (formerly Ts'ueh Nda), located on Vale Island at the mouth of the Hay River at Great Slave Lake, and Kátł'odeeche, located at the Hay River Dene Reserve No. 1. The West Point community is situated within the municipal limits of the Town of Hay River (AANDC 2015) and Kátł'odeeche is adjacent to the town.

The West Point First Nation community was born from an association between Métis and Dene people, with Dene peoples from Snowdrift (now Łutsel K'e), Fort Providence, Inuvik, Fort Simpson, Kakisa Lake, and Tathlina Lake relocating to the area around 1977 to benefit from the local fishing industry (Dehcho First Nations 2010).

Members of the Kátł'odeeche First Nation are South Slavey in origin, and their ancestors have occupied the area of the Lower Hay River Basin since time immemorial. The Hay River Dene Reserve No. 1 was created in 1974 (Kátł'odeeche First Nation 2009).

The Hay River Métis Council, a council of the Northwest Territory Métis Nation, represents the indigenous Métis of the South Slave Region of the Northwest Territories.

1.5.3 Recreational Use and Protected Areas

There are nine parks or protected areas within the Hay River Basin and many of these allow recreational activities (Table 1-5). The largest is the Chinchaga Wildland Provincial Park in Alberta, with 80,027 ha in a remote area (oil and gas activities may occur in the park, but timber harvesting was stopped in 1999, when the park was established).

Table 1-5 Parks and Protected Areas in the Hay River Basin

Jurisdiction	Park/Protected Area	Area (ha)	Notes
Upper Hay Sub-basin			
British Columbia	Hay River Protected Area	2,324	• 15 km west of the British Columbia/Alberta border • Remote and accessible only by helicopter, with no amenities or developed trails (BC Parks 2015a)
	Kotcho Lake Ecological Reserve	64	• Established for protection of wildlife, particularly waterfowl migration (BC Parks 2015b) • Protects cultural resources, including a burial site, a traditional settlement, and resource use • Significant fishery value at Kotcho Lake (BC Parks 2015a) • Supports non-destructive recreational activities
Alberta	Hay-Zama Wildlife Provincial Park	Not available	• Remote, with difficult terrain due to the many wetlands (ATPRC 2007, Alberta Parks 2015) • Recreational opportunities (fishing, canoeing, hiking, horse riding, swimming, camping, mountain biking)
	Rainbow Lake Provincial Recreation Area	Not available	• Recreational opportunities (fishing, canoeing, hiking, horse riding, swimming, camping, mountain biking (ATPRC 2007; Alberta Parks 2015)

Table 1-5 Parks and Protected Areas in the Hay River Basin

Jurisdiction	Park/Protected Area	Area (ha)	Notes
Chinchaga Sub-basin			
British Columbia	Chinchaga Lake Protected Area	1,389	• Established to protect First Nations values (Government of British Columbia 1997)
Alberta	Chinchaga Wildland Provincial Park	80,270	• Established 1999 under Alberta Special Place Program • Affected by timber harvesting (stopped in 1999) and oil and gas development (still permitted) (Alberta Wilderness Association 2016) • Protects habitat of various wildlife species, including species of management concern, the unique foothill wetlands, and old growth forests (CPAWS 2005) • Remote, with no road access, limiting recreational activities; permitted uses are fishing, canoeing, hiking, camping, and ATV use on existing trails (Alberta Wilderness and Parks 2015a)
Lower Hay Sub-basin			
Northwest Territories	60th Parallel Territorial Park	Not Available	• Small campground and picnic area with few amenities (Northwest Territories Parks 2015) • Low impact activities permitted (e.g., hiking, swimming, fishing, sightseeing, and camping)
	Twin Falls Gorge Territorial Park	Not Available	• Composed of three areas for day-use or camping (partially and fully serviced) (Northwest Territories Parks 2015) • Offers several trails and views of the Hay River Canyon and Alexandra and Louise Falls • Low impact activities permitted (e.g., hiking, swimming, fishing, sightseeing, camping)
	Hay River Territorial Park	Not Available	• Located on Vale Island at the mouth of the Hay River at Great Slave Lake; fully-serviced (Northwest Territories Parks 2015) • Low impact activities permitted (e.g., hiking, swimming, fishing, sightseeing, camping)

2.0 AMBIENT HYDROLOGIC CONDITIONS

This section describes hydrological conditions and trends in the Hay River Basin (Sections 2.1 and 2.2) and provides an analysis of river morphology and flow path, with comparison of conditions in the 1950s and 1960s to the present day (Section 2.3). Water use and allocation are reviewed in Section 6.0. Potential for climate change influences on hydrology are discussed in Section 7.9.

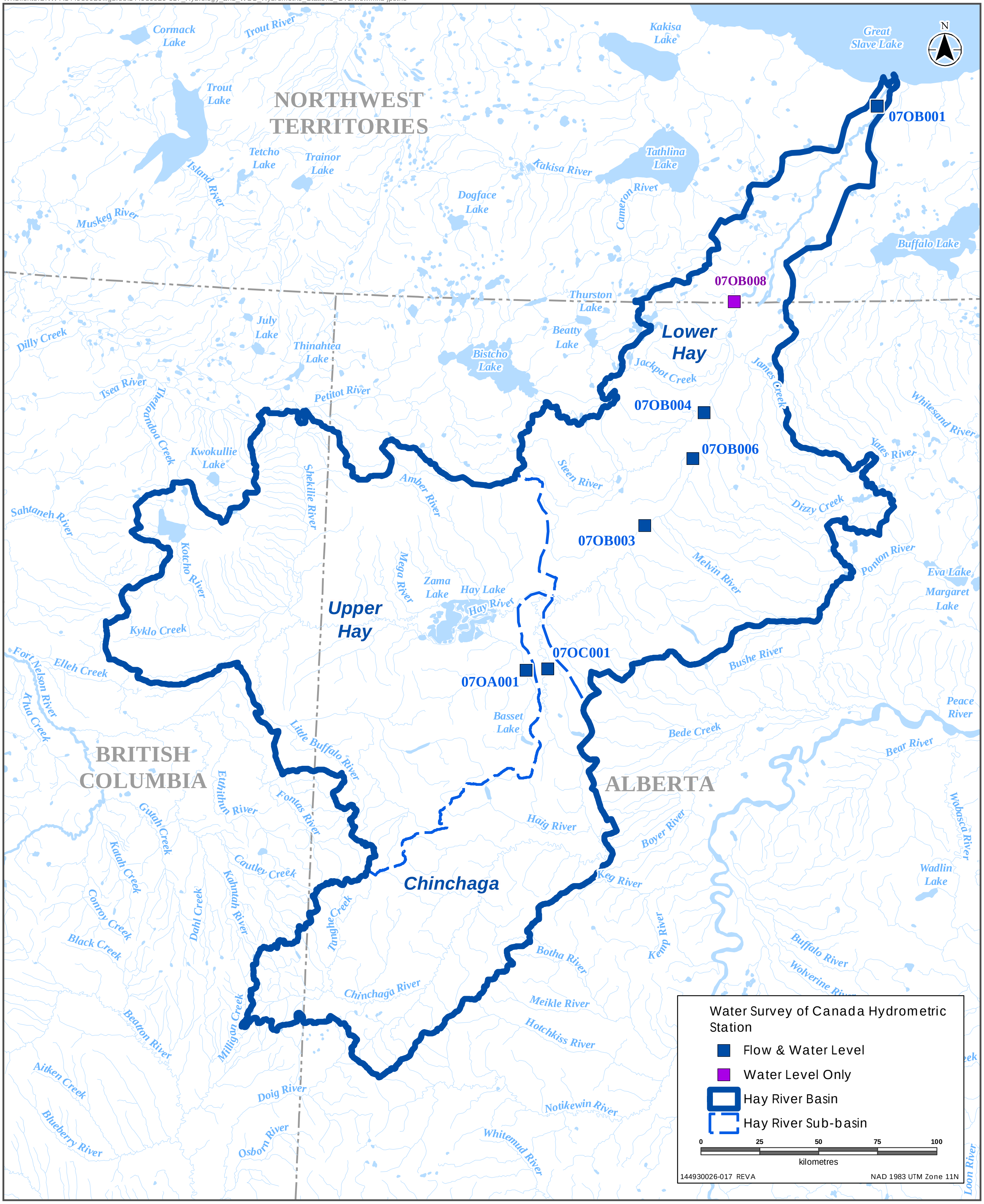
2.1 CURRENT MONITORING PROGRAMS

Hydrometric monitoring in the Hay River Basin is largely conducted by the Water Survey of Canada (WSC) as part of the National Hydrometric Program. Hydrometric data for six monitoring sites within the Hay River Basin were obtained from the WSC (Environment Canada 2015a). The sites are described in Table 2-1 and shown in Figure 2-1.

Table 2-1 Water Survey of Canada Hydrometric Stations in the Hay River Basin

WSC Station	WSC Station ID	Operation Schedule and Period of Record[1]	Location (Latitude, Longitude)	Drainage Area (km²)
Upper Hay Sub-basin				
Sousa Creek near High Level, Alberta	07OA001	Seasonal 1970–2013	58.591389° N -118.490833° W	820
Chinchaga Sub-basin				
Chinchaga River near High Level, Alberta	07OC001	Continuous 1970–1978, 1981–2012 Seasonal 1969, 1979–1980	58.596944° N -118.333889° W	10,370
Lower Hay Sub-basin				
Hay River near Meander River, Alberta	07OB003	Seasonal 1974–2013	59.149444° N -117.636111° W	36,901
Lutose Creek near Steen River, Alberta	07OB006	Seasonal 1977–2013	59.405556° N -117.280556° W	292
Steen River near Steen River, Alberta	07OB004	Seasonal 1974–2012	59.580556° N -117.196389° W	2,598
Hay River near Hay River, Northwest Territories	07OB001	Seasonal 1929–1931 Miscellaneous 1921, 1952 Continuous 1963–2014	60.742778° N -115.859444° W	51,700

NOTES:
[1] Period of record indicates data record used/available for this report; all stations are operational in 2016. All stations have some missing daily flow records.



Sources: Base Data - Government of Canada; Thematic Data - Government of Canada

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Hay River Basin and Sub-basins: Hydrology & Hydrometric Stations

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GOVERNMENT OF THE NORTHWEST TERRITORIES - STATE OF AQUATIC KNOWLEDGE FOR THE HAY RIVER BASIN

Figure 2-1

The WSC station “Hay River near ALTA/NWT Boundary” is also located within the Hay River Basin but records only water levels, not flow data, so is not included in the present analysis.

The “Sousa Creek near High Level” station is the only hydrometric station in the Upper Hay sub-basin. It is situated on Sousa Creek, near the crossing of Alberta Highway 58. Sousa Creek flows northwest through the community of Chateh and discharges into Zama Lake, in the Hay-Zama Lake wetland complex. The station is about 31 km southeast (upstream) of the wetland complex. The period of record typically spans March through October (i.e., no winter flow data).

The “Chinchaga River near High Level” station is the only hydrometric station within the Chinchaga sub-basin. It is situated on Chinchaga River, near the crossing of Alberta Highway 58. Chinchaga River flows north and discharges into the Hay River, downstream of the Hay-Zama Lakes wetland complex. The station is about 31 km south (upstream) of its confluence with the Hay River. Continuous daily flow data are generally available (Table 2-1).

There are four hydrometric stations within the Lower Hay sub-basin; these are, from upstream to downstream, “Hay River near Meander River”, “Lutose Creek near Steen River”, and “Steen River near Steen River”, all in Alberta, and “Hay River near Hay River” in the Northwest Territories. Lutose Creek and the Steen River are tributaries of the Hay River. The hydrometric stations in Alberta are situated along Alberta Highway 35; these stations typically have a period of record spanning March through October (i.e., no winter data). The “Hay River near Hay River” station is situated near the Town of Hay River, about 15 km south (upstream) of the river’s discharge point at Great Slave Lake, and generally provides continuous daily flow data.

Continuous daily flow records at the “Hay River near Hay River” station began at the end of June 1963, so the present analysis began with the 1964 data. At the “Chinchaga River near High Level” station, continuous daily flow records began in late November 1969, so analysis began with the 1970 data. The Chinchaga station also had data missing from the beginning of November 1979 to the end of February 1980. The 1979 and 1980 data were omitted from low flow analysis but were included for peak flow analysis (peak flow rarely occurs during winter).

The hydrometric stations “Sousa Creek near High Level”, “Hay River near Meander River”, “Lutose Creek near Steen River”, and “Steen River near Steen River” are missing daily flow records from the beginning of November to the end of February in the following year, for each year of record. Missing data compromises the evaluation of some temporal trends, so these stations were excluded from the present trend analyses.

2.2 CURRENT STATUS AND TRENDS

2.2.1 Flow and Yield

Daily mean flow and yield statistics were analyzed at the six stations listed in Table 2-1. Maximum, median, and minimum daily flows were calculated on an annual basis for each station using daily data from each station’s respective period of record. The normal range of daily flows per year was also calculated from the same data. Daily average yields were calculated using a 36 year data period common to all stations (1977 to 2012). Daily average yield was estimated at each station by first calculating the daily average flow per calendar day per station over the common data period. Daily average flow (m^3/s) was converted to daily average yield (mm) using the drainage area for that station (see Table 2-1). Annual average yields were calculated for each year of the period of record at the "Chinchaga River near High Level" (1970 to 2012) and "Hay River near Hay River" (1964 to 2012) stations. Conversion to yield represents runoff on an area basis, allowing comparison of sub-basins of varying size.

Figure 2-2 to Figure 2-7 illustrate the maximum, 75th percentile, median, 25th percentile, and minimum daily flow at the six WSC stations for the full period of record. The "Hay River near Hay River" station recorded the highest daily normal flows, followed by the "Hay River near Meander River"; this is expected based on location in the basin and drainage area contributing to flows (Table 2-1, Figure 2-1). The "Chinchaga River near High Level" station had the third highest daily normal flow record. The daily average flow records show peaks in late April to early May at the six stations. Following this spring freshet, the flows decrease substantially until early July, after which a consistent low flow is maintained for the subsequent summer, fall, and winter months.

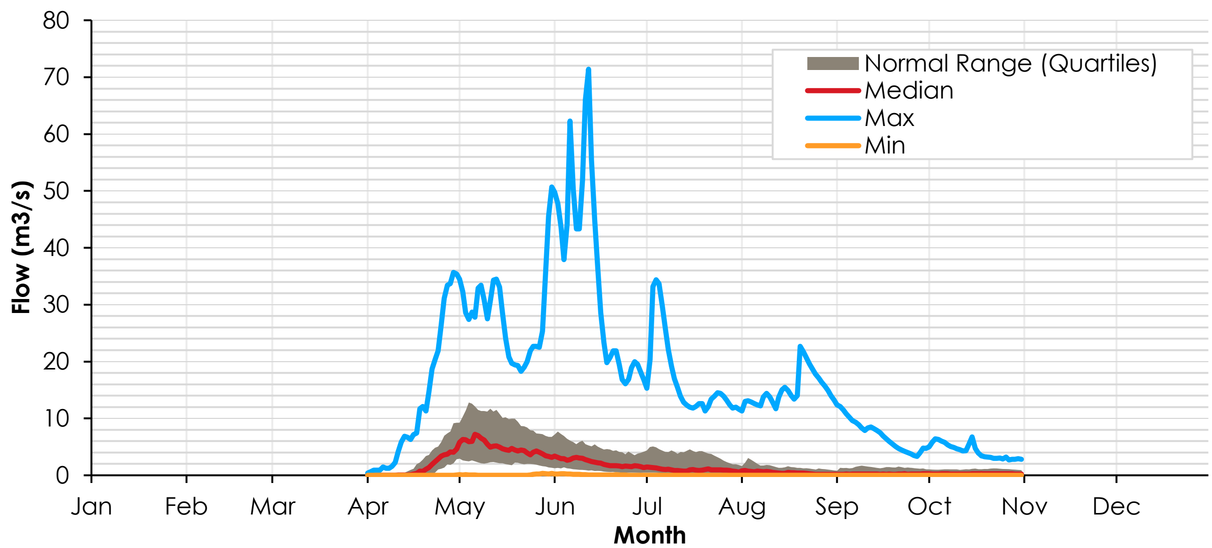

Figure 2-2 Daily Flow (1970–2012) at the WSC Station "Sousa Creek near High Level" (07OA001)

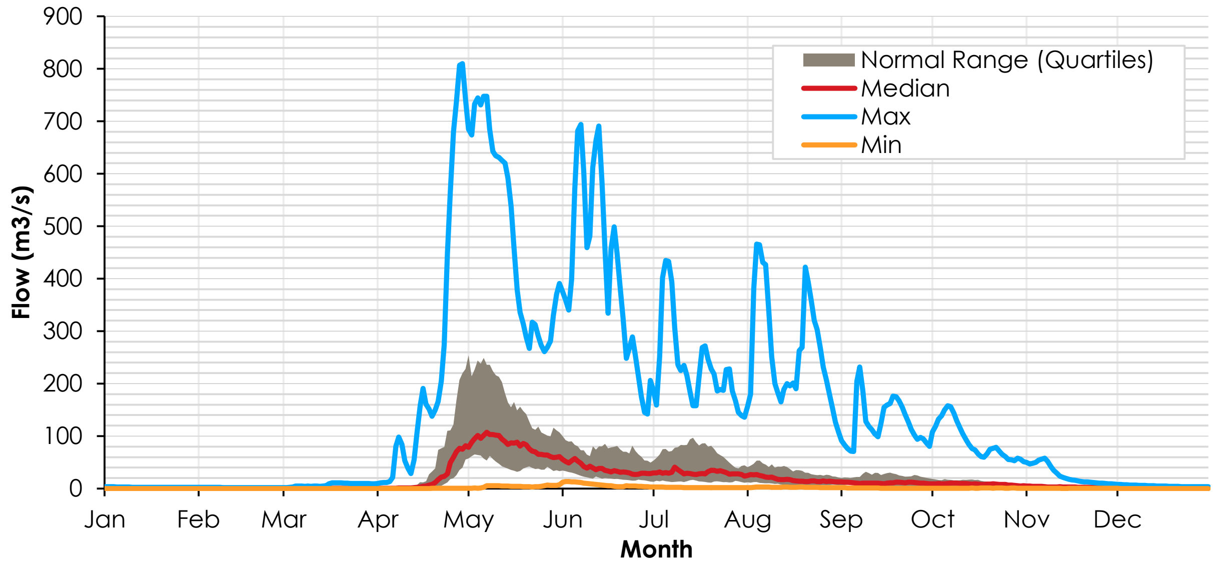

Figure 2-3 Daily Flow (1970–2012) at the WSC Station "Chinchaga River near High Level" (07OC001)

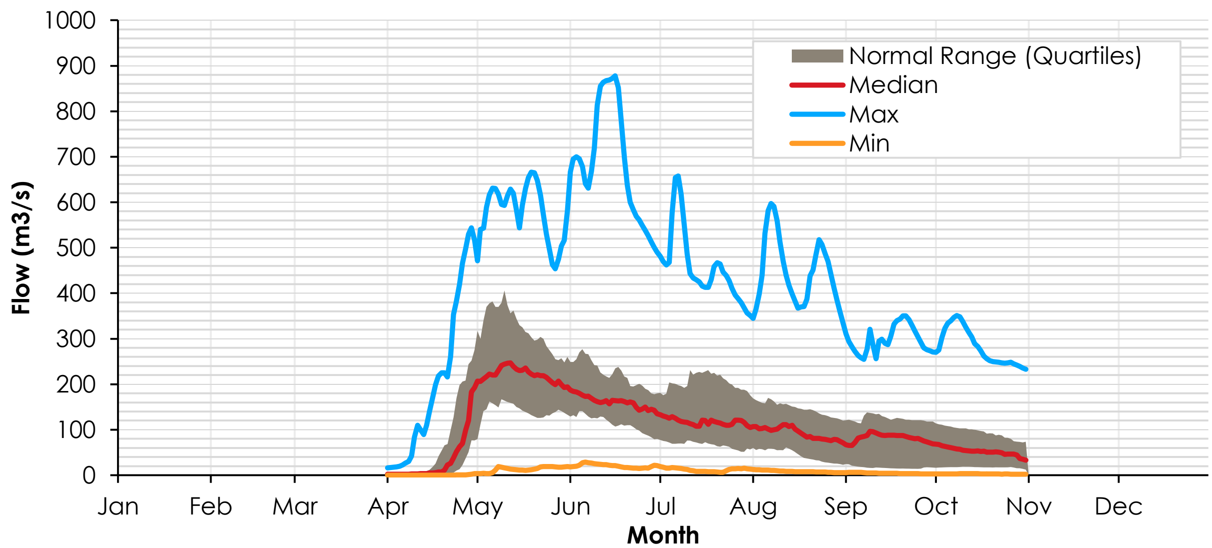

Figure 2-4 Daily Flow (1974–2013) at the WSC Station "Hay River near Meander River" (07OB003)

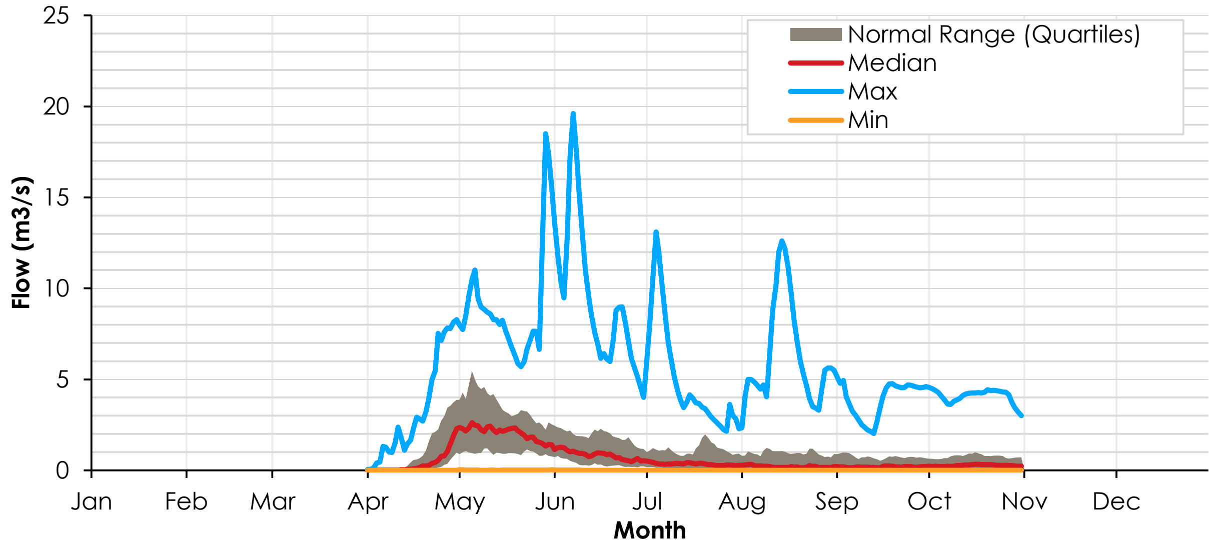

Figure 2-5 Daily Flow (1977–2013) at the WSC Station "Lutose Creek near Steen River" (07OB006)

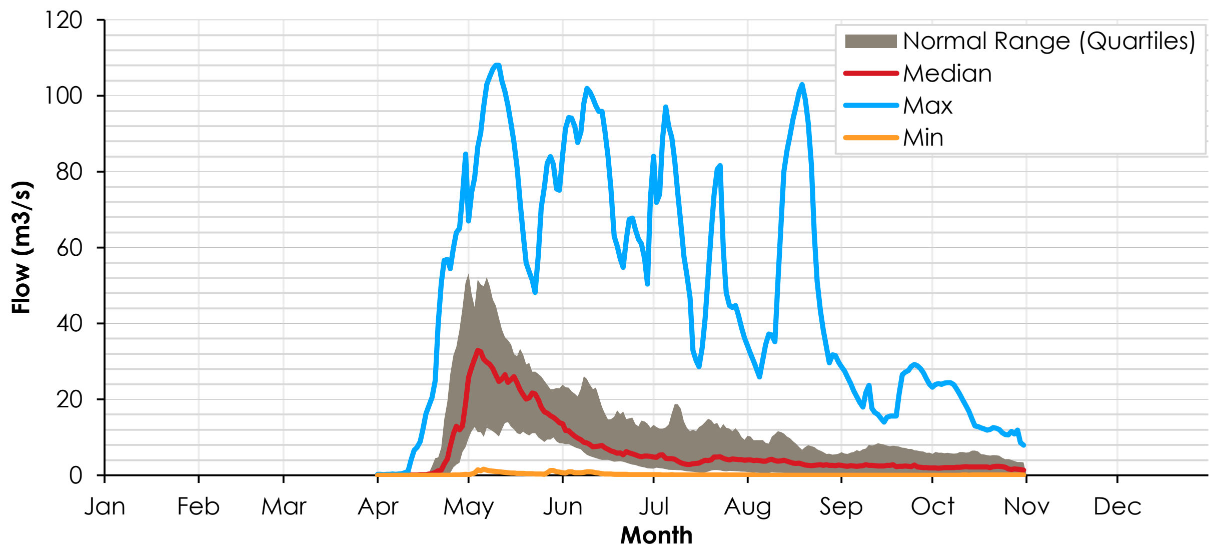

Figure 2-6 Daily Flow (1974–2012) at the WSC Station "Steen River near Steen River" (07OB004)

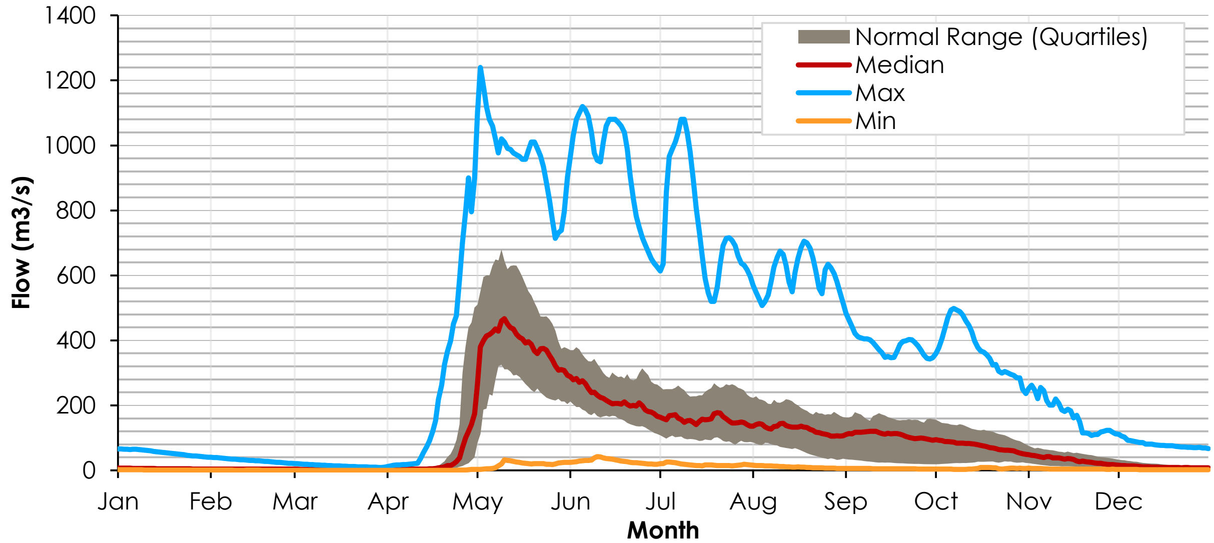

Figure 2-7 Daily Flow (1963–2014) at WSC Station "Hay River near Hay River" (07OB001)

The highest daily average yield at all stations occurs in early May, corresponding with peak flows, and ranges from 0.650 mm/day/km^2 to 1.26 mm/day/km^2 (Figure 2-8). The highest daily average yield was measured at the "Chinchaga River near High Level" station (1.26 mm/day/km^2), followed by "Steen River near Steen River" (1.12 mm/day/km^2), "Lutose Creek near Steen River" (0.965 mm/day/km^2), and "Sousa Creek near High Level" (0.895 mm/day/km^2). In May, hydrometric stations on the Hay River exhibited the lowest daily average yields, with "Hay River near Meander River" at 0.650 mm/day/km^2 and "Hay River near Hay River" at 0.801 mm/day/km^2. The yields have much more spread from mid-April to mid-May than they do at any other time of the year. The "Hay River at Meander River" station has very similar yields to the "Hay River near Hay River" station for most of the year, both of which are located on the mainstem of the Hay River. The main differences in yield occur mid-April to mid-May. The "Hay River at Hay River" station represents the average yield for the entire Hay River Basin, while the Hay River at Meander River represents 71% of the basin area.

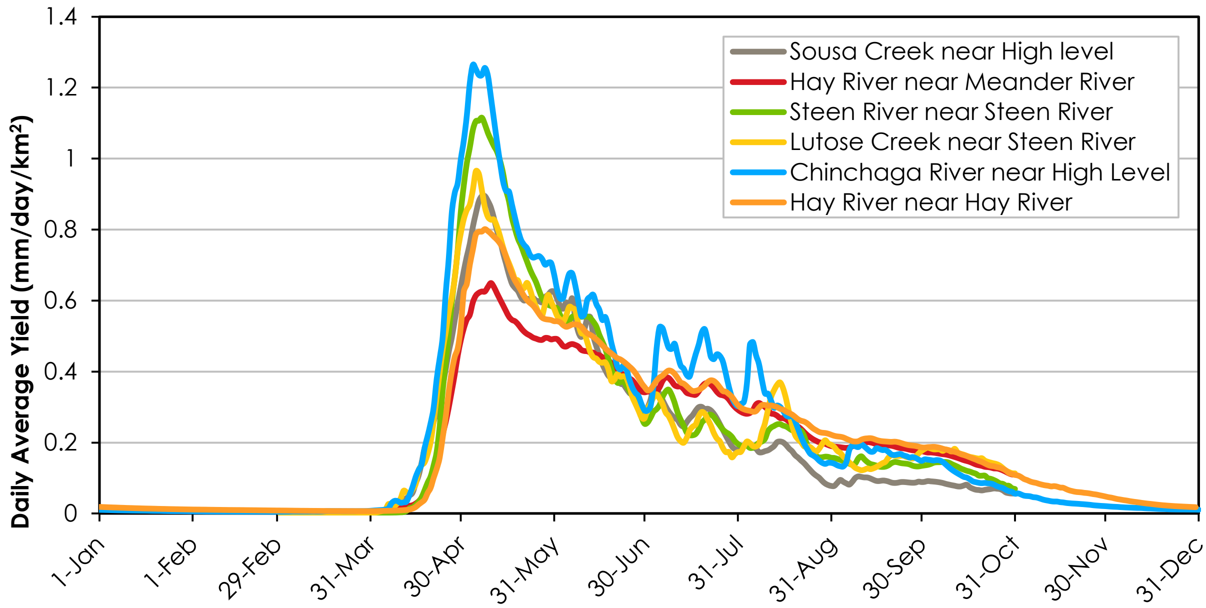

Figure 2-8 Daily Average Yield Dynamics at Six WSC Stations in the Hay River Basin (Hay River Mainstem and Tributaries)

In the Upper Hay sub-basin, there is only one monitoring station, on Sousa Creek, and there is no monitoring on the mainstem of the Hay River upstream of the Hay-Zama wetland complex, a key lowland area of the basin. The Chinchaga River station covers a key upland area for the basin in Alberta, but there is no monitoring information for the Kotcho River, the other key upland area of the Hay River (in British Columbia) (see Section 1.1 for a description of the two main headwater/upland areas). Stations representing higher elevations with steeper terrain (upland areas) would have increased precipitation and be more responsive to precipitation events and therefore produce higher yields than stations located at lower elevations on more flat terrain. The headwater areas of the basin within Alberta do have higher yields than other areas, and this is expected to be the same for the British Columbia headwater areas of the basin.

As mentioned, there is also no water level monitoring of the Hay-Zama wetland complex, making it difficult to determine the effect of the wetland complex on the overall water balance for the Hay River basin. The wetland complex may have important storage functions during peak flows, and base flow contribution during the winter season. Reduced yield in the downstream Hay River stations may be somewhat related to the lake storage effect from the Hay-Zama wetland complex in the Upper Hay sub-basin, upstream of the two Hay River mainstem stations, but is more likely related to precipitation differences across the basin (see Section 1.3). However, there is insufficient water quantity monitoring to definitively determine this.

The annual yields at the "Chinchaga River near High Level" and "Hay River near Hay River" stations, for their respective periods of data record, are presented in Figure 2-9. The long-term average annual yields at the "Chinchaga River near High Level" and "Hay River near Hay River" stations are 88 mm/year/km^2 and 70 mm/year/km^2, respectively.

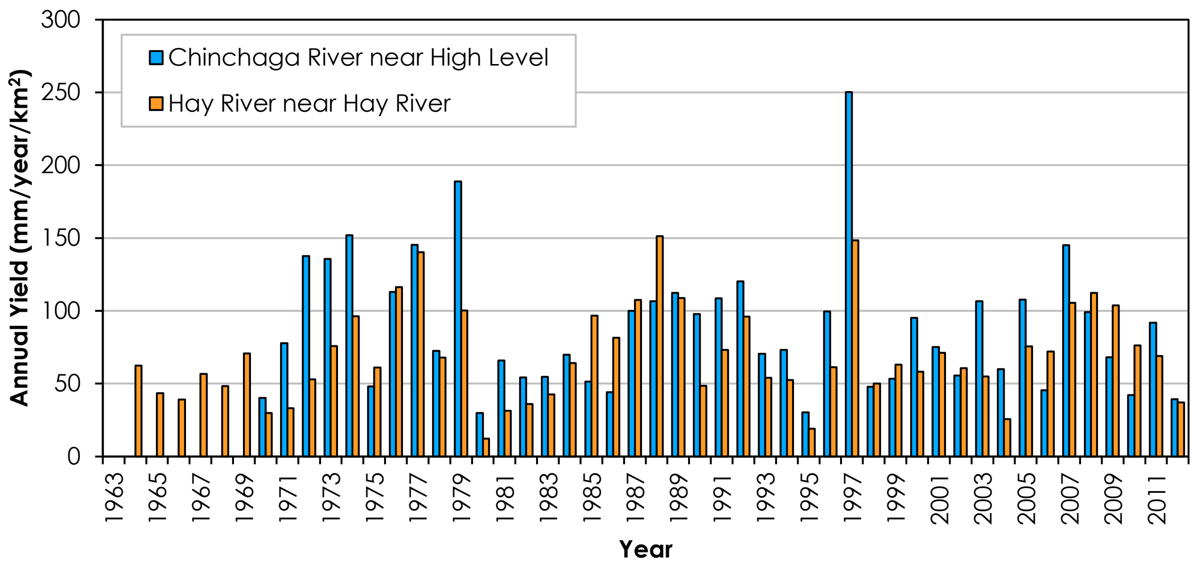

Figure 2-9 Annual Yield Dynamics at Two WSC Stations in the Hay River Basin

2.2.2 Variability over Time

Temporal variability in flow was examined using ten-year averages based on daily flow data. Variability was assessed for the Lower Hay sub-basin (represented by the "Hay River near Hay River" station, period of record 1964–2012) and the Chinchaga sub-basin (represented by the "Chinchaga River near High Level" station, period of record approximately 1970–2012). Daily flow records were evaluated for the following parameters:

- Annual mean streamflow
- Annual minimum streamflow
- Annual maximum streamflow

Annual streamflow was calculated from the water year: a-12 month period from October 1 through September 30, designated by the calendar year in which it ends, and in which 9 of the 12 months are included. For example, the period beginning October 1, 2011 and ending September 30, 2012 is defined as the "2012 water year."

Annual peak flows reported by WSC were also analyzed. The WSC annual peak flow is the highest instantaneous flow recorded during a given year, whereas the annual maximum flow is calculated from WSC daily flows (the mean flow estimated from water level data over a 24-hour period). Therefore, WSC annual peak flows are higher than the annual maximum flows calculated for this analysis. Due to some missing annual peak flows at both stations studied, 10 year averages could not be calculated for the entire period of record.

There have been no observable changes in annual mean flow for the entire period of record at the "Hay River near Hay River" and "Chinchaga River near High Level" stations, which have continuous flow monitoring data (Figure 2-10 and Figure 2-11). The annual mean flow values fluctuate greatly from year to year but the 10 year moving average shows no observable increase or decrease over time, indicating that the total volume of water flowing within the Hay River Basin, despite considerable annual variability, is the same now as it was about 40 years ago. This also suggests that, overall, the hydrological cycle has not changed measurably over the period of record.

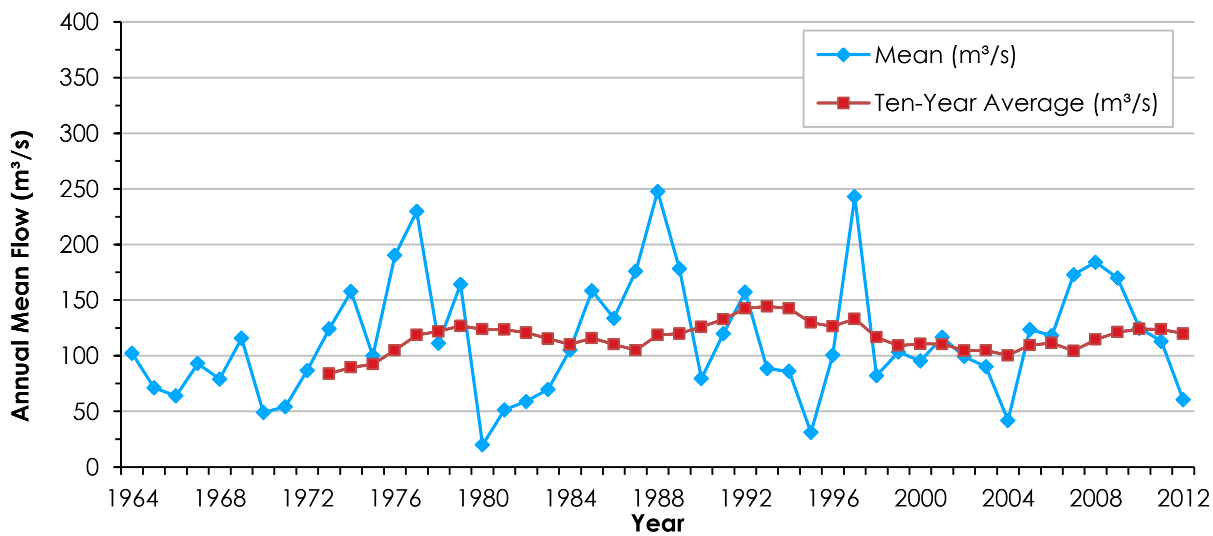

Figure 2-10 Temporal Variability in Annual Mean Flow in the Lower Hay Sub-basin, Represented by the WSC Station "Hay River near Hay River", with the 10-year Moving Average

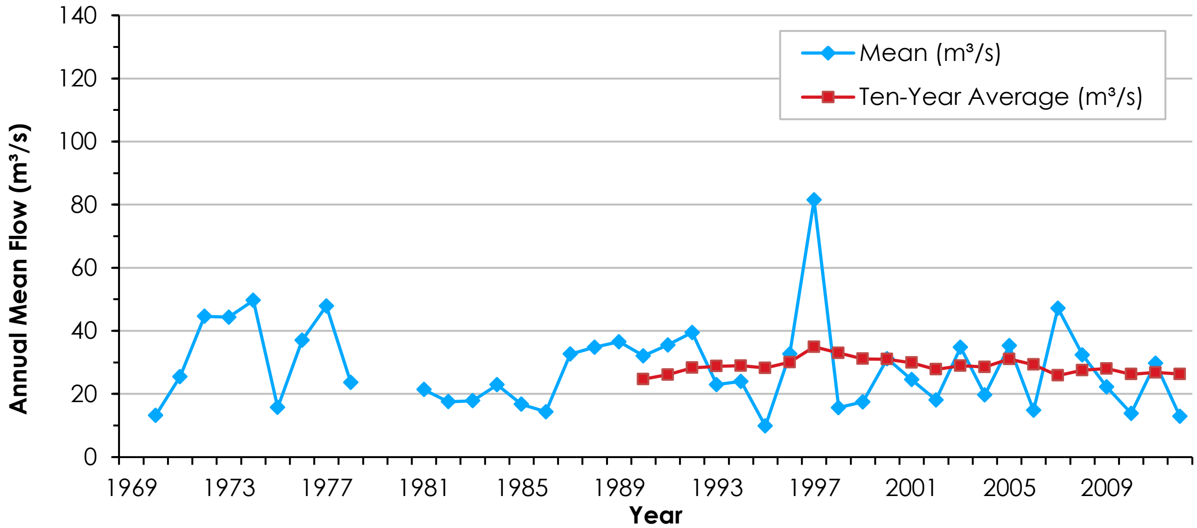

Figure 2-11 Temporal Variability in Annual Mean Flow in the Chinchaga Sub-basin, Represented by the WSC Station "Chinchaga River near High Level", with the 10-year Moving Average

Annual minimum daily flow appears to be increasing in the Lower Hay sub-basin (Figure 2-12). Conversely, annual maximum daily flow shows no observable trend, with the exception of a decrease over the period 1990 to 2000 (Figure 2-13). This suggests that, within the Lower Hay sub-basin, baseflow during the winter months has increased over the period of record.

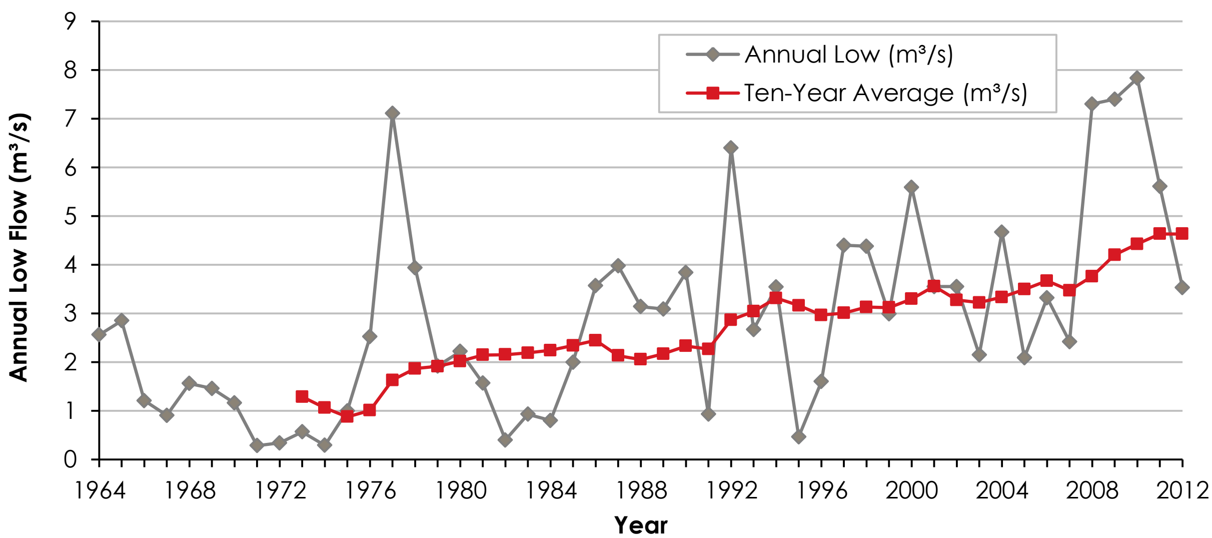

Figure 2-12 Temporal Variability in Annual Low Flow in the Lower Hay Sub-basin, Represented by the WSC Station "Hay River near Hay River", with the 10-year Moving Average

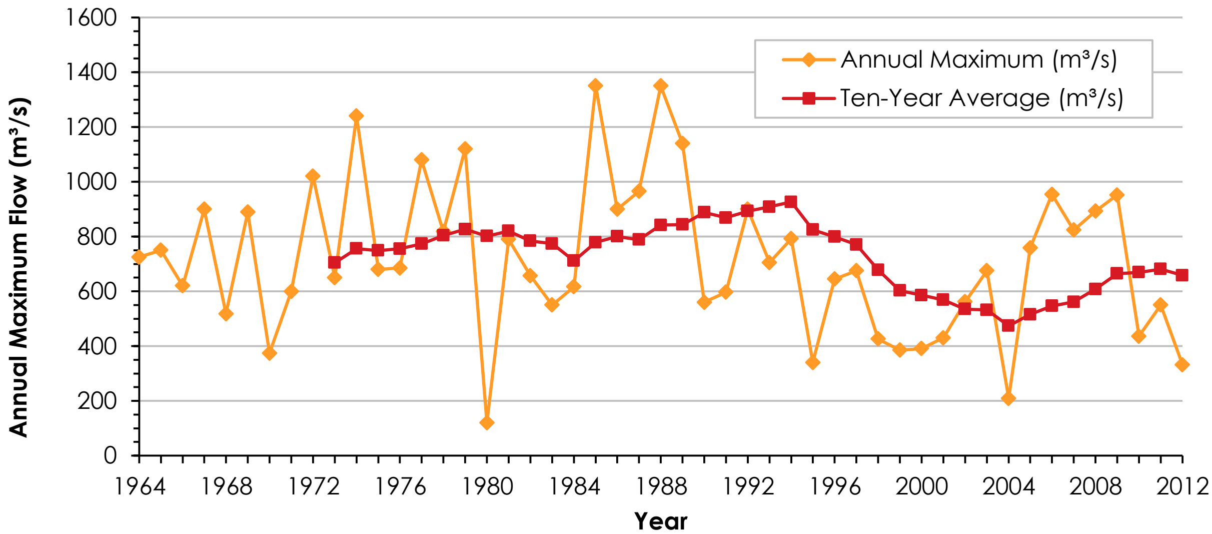

Figure 2-13 Temporal Variability in Annual Maximum Flow in the Lower Hay Sub-basin, Represented by the WSC Station "Hay River near Hay River", with the 10-year Moving Average

Annual peak flows recorded at the "Hay River near Hay River" station (Figure 2-14) correspond with the annual maximum flows calculated from the daily flow data. Due to multiple years of missing data, a 10 year moving average could not be calculated.

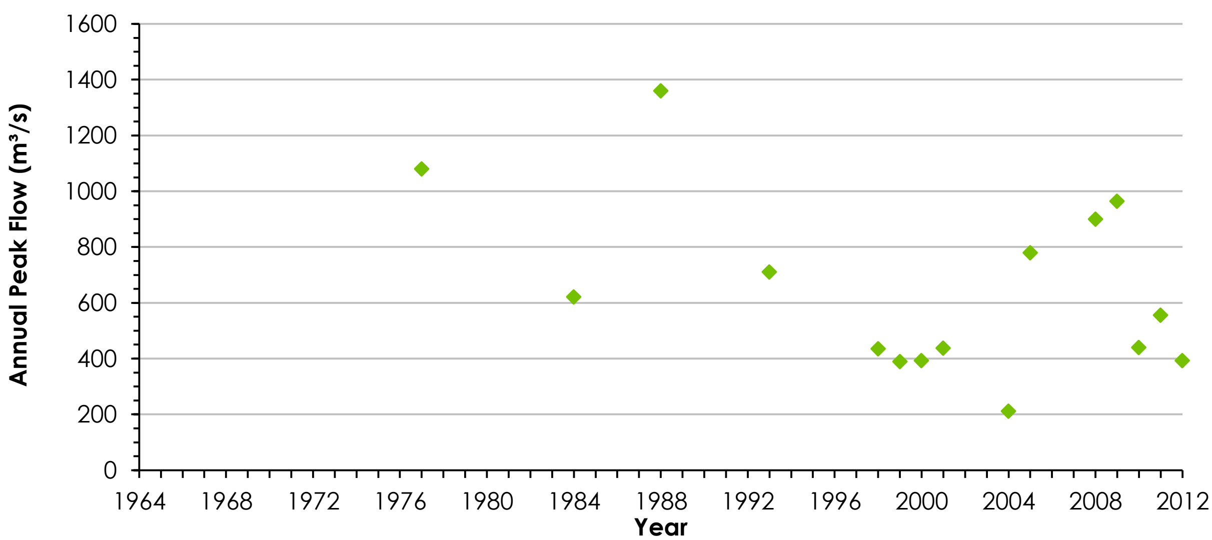

Figure 2-14 Temporal Variability in Annual Peak Flow in the Lower Hay Sub-basin, Represented by the WSC Station "Hay River near Hay River"

Within the Chinchaga sub-basin, there has been no observable change in the annual minimum daily flow (Figure 2-15) or annual maximum daily flow (Figure 2-16) over the past approximately 40 years, with the exception of a slight decrease in annual maximum flow for approximately 10 years during the 1990s (Figure 2-16). This indicates that the frequency and occurrence of extreme events, such as winter baseflow, intense summer rainstorms, precipitous freshet melting events, and/or unusually large snowpack, have not increased within the Chinchaga sub-basin.

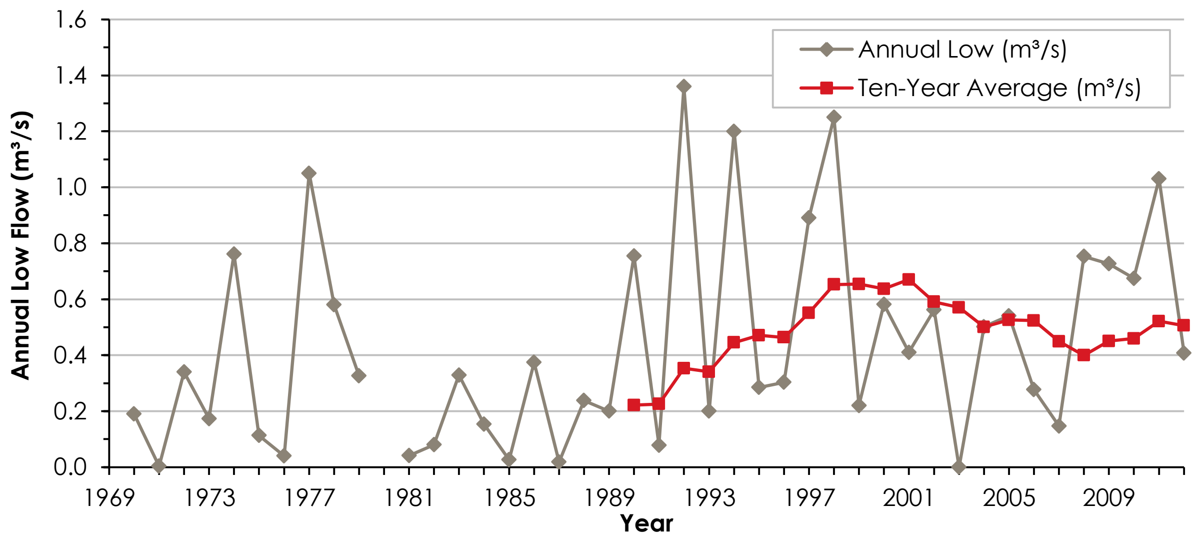

Figure 2-15 Temporal Variability in Annual Low Flow in the Chinchaga Sub-basin, Represented by the WSC Station "Chinchaga River near High Level", with the 10-year Moving Average

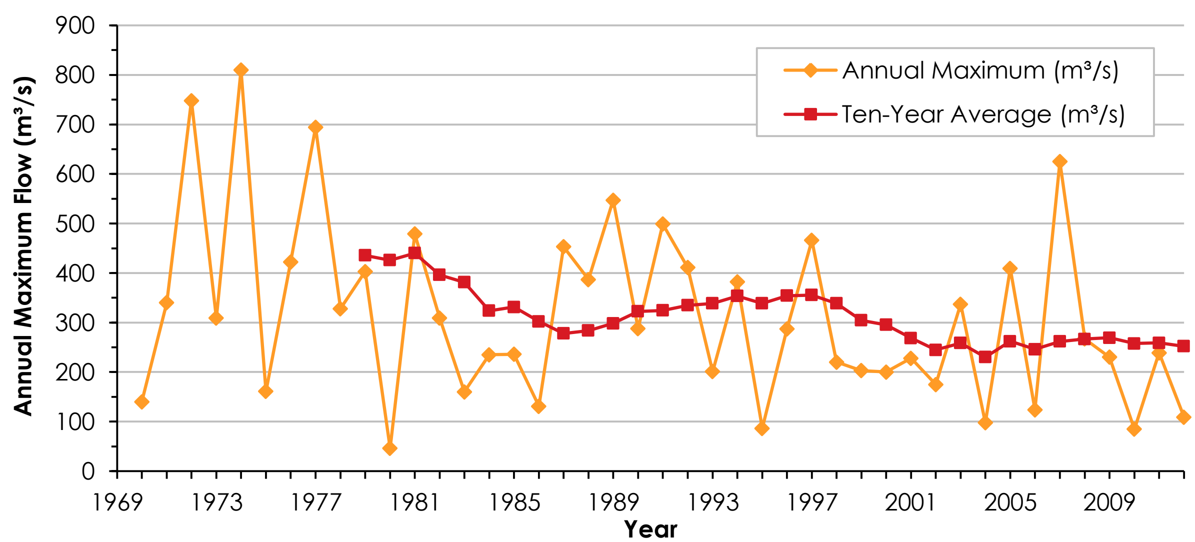

Figure 2-16 Temporal Variability in Annual Maximum Flow in the Chinchaga Sub-basin, Represented by the WSC Station "Chinchaga River near High Level", with the 10-year Moving Average

Annual peak flows recorded at the "Chinchaga River near High Level" station (Figure 2-17) correspond with the annual maximum flows calculated from daily flow data. Due to multiple years of missing data, a 10 year moving average could only be calculated from 1980 to 1992.

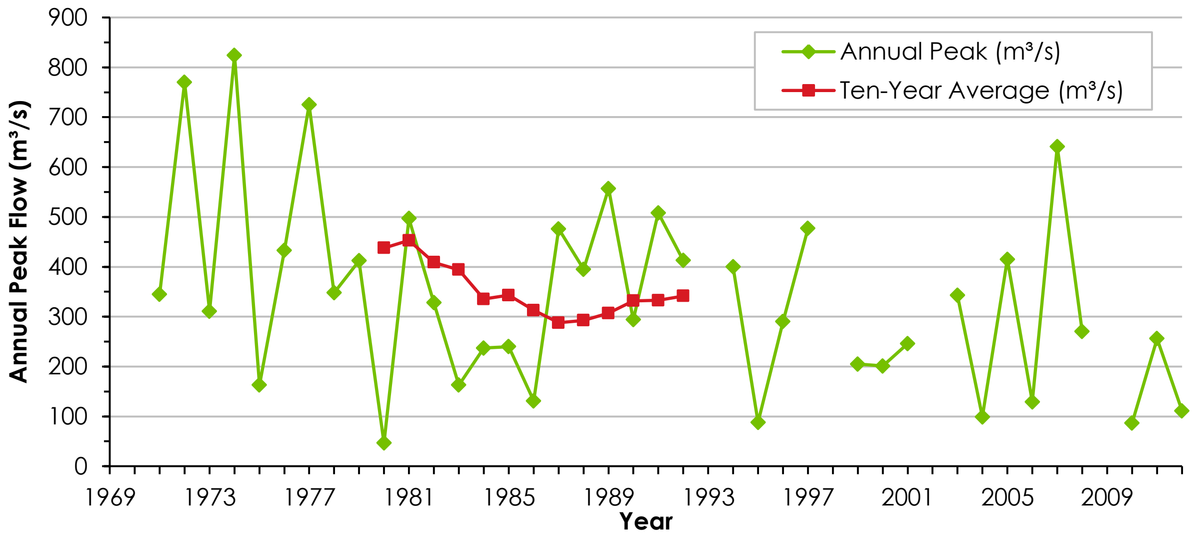

Figure 2-17 Temporal Variability in Annual Peak Flow in the Chinchaga Sub-basin, Represented by the WSC Station "Chinchaga River near High Level", with the 10-year Moving Average

2.2.3 Summary

There are two main headwaters areas in the Hay River basin; flow coming out of the headwaters areas is monitored in Alberta but not in British Columbia. There also is no flow monitoring on the mainstem of the Hay River upstream of the Hay-Zama wetland complex. The only tributary upstream of the complex that is monitored is Sousa Creek near High Level. As expected, the highest yielding tributary of the Hay River is the Chinchaga River coming out of the main headwaters area in Alberta. The Hay River at Meander River has similar yields to the Hay River near Hay River, except during the spring freshet mid-April to mid-May. Elevations in the basin, represented by station locations, also play a part with variations in precipitation and in response to precipitation, producing differences in yields.

Results of the hydrological flow analysis and evaluation of temporal variability suggest the hydrological cycle within the Hay River Basin has not experienced any observable total increase or decrease in yearly flow over the past approximately 40 years. However, a small increase in winter baseflow was observed in the Lower Hay sub-basin over the period of record, consistent with hydrologic analyses completed by Environ (2012).

Water use and allocation compared to the average annual and winter low flow data are reviewed in Section 6.0. Potential for climate change influences on hydrology are discussed in Section 7.9.

2.3 RIVER MORPHOLOGY AND FLOW PATH ANALYSIS

2.3.1 Background and Methods

River morphology and flow path was analyzed to provide baseline information on morphology of the Hay River and comment on evolution of the river flow path over the last 50 to 60 years. Seven sites within the 1,114 km length of river were selected as representative of distinct river channel morphologies found along the path of the river (e.g., very sinuous meanders near the Alberta-British Columbia border versus the more straight and entrenched river section near the Hamlet of Enterprise, Northwest Territories). Other considerations were ecological significance of the area, proximity to local communities and intensity of land use in the area. Table 2-2 provides a summary of the sites selected, along with information on the imagery reviewed for each site. Site locations are shown in Figure 2-18.

Table 2-2 Sites Selected for the Morphology and Flow Path Assessment, Including Air Photos and Imagery Used for the Assessment

Site Number	Area	Approximate location	Air photo		Bing® imagery	Google Earth® imagery
			No.	Scale		
Site 1	Hay River Delta	60° 49' 0" N 115° 47' 14" W	A14854_21 (1955-08-08)	1: 60,000	September, 2012	October 2013
Site 2	Enterprise Hamlet area	60° 33' 17" N 116° 08' 08" W	A12619_209 (1950-06-27)	1: 40,000	July 2012	July 2014
Site 3	Alberta- Northwest Territories border area	60° 0' 16" N 116° 58' 9" W	A18303_44 (1964-07-22)	1: 60,000	August 2012	March 2008
Site 4	Hay River near Meander River	59° 8' 58" N 117° 38' 10" W	A15177_69 (1955-09-07)	1: 60,000	May 2012	June 2012
Site 5	Hay-Zama wetland complex area	58° 45' 27" N 119° 22' 53" W	A15188_92 (1955-08-29)	1: 40,000	July 2011	September 2012
Site 6	Chinchaga River area	58° 35' 49" N 118° 20' 2" W	A15201_104 (1955-09-10)	1: 40,000	August 2010	April 2013
Site 7	Hay River Protected Area in British Columbia	58° 43' 36" N 120° 12' 39" W	A12539_03 (1950-04-03)	1: 40,000	May 2011	May 2005

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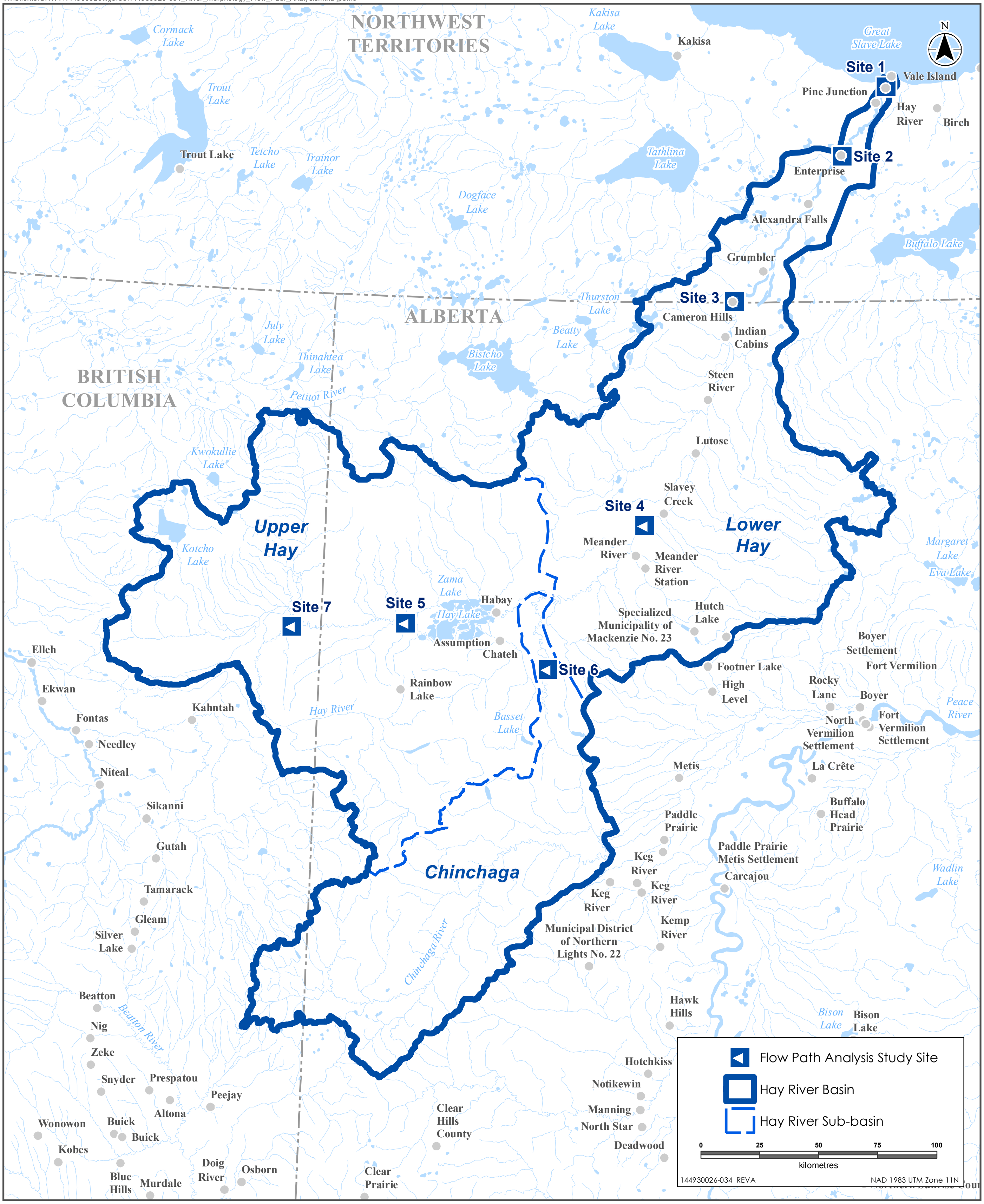


Sources: Base Data - Government of Canada; Thematic Data - Government of Canada, Stantec

Disclaimer: This map is for illustrative purposes to support this Stantec project; questions can be directed to the issuing agency.

Hay River Basin and Sub-basins:
Sites Selected for River Morphology and Flow Path Analysis

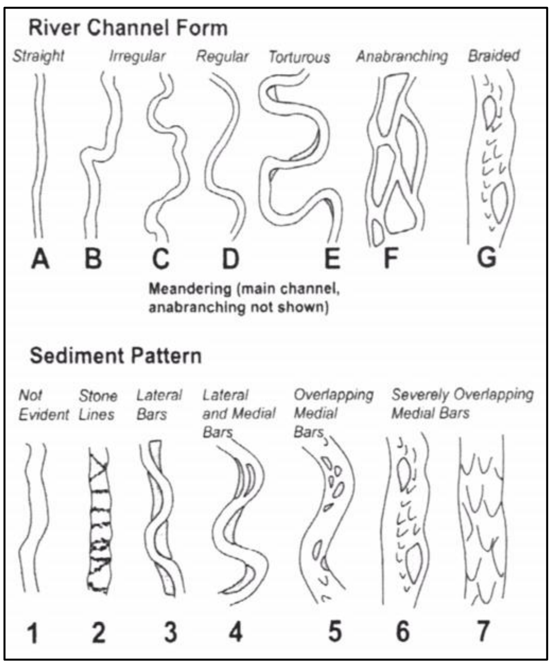
Stantec

Figure 2-18

Observations on the general physiographic setting, distinct river channel morphology, nature of the material through which the river flows, and comments on the occurrence of geomorphic processes (e.g., channel aggradation, riverbank erosion) are provided for each site.

Channel sinuosity is a relative estimate of how straight or meandering (sinuous) a channel is, and was assessed by calculating the ratio of channel length versus the corresponding down-valley distance for each site. Typically a channel distance of 20 km was used. Generally, river channels with sinuosity ratios near 1.0 are classified as straight, while those with ratios above 1.5 are classified as meandering.

Figure 2-19 displays some of the river channel forms and sediment patterns referred to in this assessment. Additional information about description, classification and typology of river channel morphology is available in Kellerhals et al. (1976), Church (1992), Hogan and Luzi (2010), and Burge and Guthrie (2013).



SOURCE: Burge and Guthrie 2013

Figure 2-19 Stream Classification System for the Identification of the River Channel Form and Sediment Pattern

Recent changes in morphology of the Hay River were examined by comparing select historical air photos to recent satellite imagery. Comments related to evolution of the river flow path were made when notable changes were visible on the imagery. Air photos from the 1950s and 1960s were acquired in digital format from the National Air Photo Library of Natural Resources

Canada. Satellite imagery used to describe the current state of the river consisted of publically available Bing imagery and Google Earth imagery dating from 2005 to 2014 (Table 2-2).

Figures were generated for each site, displaying key morphological elements of the river. Specific features, indicative of changes in channel morphology, are highlighted whenever visible. Observations on flow velocity, timing and occurrence of floods, site-specific bank aggradation and bank erosion rates are not discussed, as the current assessment was limited to a review of medium to large scale two-dimensional imagery, without any field reconnaissance.

2.3.2 Results

2.3.2.1 Site 1: Hay River Delta, Northwest Territories

2.3.2.1.1 Site Description

Site 1 is located at the mouth of the Hay River, in the Northwest Territories, where the river discharges into Great Slave Lake. The site is approximately 9 km downstream of the Water Survey of Canada hydrometric station "Hay River near Hay River". At this location, the river flows from south to north within an irregular sinuous channel that splits and becomes anabranching approximately 4.5 km upstream from Great Slave Lake. An anabranching system consists of multiple channels separated by stable vegetated islands which are large relative to the size of the channel (Knighton 1998).

Based on review of available imagery and recent surficial geology mapping compiled by the Geological Survey of Canada (2016), the Hay River delta is 10 to 12 km wide at is mouth (east/west axis along the shore of Great Slave Lake) and approximately 15 km long (north/south axis). The delta encompasses the Town of Hay River, its airport on the Vale Island, and the community of West Point (Figure 2-20).

While the river valley is cut into the sandy glaciolacustrine sediments of Glacial Lake McConnell, the current channel is incised in post-glacial lacustrine deltaic sediments (Geological Survey of Canada 2016). The river valley is about 300 m wide in the southern portion of this section (about 10 km south of the northern tip of the delta) and about 4.5 km wide at the mouth of the river. The river banks are about 1 to 3 m high and the channel gradient is less than 1% along this river section. No bedrock exposures are visible in the area. The upstream portion of the site is irregular meandering, while the downstream portion (where the river channel splits into a series of channels and islands) is anabranching (according to the classification system of Burge and Guthrie 2013; Figure 2-19).

Figure 2-20 Hay River Delta (Site 1) on the South Shore of Great Slave Lake, Northwest Territories, in 1955 and 2012

2.3.2.1.2 Changes in River Morphology and Flow Path

The comparison of recent satellite imagery (Bing 2012) with an historical air photo from 1955 reveals some minor changes along the river channel, the most obvious being related to the impact of local human occupancy on river morphology. Between 1955 and 2012, development of the Town of Hay River led to modification of several sections of river banks. One example is the closure of two secondary channels located on the west side of the main river channel (Figure 2-21). The upstream portion of the channels has been backfilled, while infrastructure (e.g., harbor, docks and landings) has been developed downstream. Also, several sections of river bank adjacent to developed areas have been lined with concrete and/or riprap material.

Minor changes to river morphology were noted at the mouth of a secondary channel located on the west side of Vale Island. A smaller island located at the mouth of this secondary channel has increased in size by approximately 4 ha since 1955 (Figure 2-22). In addition, sediment deposition at the mouth of the channel has led to growth of the shoreline at the northwestern tip of Vale Island by approximately 300 m (Figure 2-22).

Severe ice jams are known to occur at the mouth of the Hay River during spring break-up and generally cause flooding. Although ice jams and flooding events often generate bank erosion, no visible changes to the river flow path were identified by comparing the 1955 air photo to most recent satellite imagery (i.e., Google Earth 2006 imagery and Bing 2012 imagery).

Figure 2-21 Hay River Delta (Site 1) in 1955 and 2010 Showing Development of Industrial Activities on the West Side of the Main River Channel

Figure 2-22 Hay River Delta (Site 1) 1955 and 2010 Images Showing Sediment Aggradation at the Mouth of a River Channel on the Northwestern Tip of Vale Island

2.3.2.2 Site 2: Hay River near the Hamlet of Enterprise, Northwest Territories

2.3.2.2.1 Site Description

Site 2 is located near the Hamlet of Enterprise, Northwest Territories, in the Lower Hay sub-basin. Enterprise is situated on the west bank of the Hay River, about 35 km southwest of the Town of Hay River. In this area, the river flows southwest to northeast and exhibits a meandering morphology, with channel widths ranging from 80 m to about 200 m (Figure 2-23). The river channel is incised 10 to 40 m into thick glaciolacustrine deposits that were deposited in Glacial Lake McConnell (Geological Survey of Canada 2016).

The width of the river valley varies from about 300 to 800 m. The edges of the river valley are characterized by colluviated glaciolacustrine sediments indicative of past and recent mass movements. Moderate to poorly-defined fluvial terraces are visible in some areas, mostly in the inside sections of river meanders. Slope of the river banks varies from 5 to 15%, along the gently sloping river terraces, to well over 50%, in the steep, actively eroding, inside banks of meanders.

This portion of the Hay River is described as a torturous meandering channel (see Figure 2-19). A sinuosity of 1.6 was calculated along a 20 km channel segment. Based on a review of available imagery, migration of the river channel does not appear to be limited by the presence of bedrock. Sediment patterns visible along this section of river consist of lateral and medial bars (see Figure 2-19).

2.3.2.2.2 Changes in River Morphology and Flow Path

The comparison of an historical air photo dating from 1950 to Google Earth imagery from 2014 shows minor changes in overall channel morphology. One of the distinct characteristics of this site is the presence of several unstable river bank sections, mostly located along the outside bank of river meanders, where lateral erosion and progressive undercutting of the toe of the slope is causing the slope to fail. Figure 2-24 shows unstable river bank sections near the Hamlet of Enterprise. Stabilization and reactivation of some small landslides are visible in the photos; however, no major changes in slope and/or channel morphology are visible in the images.

Minor changes in the limit of the active portion of the river channel are evident when comparing the 1950 air photo to the 2014 satellite imagery, where increased vegetation cover is present on some of the lateral and medial bars (Figure 2-25).

Figure 2-23 Hay River near the Hamlet of Enterprise, Northwest Territories (Site 2), in 1950 and 2011

Figure 2-24 Unstable River Bank Sections of the Hay River near the Hamlet of Enterprise, Northwest Territories (Site 2)

Figure 2-25 Increased Vegetation Cover at Some of the Lateral and Medial Bars (Areas Highlighted with Arrows) of the Hay River near the Hamlet of Enterprise, Northwest Territories (Site 2)

2.3.2.3 Site 3: Hay River at the Alberta-Northwest Territories border

2.3.2.3.1 Site Description

Site 3 is located on the Hay River at the Alberta–Northwest Territories border. At this site, the river flows south to north and exhibits a meandering morphology (Figure 2-26). The average river channel width is about 130 m, with an active floodplain width that varies from 1 to 2 km. Channel sinuosity, calculated along a 20 km long river segment, averages 1.8.

Veneers and blankets of organic materials have accumulated in poorly drained portions of the floodplain. The floodplain itself is located within flat to very gently undulating terrain corresponding to a glaciolacustrine plain (Pawley 2010). Two small oxbow lakes are present along the river floodplain, consisting of U-shaped bodies of water that formed where river meanders were cut off from the main river body.

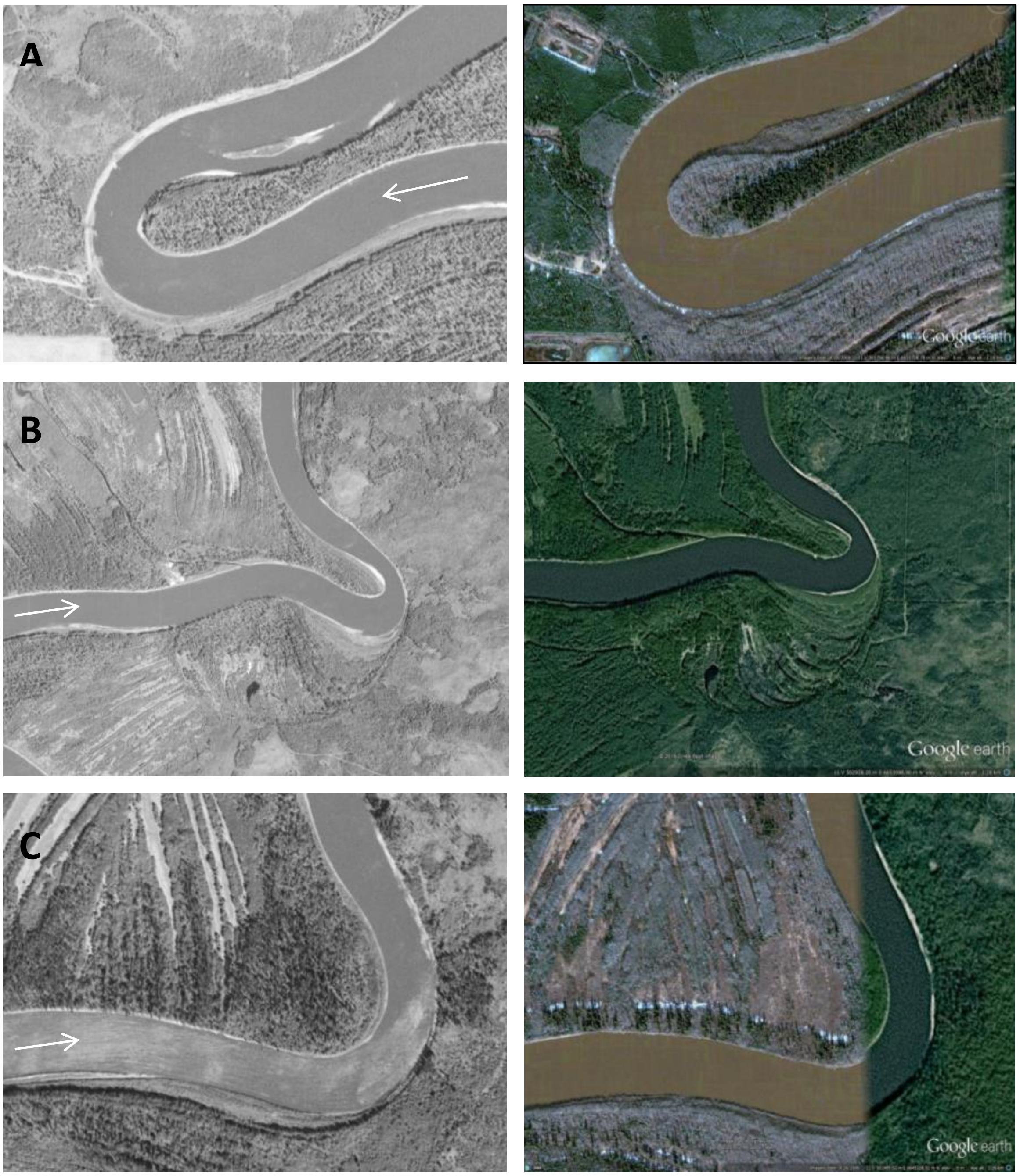
2.3.2.3.2 Changes in River Morphology and Flow Path

A review of available satellite imageries (Google Earth 2006 and Bing 2012) and existing surficial geology mapping (Pawley 2010) confirm the presence of a former river flow path 5 to 7 km east of the current channel location. This former river channel was likely active several thousand years ago, following the melt-out and retreat of late Pleistocene ice sheet in the area.

One of the key features of the river floodplain at Site 3 is the presence of distinct linear patterns related to migration of the river channel (referred as meander scrolls or scroll bar deposits). This feature is related to the slow downstream migration of the meanders within the floodplain. Scroll bar deposits are visible at several locations along the Hay River, but are particularly well-developed at this location (Figure 2-27).

Comparison of the 1964 air photo to recent satellite imagery does not suggest that major bank erosion and/or bed aggradation is occurring at this site. Only minor changes have been identified within the sinuous portions of the river channel, where sediment accumulation appears to have resulted in localized sediment aggradation (Figure 2-27).

Figure 2-26 Hay River at the Alberta-Northwest Territories Border (Site 3), in 1964 and 2012



NOTES: A) Changes in river channel width and increase vegetation coverage along the outside portion of a river meander. B) Minor erosion and aggradation that took place in a tight meander. C) Some erosion took place along the outside river bank, just upstream from the meander.

Figure 2-27 Hay River at the Alberta-Northwest Territories Border (Site 3)

2.3.2.4 Site 4: Hay River near Meander River, Alberta

2.3.2.4.1 Site Description

Site 4 is located near the small settlement of Meander River (part of the Dene Tha' First Nation), located alongside Alberta Highway 35 (the Mackenzie Highway) in northeastern Alberta, in the Lower Hay sub-basin. It is in the same location as the Water Survey of Canada hydrometric station "Hay River near Meander River".

This section of river was separated into two subsections based on differences in channel morphology (Figure 2-28). The first subsection consists of an irregular meandering channel flowing roughly southwest to northeast, with a channel width of about 100 to130 m and incised within the glaciolacustrine deposit. The second subsection, basically starting at the confluence of the Meander River, is less sinuous and flows north, with a channel width of about 120 to 160 m and flowing within both glaciolacustrine and glaciofluvial deposits (Paulen and Plouffe 2008).

In both subsections, floodplain width ranges from about 200 to 620 m. Incision of the river channel, both within the glalciolacustrine/glaciofluvial deposits and the more recent fluvial deposits, varies from 1 to 2 m to well over 10 m. Neither the existing surficial geology mapping nor the available imagery indicate the presence of bedrock along the river channel.

2.3.2.4.2 Changes in River Morphology and Flow Path

The comparison of an historical air photo from 1955 to recently acquired Bing imagery (2012) does not indicate evidence of major river flow path changes over that period. Minor changes, such as increased sedimentation near the mouth of a small tributary creek, are visible (Figure 2-29). Between 1955 and 2012, a lateral bar formerly located within the active portion of the river channel became colonized by vegetation. The 2012 imagery also shows the presence of a new medial bar in the middle of the river channel.

Although the channel flow path has not changed considerably since the 1950s, the river banks show several signs of erosion and slope instability. Lateral erosion along the toe of the slope led to development of several landslides, for the most part located on the outside banks of meander bends. A retrogressive landslide, likely developed in fine-grained glaciolacustrine sediments, is visible on Figure 2-30. These unstable river segments were also visible on the 1955 air photo.

Figure 2-28 Hay River near Meander River, Alberta (Site 4), in 1955 and 2012

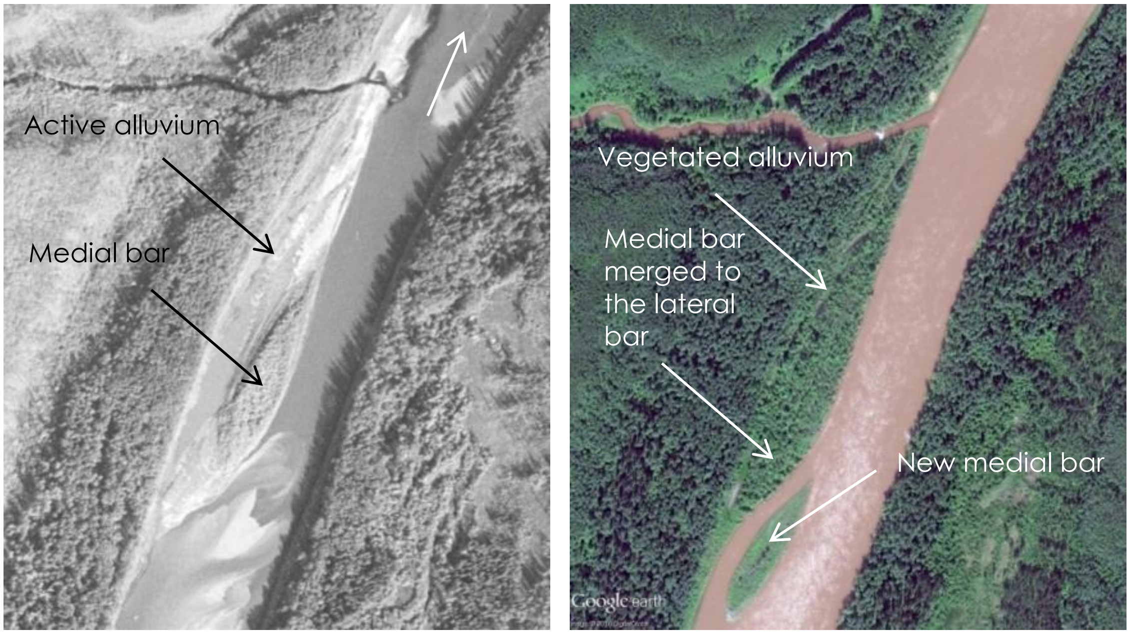


Figure 2-29 Changes in Vegetation and Stabilization of the Gravel Bars at the Hay River near Meander River, Alberta (Site 4)

Figure 2-30 Changes in the Channel Morphology in Response to the Reactivation of an Old Landslide at the Hay River near Meander River, Alberta (Site 4)

2.3.2.5 Site 5: Hay-Zama Wetland Complex Area, Alberta

2.3.2.5.1 Site Description

The Hay-Zama wetland complex is located approximately 25 to 50 km northeast of Rainbow Lake in northeast Alberta, in the Upper Hay sub-basin. The wetland complex comprises thousands of hectares of marshes, freshwater lakes, willow swamps, river deltas, floodplain woodlands, and wet meadows. Several rivers and small intermittent creeks drain into the wetland complex, with the Hay River being the largest drainage system in the area.

The wetland complex is known to be affected by extreme seasonal and annual water level fluctuations and frequent floods (Alberta Wilderness Association 2016); however, the section of the Hay River selected for the current assessment (Site 5) is located just west of the wetland complex, in an area where recurrent seasonal flooding is much less intense and where the river channel is more stable.

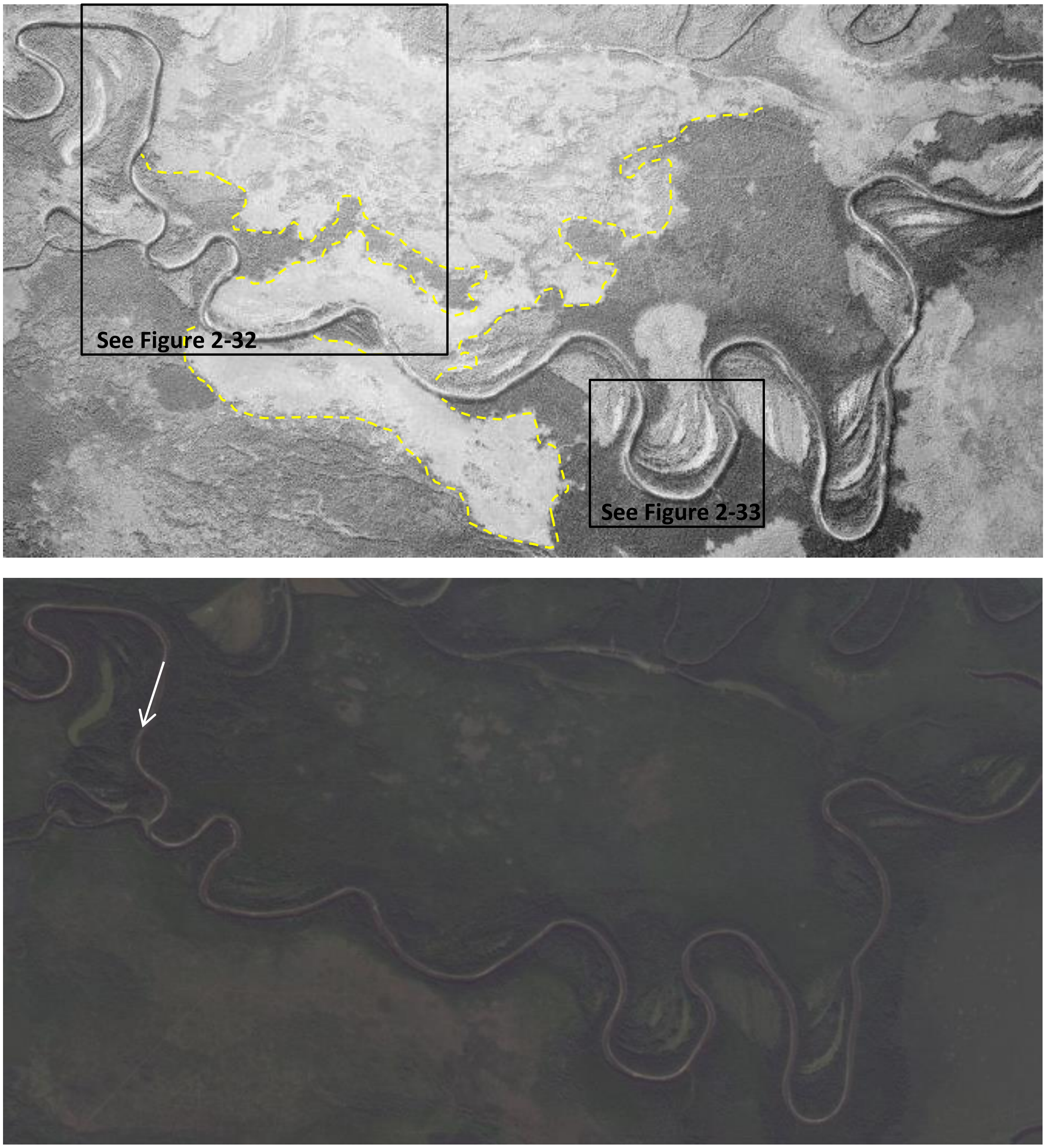
At Site 5, the Hay River flows from west to east within a very planar (flat) fluvial plain. The river morphology resembles a delta complex rather than a single river channel. Local soils have developed over fine-grained lacustrine and fluvial sediments. The low-lying terrain is generally poorly to very poorly drained and contains numerous swamps, fens, and bogs. The active river channel is meandering and its pattern ranges from tortuous to irregular (Figure 2-31). The river channel width averages about 50 m and channel sinuosity, calculated along a 20 km river section, averages to 2.2.

2.3.2.5.2 Changes in River Morphology and Flow Path

Two distinct river channels are visible within the area of interest displayed on Figure 2-31. The southern channel is the currently active Hay River channel, while the northern channel is a former, now abandoned, channel of the Hay River. Review of available satellite imageries (Google Earth 2012 and Bing2011) shows that the Hay River formerly flowed through the northern channel before cutting south and merging into what used to be the Little Hay River channel.

Figure 2-32 shows the location where the transition between river channels took place. Review of the 1955 air photo (Figure 2-31) indicates that this major change in channel flow path occurred prior to 1955.

Comparison of the historical air photo and the recent satellite imageries shows only minor differences in morphology of the river channel. Lateral bar deposits are visible on the outside bend of most channel meanders (Figure 2-33); however, resolution of the air photo and satellite imageries does not allow for precise assessment of channel migration and/or deposition at these locations.



NOTE: The footprint of an old forest fire is displayed on the 1955 air photo by the dashed yellow line. No change in the river flow path was denoted by comparing the two images.

Figure 2-31 Hay River near the Hay-Zama Wetland Complex, Alberta (Site 5), 1955 to 2012.

NOTE: Google Earth screen shot from August 2012 showing the current and former channel of the Hay River, approximately 10 km west from the Hay-Zama wetland complex. The former flow path of the Hay River is displayed by the dashed line.

Figure 2-32 Current and Former Channel of the Hay River, Approximately 10 km West from the Hay-Zama Wetland Complex, Alberta (Site 5)

Figure 2-33 Scroll Bar Deposit Along the Inside River Bank on the Hay River near the Hay-Zama Wetland Complex, Alberta (Site 5)

2.3.2.6 Site 6: Chinchaga River near Alberta Highway 58

2.3.2.6.1 River Description

The Chinchaga River is a major tributary of the Hay River in Alberta. The Chinchaga River originates from a series of small lakes (Chinchaga Lakes) in northeastern British Columbia, before crossing into Alberta and flowing east-northeast toward the small community of Keg River, Alberta. The Chinchaga River then flows north to its confluence with the Hay River, about 25 km east (downstream) of the Hay-Zama wetland complex.

Site 6 is located where the Chinchaga River crosses Alberta Highway 58, 70 km west of the Town of High Level, Alberta, in the Chinchaga sub-basin. It is in the same location as the Water Survey of Canada hydrometric station "Chinchaga River near High Level". At Site 6, the Chinchaga River flows south to north and is an 80 to 120 m wide meandering channel. The meandering pattern is irregular and the river meanders over a 1 to 2 km wide floodplain (Figure 2-34). Channel sinuosity, calculated along a 20 km river section, averages 2.2.

The floodplain is incised approximately 5 to 10 m into a flat to gently undulating glaciolacustrine plain (Paulen et al. 2005). Several large river bank exposures are visible, especially in areas where the river is located along the edges of the floodplain (i.e., where the channel is incised into the fine-grained glaciolacustrine deposits).

2.3.2.6.2 Changes in River Morphology and Flow Path

Comparison between the 1955 air photo and recent acquired Bing (2011) and Google Earth (2013) imagery shows a series of subtle changes in the overall channel morphology (Figure 2-34). The occurrence of landslides along the river banks is likely one of the key elements affecting channel morphology. These landslides are relatively small (under 1 ha) and consist mostly of small earth slides and flows.

Figure 2-35 shows an unstable riverbank section located along the outside bend of a river meander where a series of small landslides occurred in fine grained glaciolacustrine sediments. Riverbank erosion and slope movement occur mostly along outside bends of the river where fluvial erosion along the toe of the slope is more prevalent.

Comparison of the 1955 and 2010 imagery also indicates progressive river bank erosion within the narrow strip of land separating two sections of the river (Figure 2-36). The strip of land decreased in width from about 100 m in 1955 to just under 55 m in 2010. Erosion and lateral migration of the river bank will eventually lead the river channel to change its course and cut off the meander so that it reaches a straighter course.

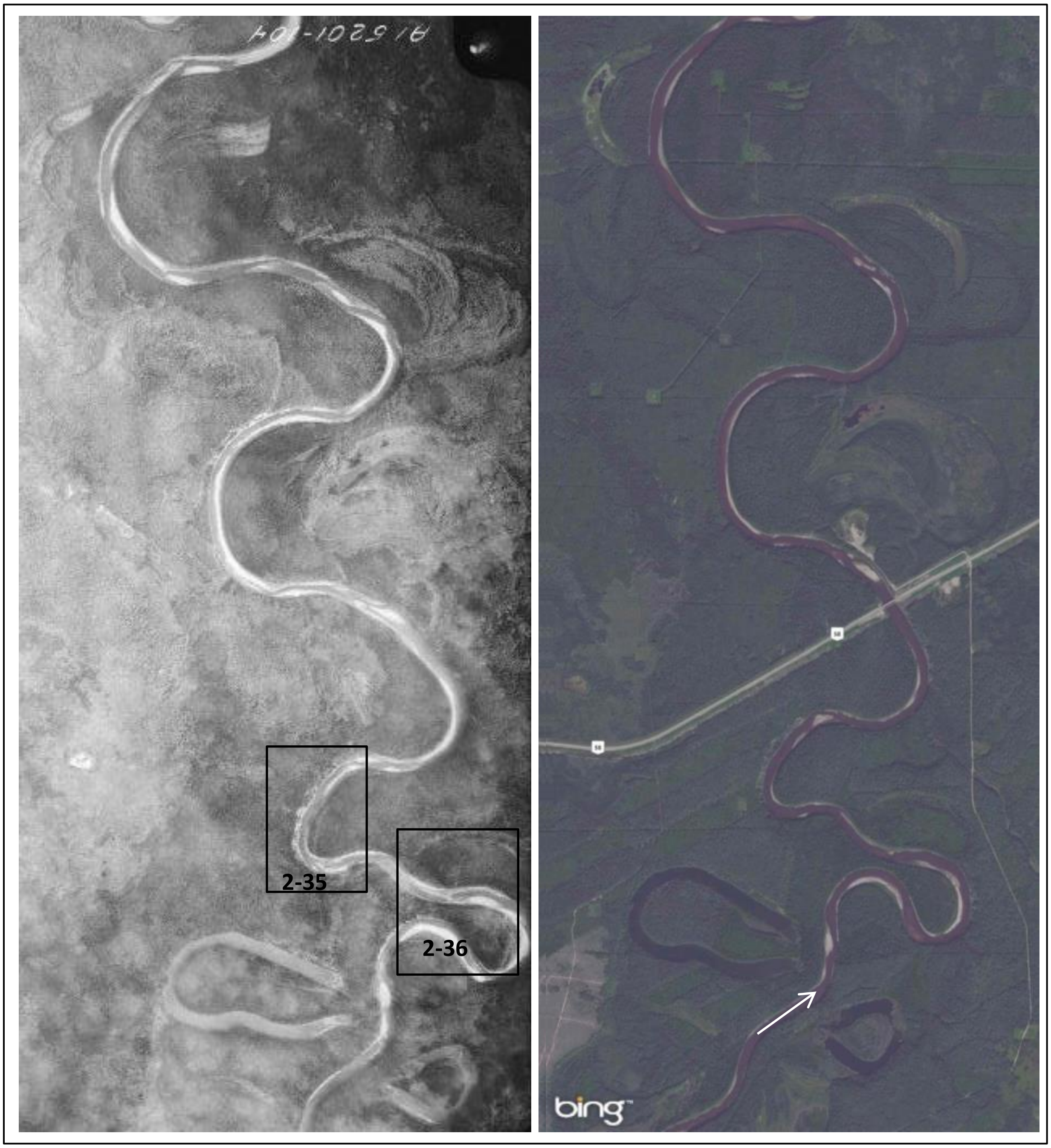


Figure 2-34 Chinchaga River near Alberta Highway 58 (Site 6), 1955 and 2010

NOTE: The black dashed line show the unstable riverbank section while the yellow dashed line shows areas where vegetation has grown and where the riverbank has stabilized.

Figure 2-35 Increased Riverbank Erosion and Landslide Activity within a Meander of the Chinchaga River, Just South of the Alberta Highway 58 Crossing (Site 6), 1955 and 2010

Figure 2-36 Progressive Bank Erosion at the Chinchaga River, near the Alberta Highway 58 (Site 6), that Took Place Between 1955 and 2010

2.3.2.7 Site 7: Hay River Protected Area, British Columbia

2.3.2.7.1 Site Description

Site 7 is located 15 km west of the British Columbia/Alberta border, about 140 km east of Fort Nelson, British Columbia, in the Upper Hay sub-basin. The area is characterized by very flat low-lying muskeg terrain with extensive wetlands, slow-moving streams, and numerous small lakes within the Boreal White and Black Spruce biogeoclimatic zone (BC Parks 2015a). In this area, the Hay River flows southwest to northeast along a very torturous meandering channel (Figure 2-37). This portion of the Hay River likely displays the highest level of sinuosity found throughout the entire river flow path, with a channel sinuosity of 3.6.

At Site 7, the active river channel is about 30 m wide and flows within a moderate to poorly-drained floodplain about 1.5 km wide. Numerous abandoned river channels (most of which now consists of wetlands) and oxbow lakes are present on either side of the active river channel. The heights of the river banks appear to range from less than 1 m to 3 m. No signs of mass movements are visible on the satellite imagery; however, the distinct sinuous morphology of the river channel is clearly indicative of the occurrence of progressive lateral erosion.

2.3.2.7.2 Changes in River Morphology and Flow Path

Differences in the river flow path are visible when comparing the 1950 air photo to recent Google Earth (2005) and Bing (2011) satellite imageries. The presence of a cluster of abandoned river channels and oxbow lakes is considered a reliable indicator of continuous geomorphic changes occurring along this portion of the Hay River.

At least two meander cutoffs have occurred since 1950, each resulting in the creation of an oxbow lake (Figure 2-38). Review of the air photo and satellite imageries demonstrates that progressive channel migration leads to channel cutoffs. The formation of cutoffs is followed by sedimentation of bed load materials at the ends of the cutoff channel, which then results in formation of an oxbow lake. Once this occurs, the lake becomes a closed system where organic material starts to accumulate. These four main morphological stages (i.e., bank erosion, channel cutoffs, formation of oxbow lakes, and progressive wetlands development) are visible in the study area (Figure 2-39).

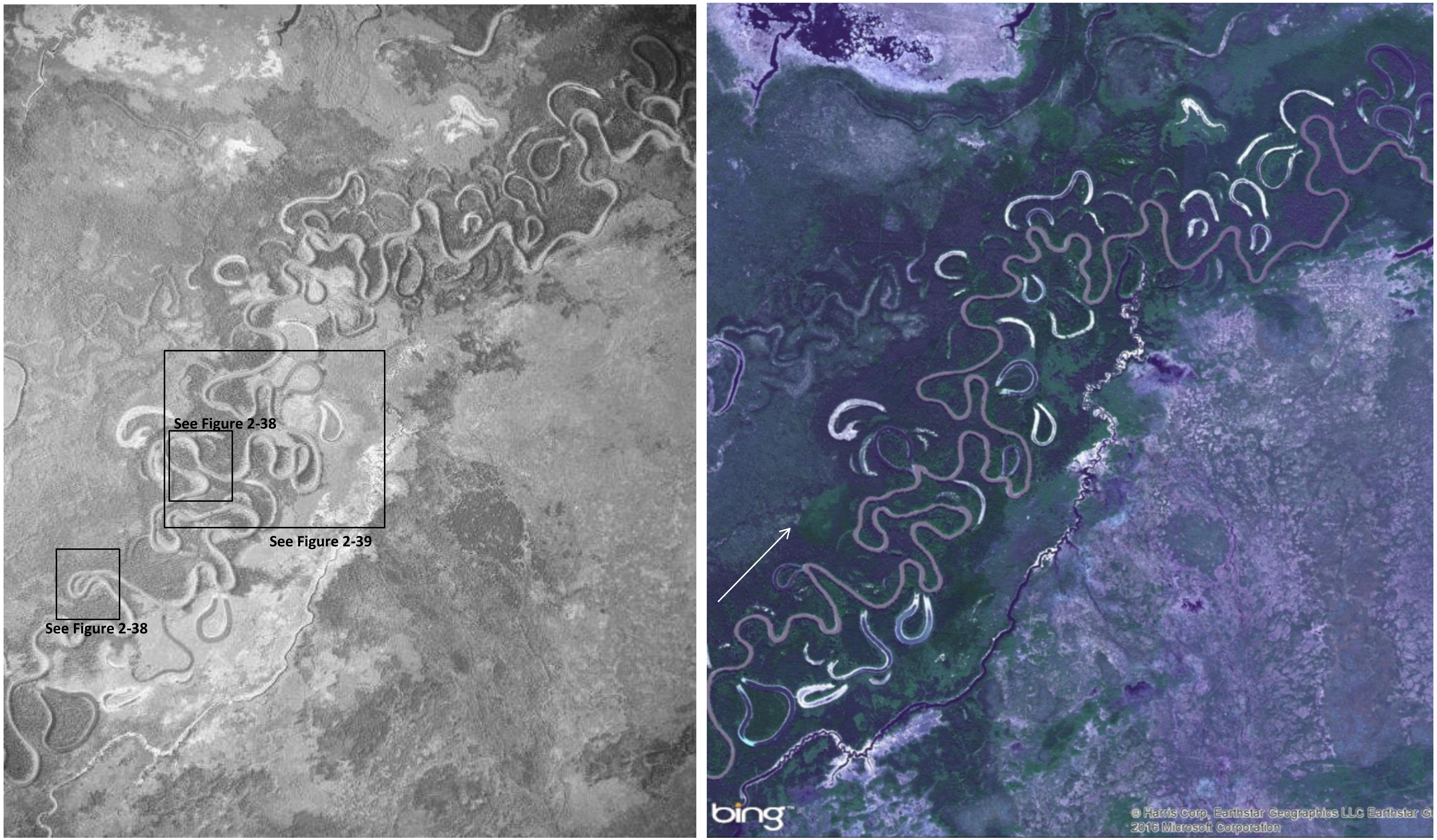


Figure 2-37 Hay River within the Hay River Protected Area, British Columbia (Site 7), 1950 and 2005.

Figure 2-38 Meander Cutoffs that Occurred Over the 1950 to 2005 Period on the Hay River, within the Hay River Protected Area, British Columbia

Figure 2-39 Various Stages of Formation of Channel Cutoffs, Oxbow Lakes, and Wetlands near the Hay River, within the Hay River Protected Area, British Columbia

2.3.3 Summary

Publically available satellite imagery was used to compile baseline information on morphology of the Hay River. Factors that influence local river morphology include its overall length (1,114 km) and the crossing of several physiographic regions with varying topography and surficial geology types. The seven key locations analyzed along the river show variation in channel morphology from site to site, but generally show a meandering structure.

Comparing historical air photos (dating from the 1950s and 1960s) to recently acquired satellite imagery (dating from 2005 to 2014) allowed for identification of subtle changes in channel morphology. The results of this high-level analysis show that there are only minor modifications to the overall flow path, limited to localized river sections. These changes or modifications mainly consist of progressive river bank erosion and channel aggradation, which occurs naturally over time. Although human activities in development sectors such as oil and gas, forestry, and agriculture, have the potential to affect the Hay River and its channel morphology, the current assessment did not identify any pressures or direct impacts currently affecting overall morphology or stability of the Hay River. However, detailed site analyses, including field assessments and air photo analysis at a finer scale than the present assessment, would be needed to evaluate site-specific morphological changes as a result of local land development activities.

3.0 AMBIENT HYDROGEOLOGIC CONDITIONS

This section describes groundwater conditions and trends in the Hay River Basin (Sections 3.1 and 3.2). Groundwater use and allocation are reviewed in Section 6.0.

3.1 CURRENT MONITORING PROGRAMS

There are currently three groundwater monitoring wells in the Hay River Basin maintained by Alberta Environment as part of their Groundwater Observation Well Network (GOWN). This includes two nested monitoring wells in the Upper Hay sub-basin (Zama North 87-5 North-0387 and Zama North 87-4 South-0389) and one well in the Lower Hay sub-basin (Meander River 87-2_0381) (Figure 3-9). Two of the wells (Zama North 87-5 North-0387 and Meander River 87-2_0381) are installed in unconfined aquifer conditions and the third (Zama North 87-4 South-0389) is installed in confined aquifer conditions (buried valley overlain by till deposits) (Table 3-1).

Table 3-1 Groundwater Observation Well Network Monitoring Wells in the Upper and Lower Hay Sub-Basins

Monitoring Well	Sub-Basin	Location (Latitude, Longitude)	Well Production Interval[1] (Well Depth) (m)	Aquifer Name	Lithology	Period of Record[2]
Zama North 87-5 North-0387	Upper Hay	58.9775° N, -118.90583° W	4.27 to 5.79 (5.8)	Surficial	Sand	1989–1994 1996–1998 2002–2015
Zama North 87-4 South-0389	Upper Hay	58.97960° N, -118.91532° W	41.16 to 42.7 (48.8)	Buried Valley	Sand	1989–1994 1996–1998 2002–2015
Meander River 87-2-0381	Lower Hay	58.99536° N, -117.65639° W	47.2 to 48.7 (48.7)	Surficial	Sand	1989–1993 1996–1997 2005–2015

NOTES:
1. Well production interval refers to the section of the well that contains screening, through which groundwater flows into the well.
2. Period of record implies years with monitoring data (number of data points vary per year)

These three monitoring wells have been monitored for groundwater quality and water level since 1989; however, the data record has gaps when the stations were not active (Table 3-1). The number of days monitored per year varies by well and, for groundwater level data for the Zama wells, ranges from one day (1998) to complete years (2006 on for Zama North 87-5 North-0387 and 2008 on for Zama North 87-4 South-0389). For the Meander monitoring well, the number of groundwater level monitoring days per year ranges from 34 days (1991) to complete years (2006 onward). Groundwater quality data were not available for incorporation into this report.

There is no other consistent or continuous monitoring of transboundary groundwater in the Mackenzie River Basin, including the Hay River Basin (Alberta and Northwest Territories 2015) at this time. Groundwater monitoring wells are part of the Town of Hay River's Surveillance Network Program, as required under their Water Licence for their municipal landfill (Northwest Territories Water Stewardship 2013).

In early 2016, the Department of Municipal and Community Affairs (GNWT) submitted a land use permit application to drill groundwater monitoring wells in many of the South Slave communities, including Enterprise. The groundwater wells will be situated strategically to monitor groundwater quality around the Enterprise landfill and sewage lagoon (GNWT 2016a).

3.2 CURRENT STATUS AND TRENDS

3.2.1 Groundwater Levels

Groundwater level data were examined for the two monitoring wells in the Upper Hay sub-basin and the monitoring well in the Lower Hay sub-basin, all in Alberta. Over the period of record, the groundwater level in the shallow monitoring well Zama North 87-5 ranged from 345.39 masl to 347.69 masl, a 2.3 m variation in water level from July 1989 to September 2015 (Figure 3-1). At the deep monitoring well Zama North 87-4, groundwater levels ranged from 339.54 masl to 342.45 masl, a 2.9 m variation over the same period of record (Figure 3-2).

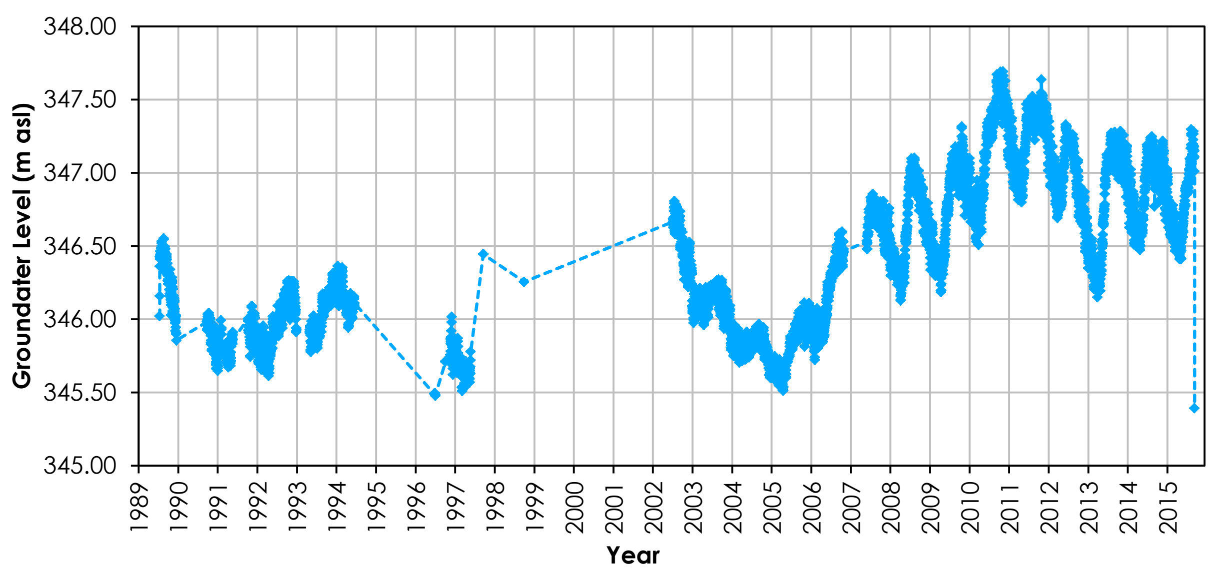


Figure 3-1 Daily Groundwater Elevation at Shallow Monitoring Well Zama North 87-5 North-0387, from July 1989 to September 2015

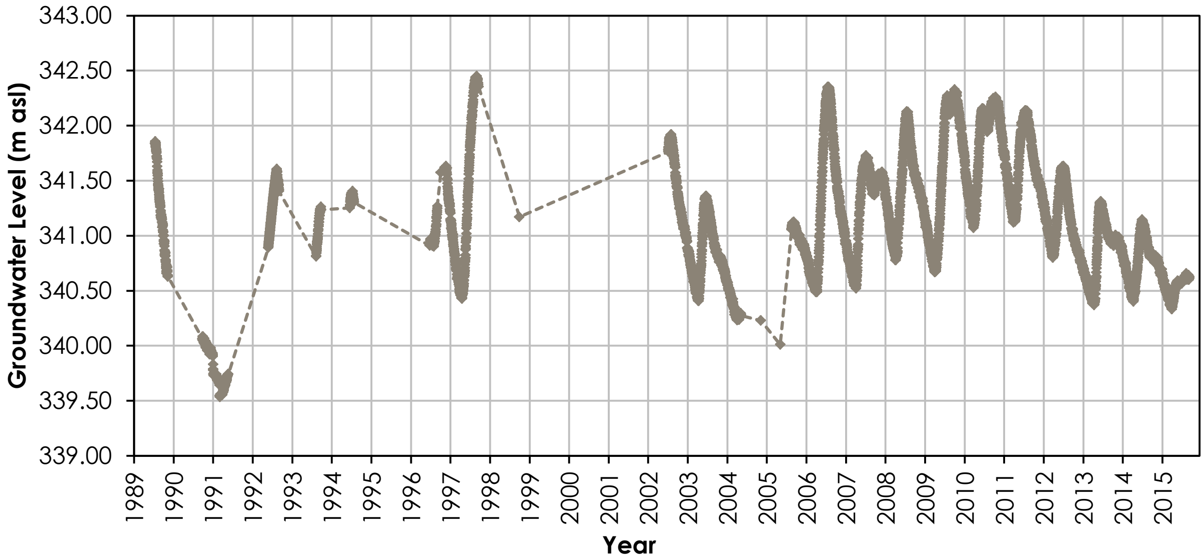


Figure 3-2 Daily Groundwater Elevation at Deep Monitoring Well Zama North 87-4 South-0389, from July 1989 to September 2015

Average daily data for the two Zama area monitoring wells were examined to identify annual patterns in groundwater level. Daily groundwater level data were averaged over the data record. Groundwater levels in the Zama wells appear to peak in late July/early August and steadily decline through fall and winter, reaching minimum levels in April/May (Figure 3-3 and Figure 3-4). Following this, groundwater levels rise sharply through spring and summer before reaching their peak again. This pattern is typical for Alberta and implies groundwater levels in these two wells are influenced by surface water inputs. Overall average annual variability ranges from 346.15 to 346.76 masl (0.61 masl) for the shallow Zama North 87-5 well, and from 340.54 to 341.65 masl (1.11 masl) for the deep Zama North 87-4 well. Groundwater levels for these two wells show a relatively good correlation with interpolated precipitation data and the incidence of wet and dry years (Figure 3-5), obtained for the township where these wells are located (Alberta Agriculture and Forestry 2016a).

Figure 3-3 Average Daily Groundwater Levels at Shallow Monitoring Well Zama North 87-5 North-0387, Over the Period July 1989 to September 2015

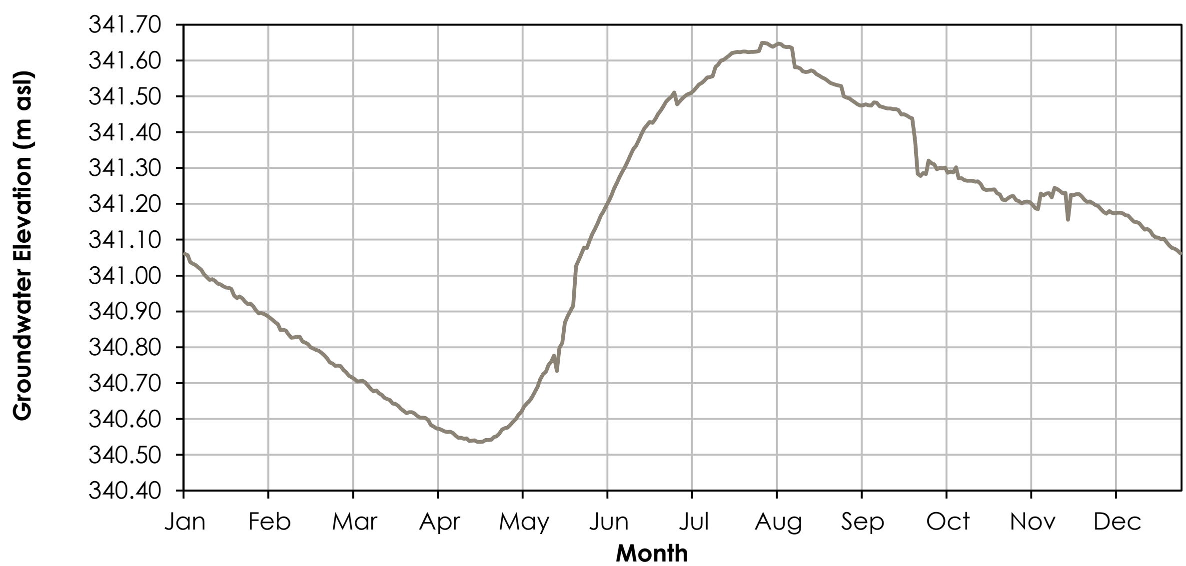
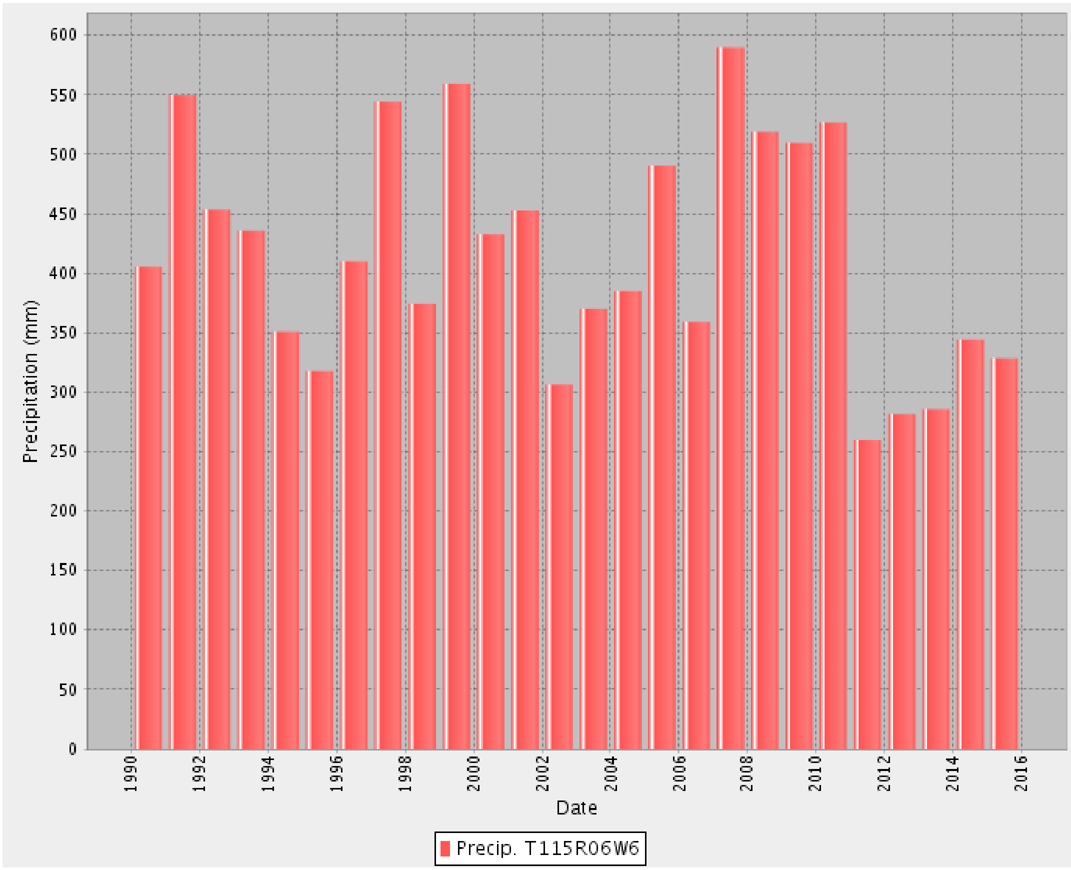


Figure 3-4 Average Daily Groundwater Levels at Deep Monitoring Well Zama North 87-4 South-0389, Over the Period July 1989 to September 2015



SOURCE: Alberta Agriculture and Forestry 2016a

Figure 3-5 Interpolated Annual Precipitation Summary for Zama Area Township T115R06W6

At monitoring well Meander River 87-2-0381, the groundwater level ranged from 301.46 masl to 302.06 masl over the period of record, with an overall range of 0.6 m between July 1989 and September 2015 (Figure 3-6). Similar to the Zama monitoring wells, average daily data were examined over the period of record. Groundwater levels at the Meander River well do not show the strong seasonal patterns evident for the Zama wells (Figure 3-7). The range of variability appears to decrease through the summer, though overall average annual variability (range from 301.70 to 301.83 masl, or 0.13 masl) is relatively low compared to the Zama wells. Additional information on the aquifer and geologic deposits are needed to explore this further. The groundwater levels for the Meander River well still show a relatively good correlation with interpolated precipitation data and wet/dry year occurrence (Figure 3-8) obtained for the township where this well is located (Alberta Agriculture and Forestry 2016a).

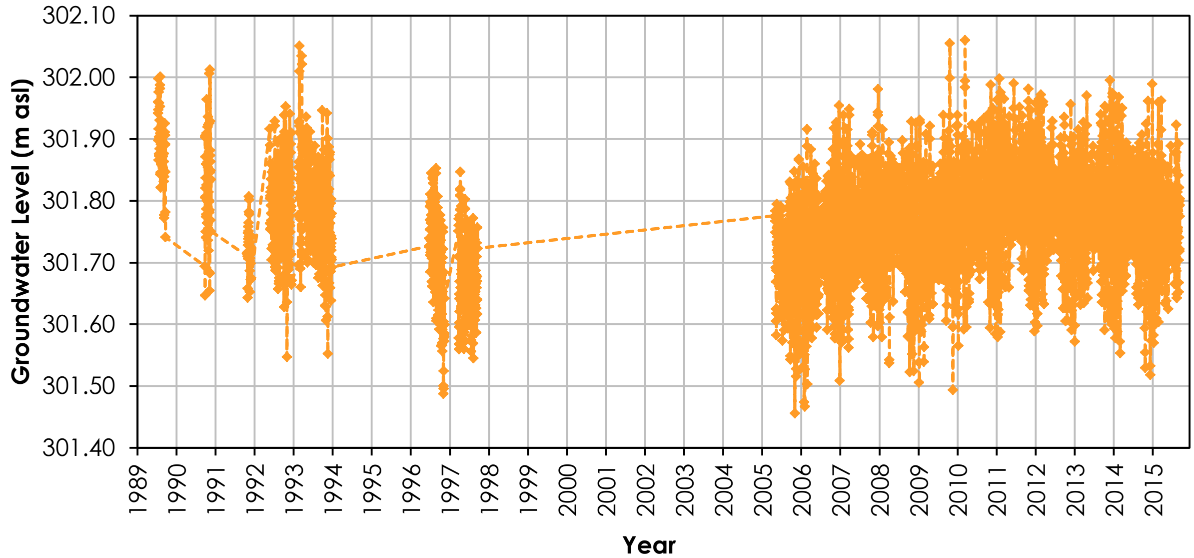


Figure 3-6 Daily Groundwater Elevation at Monitoring Well Meander River 87-2-0381, from July 1989 to September 2015

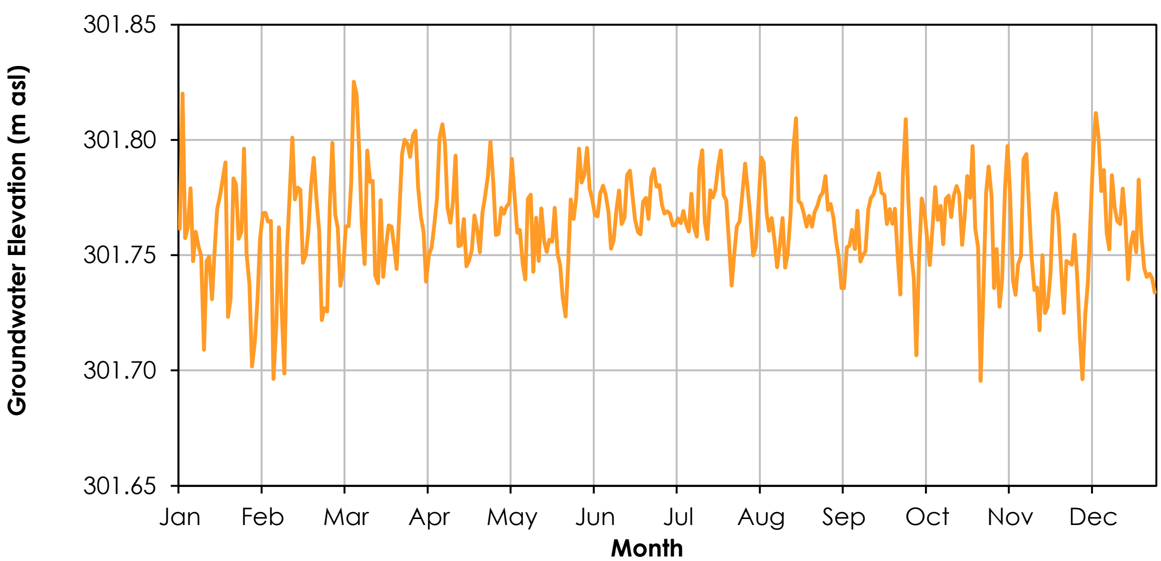
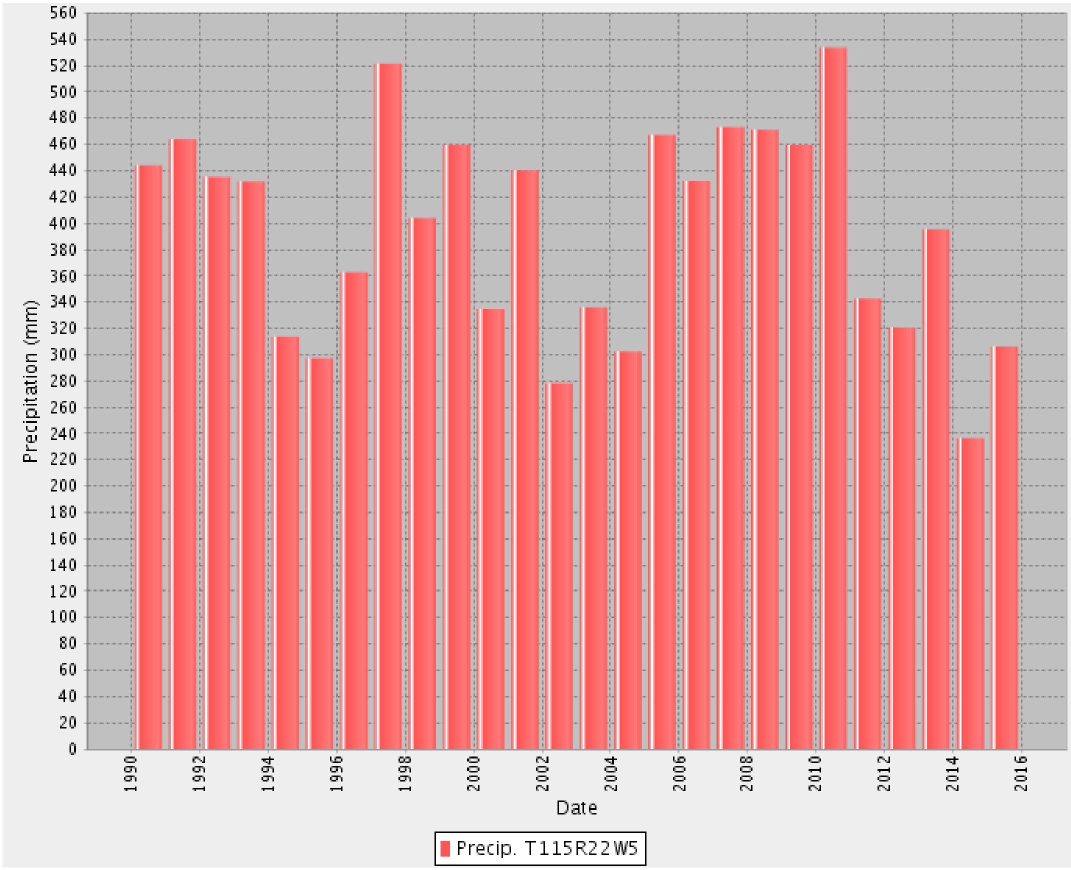


Figure 3-7 Average Daily Groundwater Levels at Monitoring Well Meander River 87-2-0381, Over the Period July 1989 to September 2015



SOURCE: Alberta Agriculture and Forestry 2016a

Figure 3-8 Interpolated Annual Precipitation Summary for Meander River Township T115R22W6

3.2.2 Water Wells

3.2.2.1 Data Collection

Existing publicly available hydrogeological information was obtained from two sources:

- Alberta Water Well Information Database, maintained by the Government of Alberta, Environment and Parks (Alberta Environment and Parks 2015b)
- British Columbia Ground Water Wells and Aquifer Database (Version 2.9), maintained by the Government of British Columbia Ministry of Environment (BC Ministry of Environment 2015)

Water well information from these sources was reviewed and compiled into a central database for the Hay River Basin. Water wells include all wells drilled for the purpose of groundwater extraction, (e.g., domestic use), groundwater disposal (e.g., oil and gas injection wells), or groundwater monitoring/research. Water well information is not centrally compiled for the Northwest Territories and groundwater or water well data are largely not available. Locations of wells with *Water Act* Approvals or Licences in Alberta and British Columbia are shown in Figure 3-9.

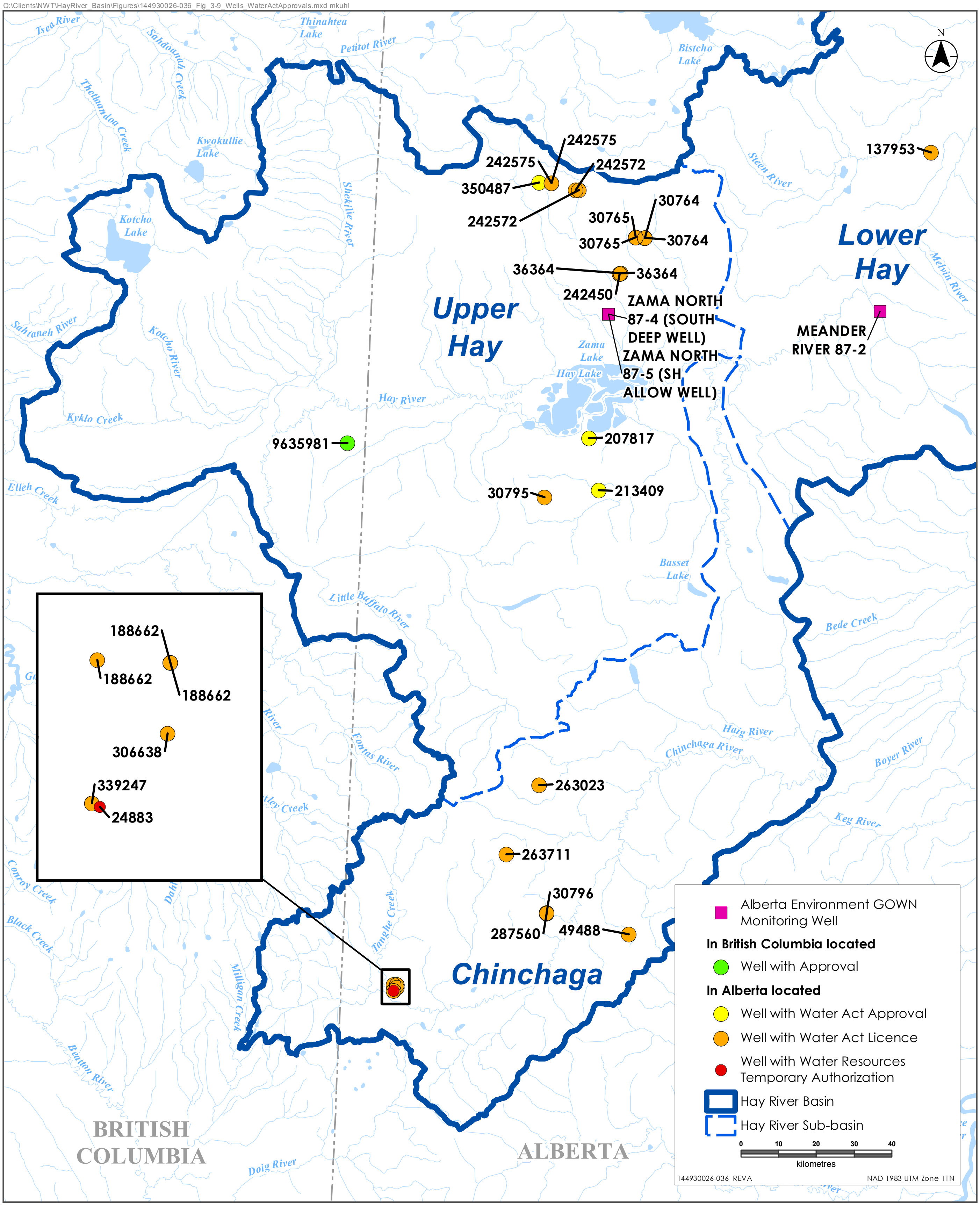
Information within the Alberta and British Columbia databases provides basic hydrogeological data such as well depth, depth to groundwater (below ground surface), and a water well use category by development sector. The data records are not always complete and well locations are approximate to the center of quarter sections.

The compiled database for the Hay River Basin was linked to a geographic information system, where water well and other hydrogeologic information was plotted and analyzed together for Alberta and British Columbia, with bedrock and surficial geology data (Alberta Geological Survey 2012, 2013a, 2013b). The hydrogeologic database developed for the Hay River Basin is a high-level overview of relatively shallow groundwater resources, and does not provide detailed, site-specific information regarding hydrogeologic conditions at any given location.

In Alberta, water well information is required to be reported for all water wells drilled, including those for domestic purposes. In British Columbia, water well reporting is voluntary, resulting in incomplete water well records and incomplete reporting of water wells in the basin. No water wells with associated Water Licences were identified from the British Columbia Ground Water Wells and Aquifer Database. However, existing and future water wells for domestic, municipal, industrial, and commercial water supply systems will require a well identification number and known location (BC Ministry of Environment and Alberta Environment 2009), though regulations requiring this have not yet been approved.

In the Northwest Territories, the Office of the Regulator of Oil and Gas Operations, established April 1, 2014, has regulatory jurisdiction over all oil and gas wells drilled through sedimentary rock to a depth greater than 150 m. The Office maintains a public registry of documents associated with applications and decisions and some limited information on groundwater wells in the Northwest Territories may be available. For the Dehcho region, within which the Hay River Basin is located, several records are identified, including some for Strategic Oil and Gas, which has operations within and near the basin. The locations of these wells, or other documentation, were not accessed in time for inclusion in this report. Additional information on groundwater and hydrogeological conditions in the Northwest Territories portion of the Hay River Basin may be available.

Otherwise, indirect evidence of the existence of domestic water wells was found for the Hay River Basin in the Northwest Territories within an Inspection Report (AANDC 2013a) for the Hamlet of Enterprise's Water Licence (MV2008L3-0040), which was issued for sewage and solid waste disposal. The Hamlet of Enterprise receives trucked water delivery from the Town of Hay River; however, a note in the Inspection Report mentions that "some people supplement their water needs with the use of private shallow wells". No other information is available.



Sources: Base Data - Government of Canada; Thematic Data - Government of Canada

Disclaimer: This map is for illustrative purposes to support this Stantec project; questions can be directed to the issuing agency.

Hay River Basin and Sub-basins: Groundwater Monitoring Wells and Wells with Water Act Approvals

Figure 3-9

Stantec

3.2.2.2 Existing Water Wells in the Hay River Basin

Locations of water wells and geologic conditions in the Hay River Basin are presented for geological units in Alberta and British Columbia (Figure 3-10, sheets A1 to C2). This level of geological data is not available for the Northwest Territories. Figure 3-10 is presented in nine sheets, labeled as A1 to C2 and arranged from north to south and west to east. Figure 3-10 also presents the spatial distribution of all registered wells in Alberta and British Columbia and indicates wells completed in bedrock and those completed in the unconsolidated overburden deposits. Depths of the shallow wells are indicated in Figure 3-10, as well as those for which no depth, screen depth, or geologic data are available.

There are 1,238 registered water wells in the Hay River Basin (see Figure 3-10). Of these, 1,224 are located in Alberta, with 494 in the Upper Hay sub-basin, 316 in the Chinchaga sub-basin, and 414 in the Lower Hay sub-basin. Only 14 registered water wells were identified for the Hay River Basin in British Columbia, with 12 in the Upper Hay sub-basin and two in the Chinchaga sub-basin. Of the total registered wells, 25% (306) are completed in overburden (i.e., not bedrock), 29% (361) are completed in bedrock and 46% (571) have no depth, screen depth, or geologic information to identify them as completed in overburden or bedrock units. This information helps to identify potential differences in groundwater geochemistry, and identifies wells completed in overburden, which have a greater potential to be affected or contaminated by surface activities.

Figure 3-11 shows the number of registered water wells by depth distribution across the Hay River Basin and sub-basins. About 48% of the wells (598) in the basin are completed at depths less than 30 m below ground surface (m bgs) and 27% (338) are completed at depths between 30 to 150 m bgs. About 19% of the wells (233) are completed at depths between 150 to 3,000 m bgs, and are likely associated with oil and gas activity for injection purposes. Only 6% of the wells (69) have no depth information reported.

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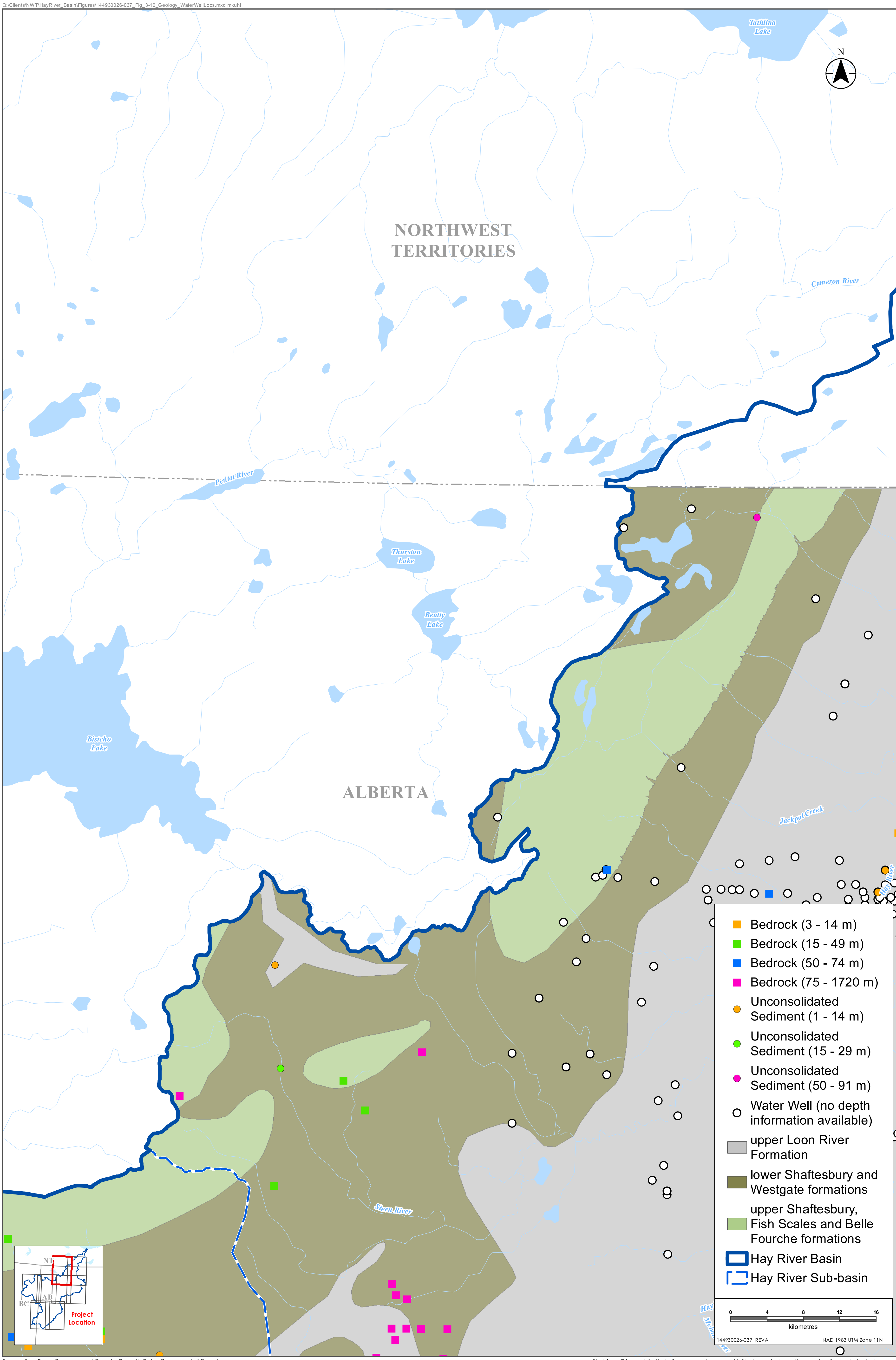

Sources: Base Data - Government of Canada; Thematic Data - Government of Canada

Disclaimer: This map is for illustrative purposes to support this Stantec project; questions can be directed to the issuing agency.

Hay River Basin and Sub-basins: Geology and Water Well Locations

Figure 3-10-A1

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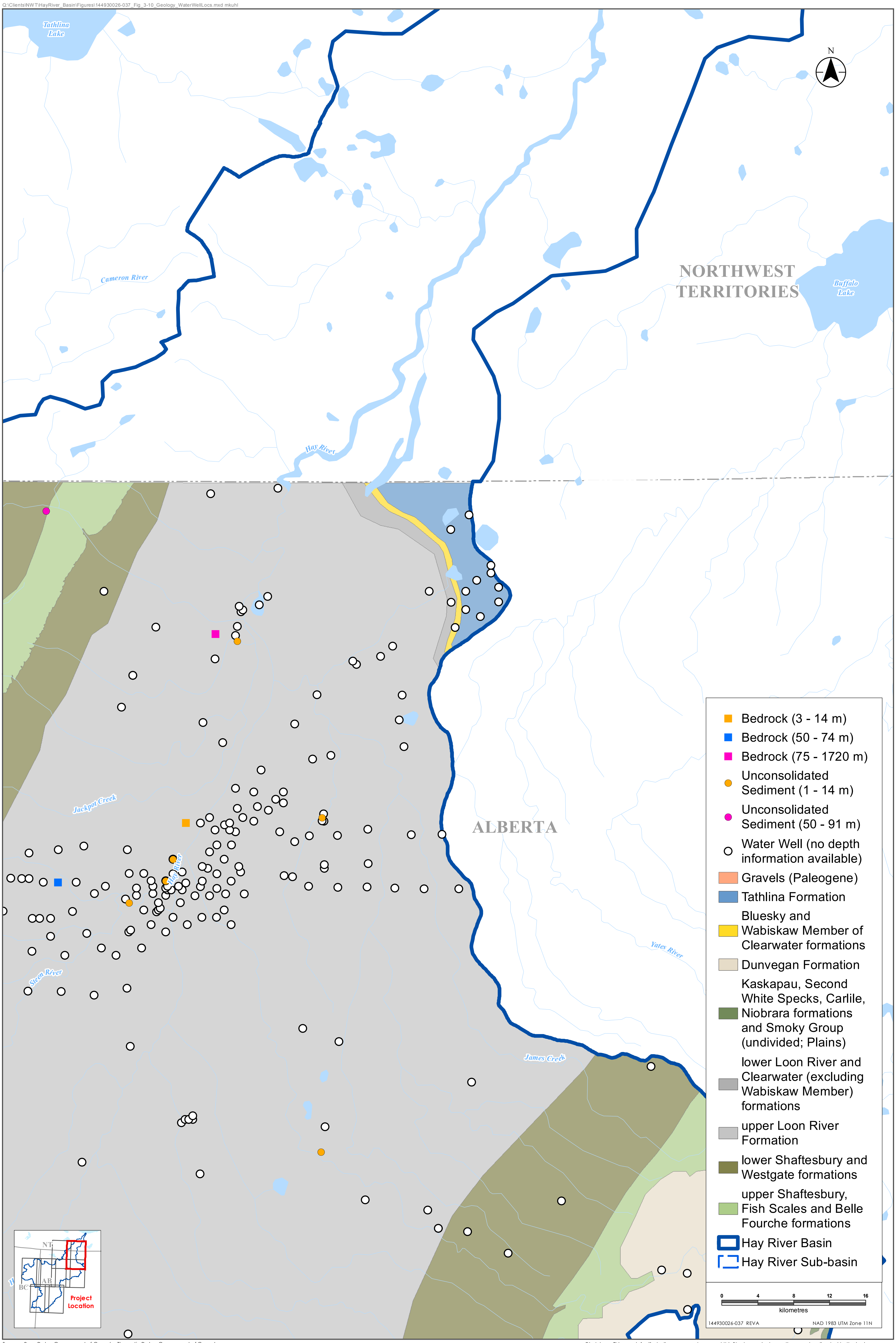

Sources: Base Data - Government of Canada; Thematic Data - Government of Canada

Disclaimer: This map is for illustrative purposes to support this Stantec project; questions can be directed to the issuing agency.

Hay River Basin and Sub-basins: Geology and Water Well Locations

Figure 3-10-A2

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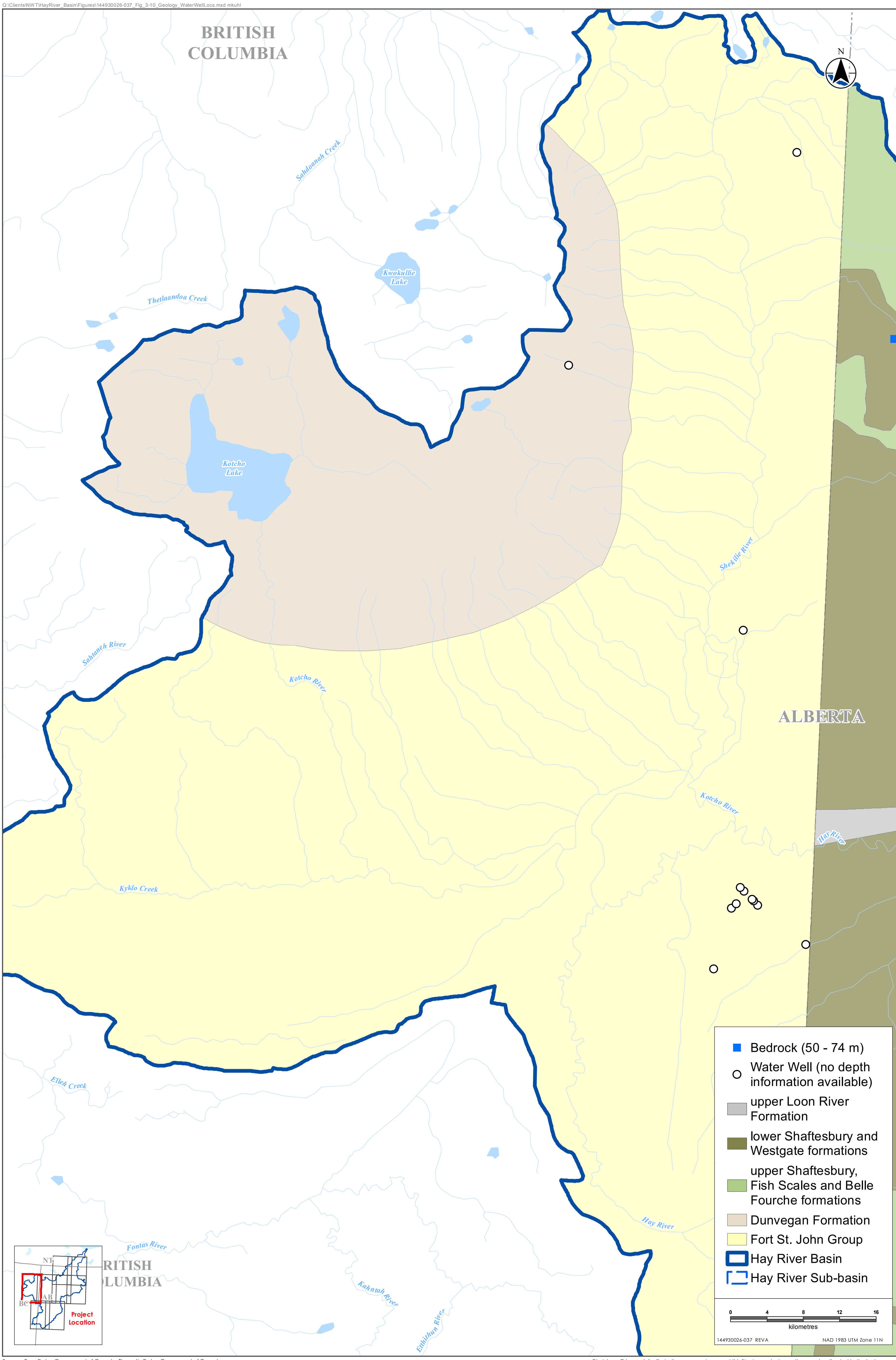

Sources: Base Data - Government of Canada; Thematic Data - Government of Canada

Disclaimer: This map is for illustrative purposes to support this Stantec project; questions can be directed to the issuing agency.

Hay River Basin and Sub-basins: Geology and Water Well Locations

Figure 3-10-B1

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GOVERNMENT OF THE NORTHWEST TERRITORIES - STATE OF AQUATIC KNOWLEDGE FOR THE HAY RIVER BASIN

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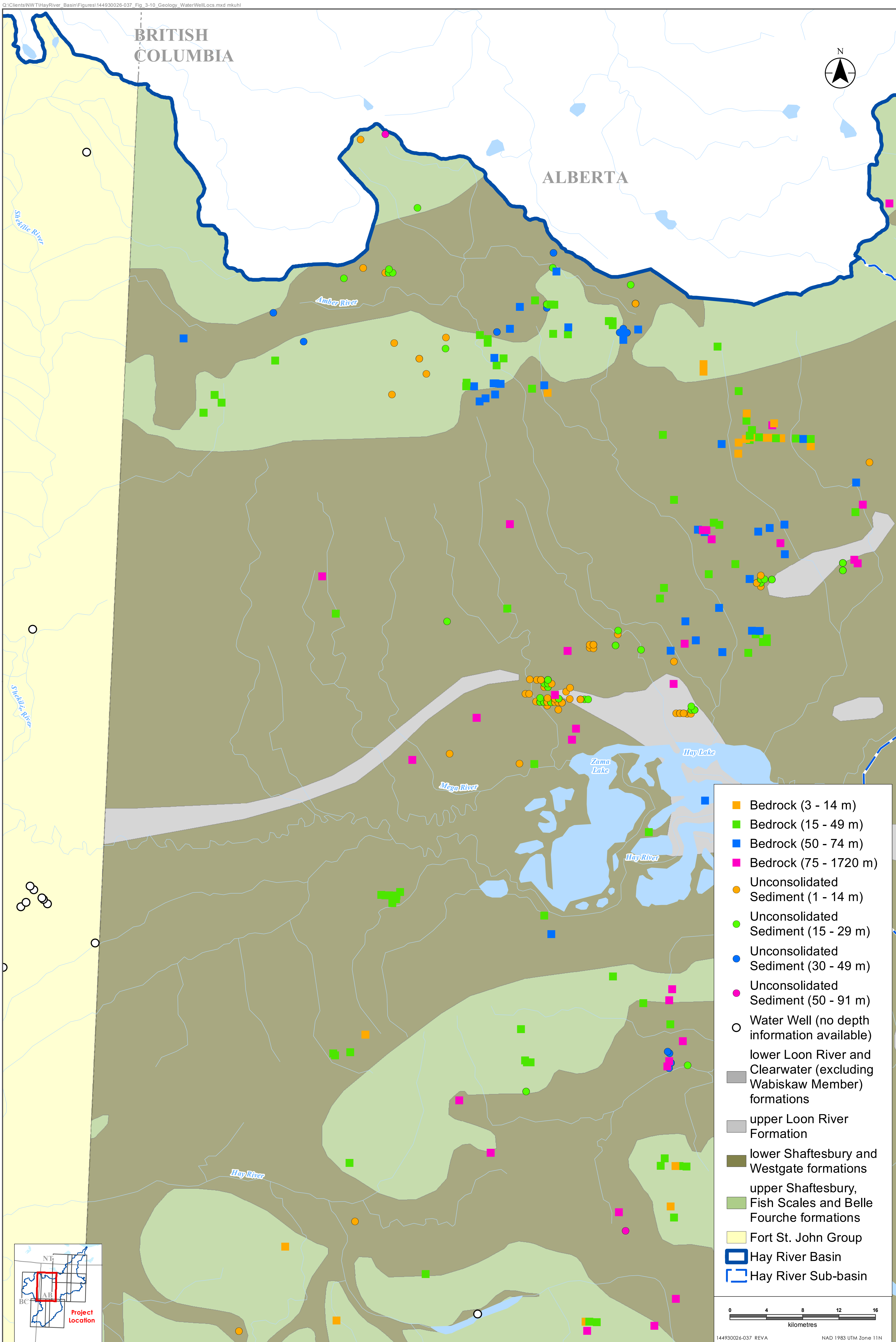

Sources: Base Data - Government of Canada; Thematic Data - Government of Canada

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Hay River Basin and Sub-basins: Geology and Water Well Locations

Figure 3-10-B2

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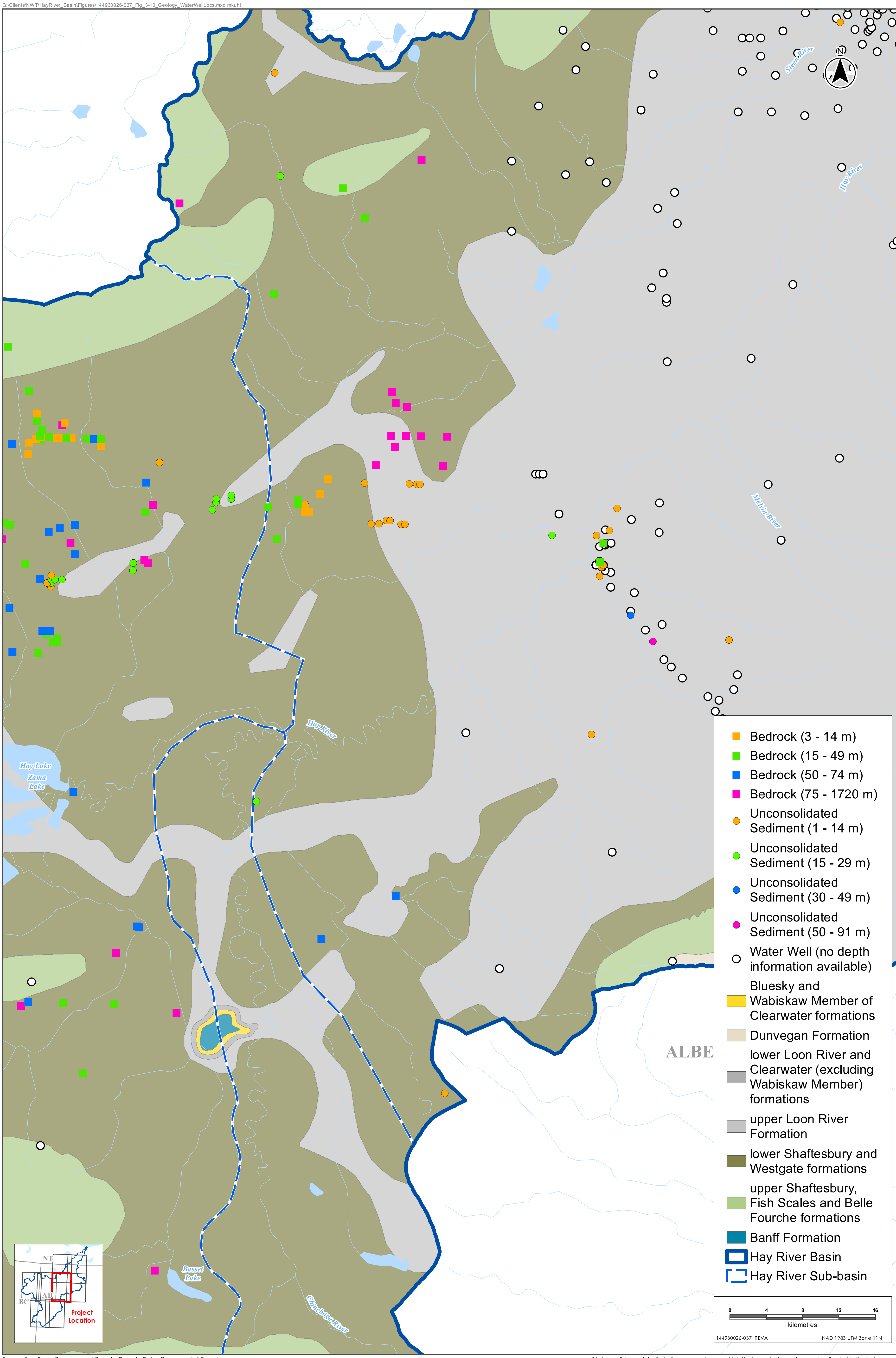

Sources: Base Data - Government of Canada; Thematic Data - Government of Canada

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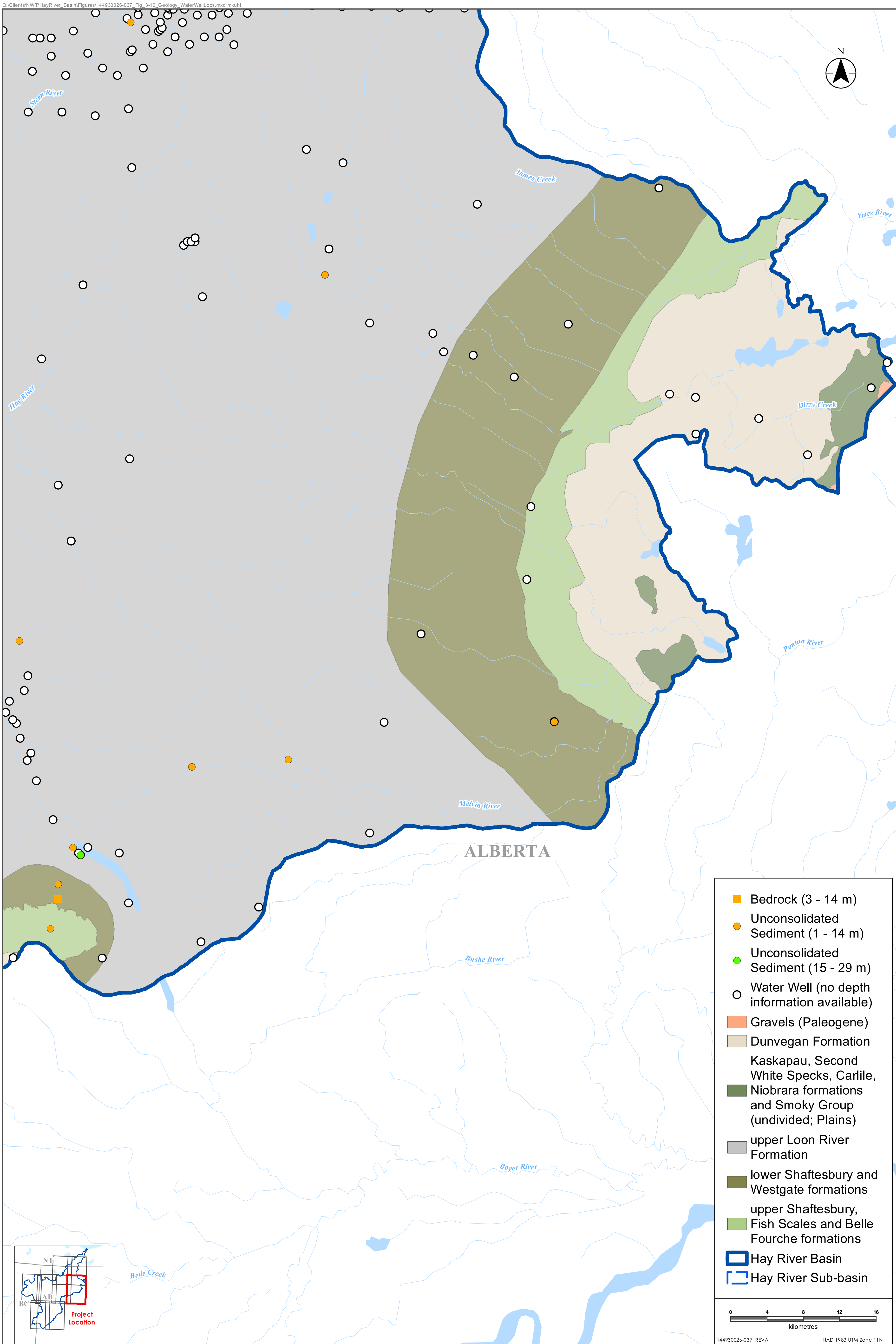
Hay River Basin and Sub-basins: Geology and Water Well Locations

Figure 3-10-B3



Sources: Base Data - Government of Canada; Thematic Data - Government of Canada

Disclaimer: This map is for illustrative purposes to support this Stantec project; questions can be directed to the issuing agency.

Hay River Basin and Sub-basins: Geology and Water Well Locations

Figure 3-10-B4

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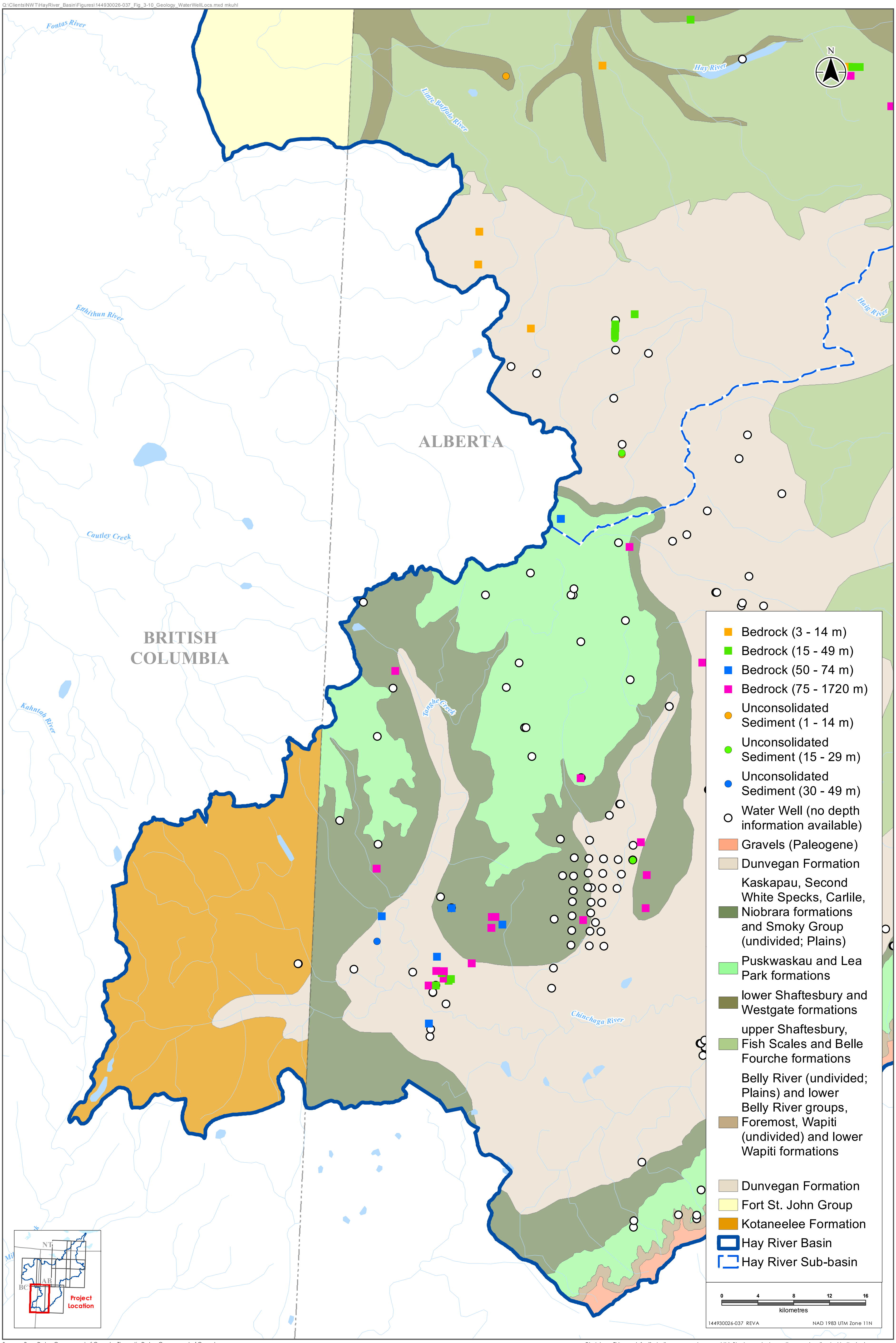

Sources: Base Data - Government of Canada; Thematic Data - Government of Canada

Disclaimer: This map is for illustrative purposes to support this Stantec project; questions can be directed to the issuing agency.

Hay River Basin and Sub-basins: Geology and Water Well Locations

Figure 3-10-C1

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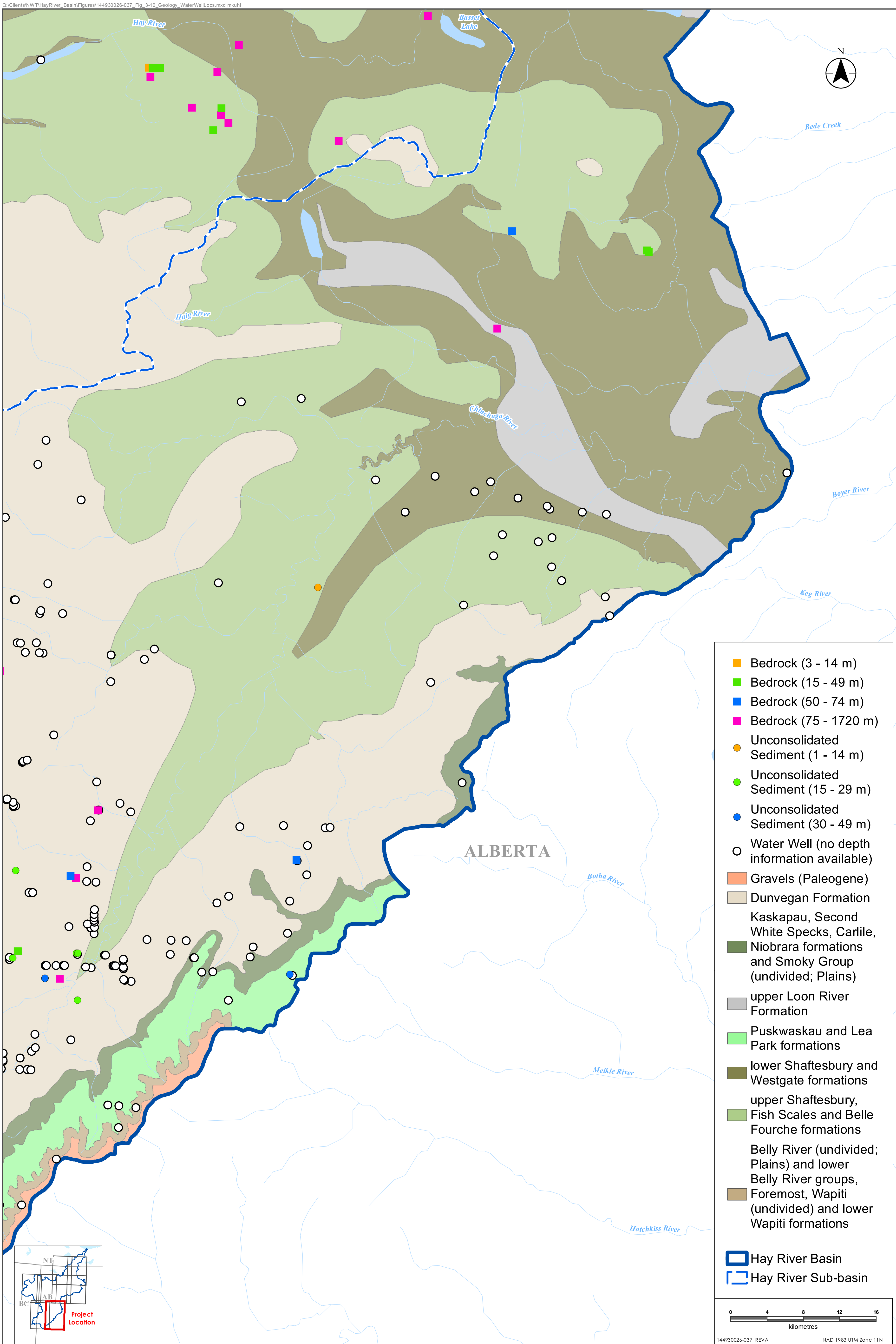

Sources: Base Data - Government of Canada; Thematic Data - Government of Canada

Disclaimer: This map is for illustrative purposes to support this Stantec project; questions can be directed to the issuing agency.

Hay River Basin and Sub-basins: Geology and Water Well Locations

Figure 3-10-C2

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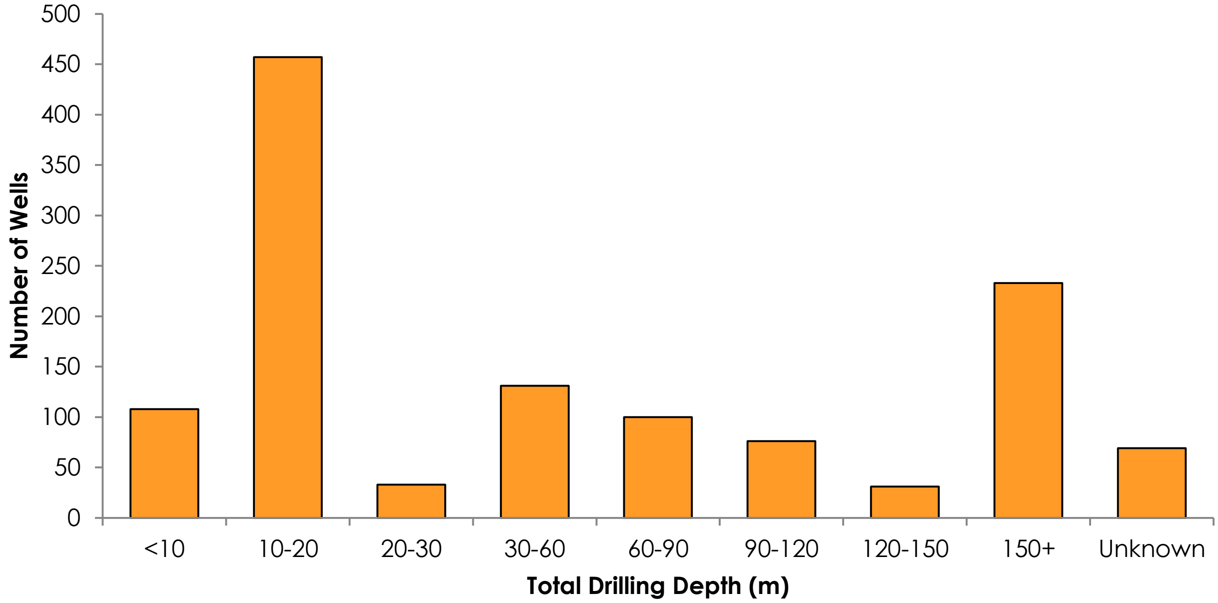


Figure 3-11 Number of Water Wells and Well Completion Depths in the Hay River Basin

Water wells are drilled for a variety of economic sectors, including domestic/municipal use and industrial purposes. Well-use categories for the 1,238 water wells in the Alberta and British Columbia portions of the Hay River Basin are presented in Figure 3-12. Several similar well use categories noted in the Alberta and British Columbia water well databases were merged for this figure to simplify the number of categories presented. Commercial/industrial wells represent the primary water well use (about 75%, or 924 wells) and the remaining water wells are for domestic/municipal (10%), investigation (7%), other/unknown (6%), monitoring/observation (2%), and oil and gas injection (0.5%). Injection wells are drilled by the oil and gas industry for disposal of groundwater associated with oil and gas productions. Injection wells are drilled in deep aquifers with poor water quality that are not used for domestic or municipal purposes.

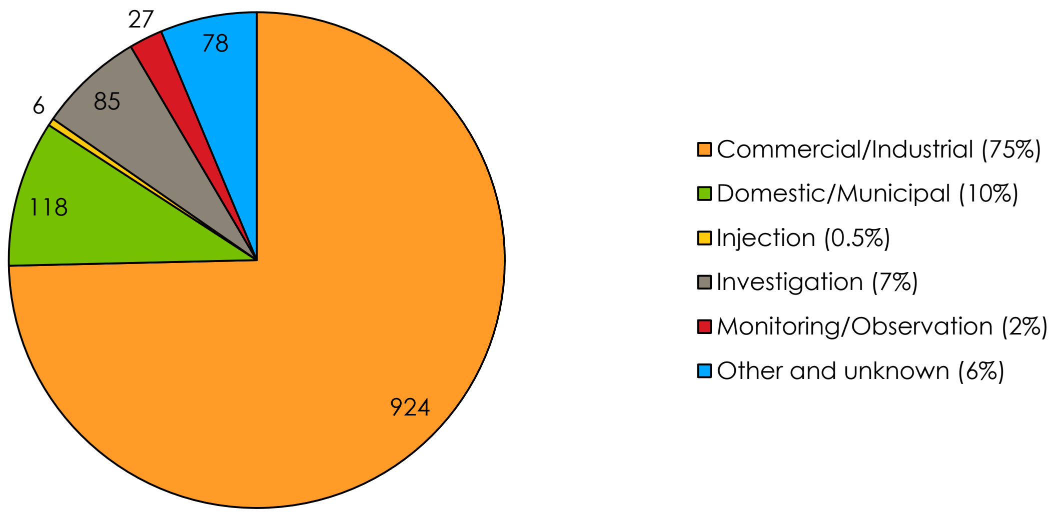


Figure 3-12 Water Wells Drilled/Completed by Sector in the Hay River Basin

3.3 SUMMARY

Overall, there are very few data for groundwater quality and levels in the Hay River Basin. Groundwater level data have been collected for three monitoring wells from mid-1989 to the present; however, there are data gaps in the record. The monitoring wells are located in the Zama area of the Upper Hay sub-basin (two nested wells) and in the Meander River area of the Lower Hay sub-basin. Groundwater levels in the two Zama monitoring wells appear to be influenced by surface water inputs and show seasonal variation correlated with precipitation data (i.e., wet/dry years). Groundwater levels in the Meander River well do not show seasonal variations but annual levels overall correlate well with precipitation data.

The results of the centralized database query for the Hay River Basin (Alberta and British Columbia) show that approximately 48% of known water well records are completed at depths less than 30 m bgs. These water wells may be more susceptible to surface-related contamination of groundwater. Commercial/industrial water wells represent the primary water well use in the basin (75%).

4.0 AMBIENT WATER QUALITY

The Hay River Basin includes small headwater streams, lakes, and larger rivers. Water quality reflects the influence of the surrounding land areas, size of contributing sub-basin, hydrologic patterns, and human uses on the streams, lakes, and rivers. The Hay River, like many other large rivers in northern Canada, carries naturally elevated loads of suspended sediment at various times of year, reflecting runoff from the large land base (Hatfield 1999).

A long-term water quality monitoring program can provide data that can be used to determine baseline conditions and assess trends, examine relationships to human activities, and identify triggers to recognize and address degradation of water quality. Water quality is traditionally assessed using generic water quality guidelines (WQGs), developed on a national or provincial basis; however, some waterbodies have site-specific characteristics, such as naturally elevated metal concentrations or absence of sensitive aquatic species. In such cases the generic guidelines are less useful for identifying site-specific water quality concerns. The Alberta-Northwest Territories Bilateral Water Management Agreement, which includes the Hay River (AB-NWT 2015), contains commitments to protect various water uses and the intent to manage water quality within the range of natural variability, using water quality objectives and triggers (pre-defined early warning of change) as management tools. Section 4.1 describes use of WQGs, objectives, and triggers in more detail.

Water monitoring programs typically provide information about general parameters (e.g., pH, hardness, turbidity, major ions), nutrients (nitrogen, phosphorus, organic matter), and metals (total and dissolved). These parameters describe baseline conditions and can provide indications of human activities within a basin (e.g., increased sediment levels from soil disturbance, metal concentrations from mining, or nutrient supply related to agricultural activities or wastewater discharges). Some changes may be related to long-range atmospheric transport; for example, mercury can be transported from locations far outside the basin (AANDC 2012a).

Section 4.2 describes trends in general water characteristics. Organic contaminants have also been monitored in the Hay River to identify the presence of hydrocarbons, chlorinated organics, pesticides, and other compounds that may originate within the Hay River Basin or arrive from long-range atmospheric transport (Macdonald et al. 2000; Hung et al. 2010; AANDC 2013b; AANDC 2014). Section 4.2.3 describes the status of organic contaminants in detail, as many of these data have not been previously published or evaluated.

4.1 METHODS FOR ASSESSING WATER QUALITY

In this report, data are compared to national WQGs for the protection of aquatic life developed by the Canadian Council of Ministers of Environment (CCME), referred to as CCME WQG (CCME

2016). There are also WQGs for Alberta (Alberta Environment and Sustainable Resource Development[1] [AESRD] 2014) and British Columbia (BC Ministry of Environment 2016). The WQGs are generic, designed to protect the most sensitive aquatic species tested, and conservative, incorporating a 2- to 10-fold safety factor. Caution is needed when using the generic CCME WQGs to assess Hay River water quality as they may not provide a reliable tool for evaluating risks to aquatic life when metals are naturally elevated due to high sediment loads or underlying geology. There are also WQGs for protection of drinking water, wildlife, and other users of water; however, for the majority of parameters, the most protective WQGs are those for aquatic life, given that aquatic organisms spend most or all of their lives in the water.

The Alberta-Northwest Territories Bilateral Water Management Agreement assigns a Risk Informed Management Class 3 for water quality in the Hay River Basin on the basis of land development and/or activities, high traditional use, existing annual trends in water quality, and use as a community drinking water supply (AB-NWT 2015). Interim triggers, designed to recognize when monitoring data suggest a potential change, have been developed for the Hay River. These interim triggers can be updated when additional monitoring data are available or when outstanding questions about the methods used to derive the numbers are resolved. The triggers were developed from a statistical analysis of monitoring data collected between 1988 and 2014 (HDR 2015). Table 4-1 describes the triggers and potential management actions; Appendix A (Table A2) lists all available interim triggers for the Hay River. The interim triggers are defined as the 50th percentile (Trigger 1) and 90th percentile (Trigger 2) for each parameter on an annual basis, or, where there are sufficient data, for open water and ice-covered periods (AB-NWT 2015). The interim triggers have been set such that an exceedance of the 50th reference percentile, beyond what is statistically expected, identifies potential changes in typical water quality conditions, while an exceedance of the 90th reference percentile, beyond what is statistically expected, identifies a potential change in extreme conditions. Over time, site-specific Transboundary Water Quality Objectives for the Hay River will be developed.

Table 4-1 Definitions, Examples, and Potential Management Actions for Transboundary Water Quality Triggers

Trigger	Definition	Interim Definition	Potential Management Actions
Trigger 1	A pre-defined early warning of potential changes in typical conditions which results in Jurisdictional and/or Bilateral Water Management to confirm that change. Multiple triggers can be set to invoke additional actions if conditions decline.	An exceedance of the 50th reference percentile, beyond what is statistically expected, identifies potential changes in typical water quality conditions	• Use Trigger 1 alone or in conjunction with Trigger 2 • Jointly review water quality data and changes • Confirm the change is real • Jointly investigate cause and risk (e.g., land uses change) • Investigate other media (hydrometric, sediment and/or biota), as appropriate, to provide supporting evidence

[1] Alberta Environment and Parks was formerly Alberta Environment and Sustainable Resource Development

Table 4-1 Definitions, Examples, and Potential Management Actions for Transboundary Water Quality Triggers

Trigger	Definition	Interim Definition	Potential Management Actions
Trigger 2	A second early warning indication that extreme conditions are changing, which results in Jurisdictional and/or Bilateral Water Management	An exceedance of the 90th reference percentile, beyond what is statistically expected, identifies a potential change in extreme conditions	• Use Trigger 2 alone or in conjunction with Trigger 1 • Continue investigation using an ecosystem approach using all available evidence (i.e., weight of evidence approach) • Adjust monitoring design (e.g., increase frequency, parameters, and/or sites) as necessary • Compare to upstream, downstream and/or regional sites • Discuss the need to change to Class 3
SOURCE: adapted from Alberta-Northwest Territories (2015) Bilateral Water Management Agreement, Table 6			

4.2 GENERAL WATER CHEMISTRY

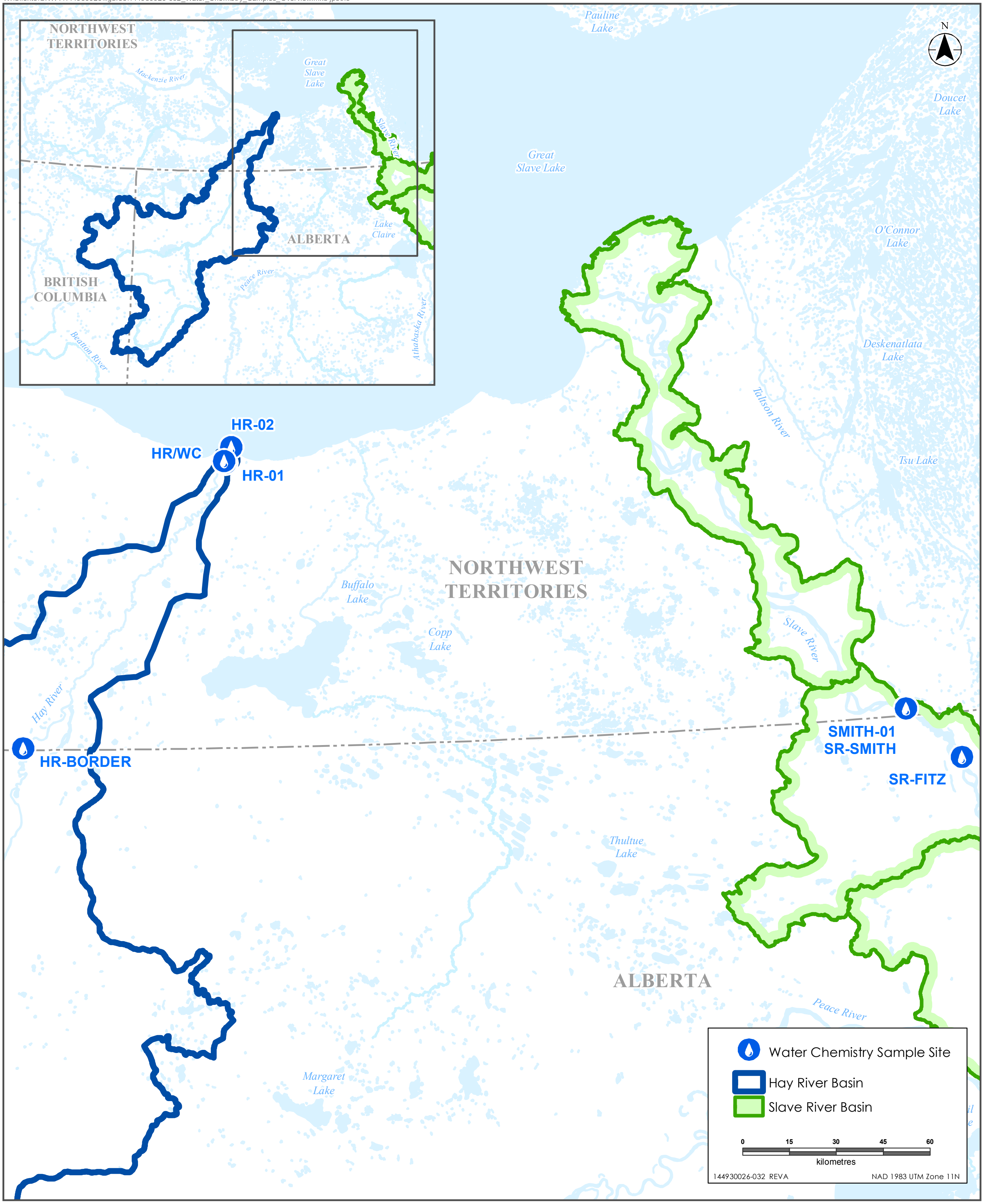
Water quality monitoring programs in the Hay River Basin have consistently focused on the lower Hay River. There is little information available about lakes and smaller watercourses in the basin. This section describes conditions for general parameters, nutrients, and metals.

4.2.1 Current Monitoring Programs in the Hay River Basin

Water quality monitoring in the Hay River dates back to 1969. Consistent monitoring began in 1988 at the Alberta-Northwest Territories border at the HR-BORDER site (Figure 4-1). Environment Canada and the GNWT (previously Aboriginal Affairs and Northern Development Canada [AANDC] prior to devolution) monitor water and suspended sediment chemistry at this site. The Environment Canada program is part of its national long-term freshwater quality monitoring network. The GNWT program is part of its transboundary water quality monitoring program.

Environment Canada collected surface water samples on a monthly basis from October 1988 to 1994 and three to six times a year since 1995. General chemistry (pH, conductivity, total suspended solids, major ions), nutrients, and metals are analyzed in water. Since 1995, both Environment Canada and the GNWT (previously AANDC) have collected suspended sediment and centrifugate water (sediment-free surface water) samples by centrifuging river water. These samples are analyzed for metals, nutrients, and select hydrocarbons, one or more times a year to examine concentrations associated with the naturally sediment-rich fraction of river water. Organic contaminants, including hydrocarbons, pesticides, and other persistent organic pollutants, have also been monitored (see Section 4.3).

W:\Clients\GNWT\144930026\figures\144930026-032_Water_Chemistry_Samples_Overview.mxd jpetho



Sources: Base Data - Government of Canada; Thematic Data - Government of Canada, Government of NWT.

Disclaimer: This map is for illustrative purposes to support this Stantec project; questions can be directed to the issuing agency.

Water Chemistry Monitoring Sites within the Lower Hay and Slave River Basins

Stantec

Figure 4-1

Since 2011, the Government of the Northwest Territories has collected additional water samples at the HR-BORDER site for analysis of general water chemistry, nutrients, metals, and organic contaminants to better understand the presence of and trends for contaminants, and to supplement the data collected by Environment Canada. Detection limits for organic contaminants, which typically occur in very low concentrations, are substantially lower than the routine detection limits used in the Environment Canada program. Organic contaminants are analyzed in surface water, suspended sediment, and centrifugate water, to provide data for all fractions of river water. In turbid rivers with relatively high suspended sediment loads, such as the Hay River, total metals levels may be elevated because they are part of the silt and clay particles. Also, organic contaminants with poor solubility in water bind preferentially to sediment. By collecting the suspended sediment fraction through centrifugation, it is possible to collect sufficient material for analysis using low detection limits and to compare concentrations in suspended sediment and water.

Water and suspended sediment are also sampled in other transboundary rivers (the Slave, Liard, and Peel rivers), allowing for comparisons among rivers with varying intensities and types of human activities that can affect water quality.

The GNWT (previously AANDC) established a monitoring site on the Hay River West Channel (HR/WC) near the Town of Hay River in the Northwest Territories in 1982 (Figure 4-1). This site is about 5 km upstream of the Hay River confluence with Great Slave Lake and 114 km downstream of the HR-BORDER site. General water chemistry, nutrients, and metals are measured in surface water at the HR/WC site twice a year (May and October). Data from HR-BORDER and HR/WC were evaluated in a 2012 study of status and trends of water quality in the Hay River (Environ 2012).

There has been little monitoring in the smaller rivers and lakes of the basin. Alberta Environment and Parks has some historical records for the Alberta portion of the basin. Unnamed Lake, Hutch Lake, Hottie Lake, South Chain Pond, East Osland Lake, Chinchaga River, and Meander River were sampled on one or a few dates for general chemistry and, in some cases, metals in the 1970s to 1990s (Hatfield 2009). No records were found for waterbodies in British Columbia.

Water quality data collected in the various Hay River monitoring programs were examined in three recent studies, using slightly different data sets, analytical and statistical methods, and to meet varying objectives (Hatfield 2009; Environ 2012; and HDR 2015). These reports focused on general water chemistry, nutrients, and metals in surface water, although the Environ study also examined suspended sediment data. Appendix A1 discusses differences in key questions, analytical and statistical approaches, time periods, and assumptions used, any of which could influence the conclusions of each study. The key questions investigated are summarized in Table 4-2. The three studies provided consistent conclusions regarding parameters that exceed CCME WQG; however, the HDR and Environ studies differed in their conclusions about long term trends for a few parameters. For example, HDR (2015) identified a decreasing trend for total iron over time that Environ (2012) did not identify. HDR (2015) identified a decreasing trend for total lithium and an increasing trend for particulate nitrogen, parameters that were not included in the

Environ (2012) trend analysis. Both studies identified an increasing trend for pH measured in the laboratory and for total vanadium over time. HDR (2015) also identified statistically significant trends for several dissolved metals but recommended caution in interpreting the trends, given the relatively small number of observations available. Neither HDR (2015) nor Environ (2012) discussed environmental relevance of these changes over time.

Table 4-2 Overview of Studies on Temporal Trends in Water Quality at the Hay River Border Site

Study	Title	Study Purpose/Goal
Hatfield (2009)	Current state of surface water quality and aquatic ecosystem health in Alberta--Northwest Territories transboundary waters. Report prepared for Alberta Environment.	Review of water quality and aquatic ecosystem data available for the Hay River and other transboundary rivers, with a focus on identifying parameters that exceed water quality guidelines and potential effects on aquatic biota.
Environ (2012)	Status and trends of hydrology, water quality, and suspended sediment quality of the Hay River. Yellowknife, NT. Report prepared for Aboriginal Affairs and Northern Development Canada.	Assessment of long-term and seasonal trends in hydrology, water quality, and suspended sediment quality; comparison of trends at the HR-BORDER and HR/WC sites; and comparison of recent (2000 to 2010) and longer term (1989 to 2011) data.
HDR (2015)	Site specific water quality objectives for the Hay and Slave transboundary rivers: technical report. Report prepared for Department of Environment and Natural Resources, Government of the Northwest Territories.	Identification of periods of unchanging (baseline) water quality at the HR-BORDER site, to support development of site-specific surface water quality objectives that could be used to indicate when water quality leaves the range of natural variability and would require actions to address these exceedances (triggers for action).

4.2.2 Current Conditions and Trends for the Hay River at the Border

4.2.2.1 Water Chemistry

The only continuous long-term dataset for the Hay River Basin is that for the HR-BORDER site, which has been monitored since late 1988. Trends over time that reflect activities upstream of the border or regional climate influences, can be assessed using this dataset but, with no monitoring sites in the Upper Hay and Chinchaga sub-basins, spatial trends across the basin cannot be assessed. Current status and temporal trends in physical parameters, major ions, nutrients, and metals at the HR-BORDER site are described in Sections 4.2.2.1.1 through 4.2.2.1.4, summarized from Hatfield (2009), Environ (2012), and HDR (2015). Given the emphasis on transboundary conditions, the following sections focus on data collected at HR-BORDER. Results are compared to CCME WQGs. The interim triggers (50^{th} and 90^{th} percentiles) for open water and ice-covered periods are presented.

4.2.2.1.1 Physical Parameters

Physical parameters measured at the HR-BORDER site are pH, conductivity, total dissolved solids (TDS), turbidity, total suspended solids (TSS) and dissolved oxygen (DO). The range in TDS, turbidity, and DO values over the period 1989 to 2014 (compiled from data provided by the GNWT) is shown in Figure 4-2.

Overall, the pH ranges from 6.9 to 8.3 (HDR, 2015), with a slightly alkaline median value (pH 7.6 cited in HDR 2015; pH 7.7 cited in Environ 2012). The majority of values are within the CCME WQG range of 6.5 to 8.5, with only one instance below pH 6.5 and two instances above pH 8.5 (Figure 4-2). A statistically significant increasing annual trend (across all seasons) was identified (Environ 2012; HDR 2015) though the magnitude of the trend was not identified. The interim triggers (50^{th} and 90^{th} percentiles) for pH are 7.8 and 8.1 in the open water season and 7.5 and 7.8 under ice (AB-NWT 2015).

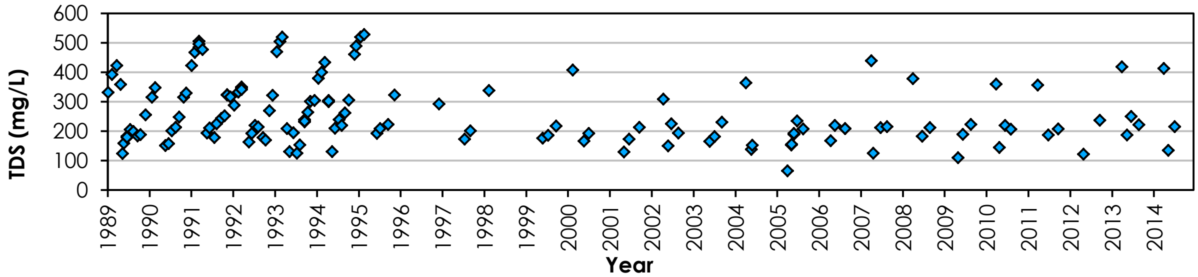
Conductivity ranges from 123 to 860 µS/cm, with a median of 355 µS/cm (cited by Environ 2012) or 366 µS/cm (cited by HDR 2015). There is no CCME WQG for conductivity. No temporal trends were identified over the entire study period or most recently, between 2000 and 2010 (Environ 2012; HDR 2015). The interim triggers (50^{th} and 90^{th} percentiles) for conductivity are 322 and 401 µS/cm in the open water season and 584 and 793 µS/cm under ice (AB-NWT 2015).

Concentrations of TDS range from 42 to 2,700 mg/L, with a median of 247 mg/L (cited by Environ 2012) or 264 mg/L (cited by HDR 2015). There is no CCME WQG for TDS. Concentrations are highest between November and April, suggesting an increase in relative inputs of groundwater during winter (Hatfield 2009). There is no evidence of a trend on an annual basis over the study period (Environ 2012; HDR 2015). The interim triggers (50^{th} and 90^{th} percentiles) are 249 and 302 mg/L in the open water season and 414 and 549 mg/L under ice (AB-NWT 2015).

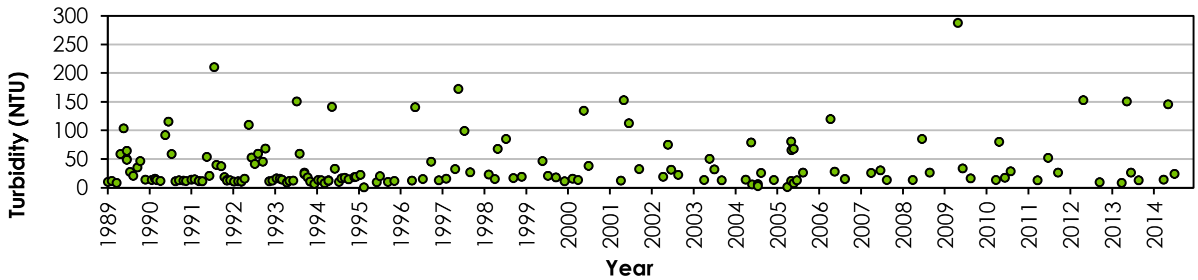
Water at the HR-BORDER site is considered to carry a moderate suspended sediment load, but to a lesser extent than many large northern rivers (Hatfield 2009). The median TSS concentration is lower at the HR-BORDER site (12.5 mg/L; HDR 2015) than at long term monitoring sites in the Slave River (76 mg/L at Fitzgerald, 108 mg/L at Fort Smith), Liard River (31 mg/L), and Peel River (17 mg/L) (AANDC 2012b), with similar trends noted for turbidity. At the HR/BORDER site, TSS ranges from less than detection (less than 3.0 mg/L) to 788 mg/L and turbidity ranges from 0.2 to 611 nephelometric turbidity units (NTU) (HDR 2015). Maximum TSS and turbidity concentrations typically occur in May, during spring freshet and peak flows (Hatfield 2009). No temporal trends in annual TSS and turbidity values were identified over the study period (Environ 2012; HDR 2015). The interim triggers (50^{th} and 90^{th} percentiles) for turbidity are 33.1 and 149 NTU in the open water season and 12.5 and 20.5 NTU under ice. For TSS, the interim triggers are 41 and 218 mg/L in the open water season and 6.0 and 12.0 mg/L under ice (AB-NWT 2015).

Levels of DO vary seasonally, from 0.34 to 13.8 mg/L (HDR 2015; Figure 4-2). Winter values under ice, which are the lowest of the year, can fall below the recommended minimum threshold for cold water aquatic life (6.5 mg/L; CCME 2016). This has occurred in 31 of 128 measurements taken between 1990 and 2014, typically in December to April. No temporal trends in annual DO values were identified (HDR 2015). The interim triggers (50th and 90th percentiles) are 8.8 and 11.2 mg/L during the open water season and 5.8 and 10.1 mg/L under ice (AB-NWT 2015).

a) Total Dissolved Solids (TDS)



b) Turbidity



NOTE: Two values for turbidity (greater than 300 NTU) excluded from above figure

c) Dissolved Oxygen

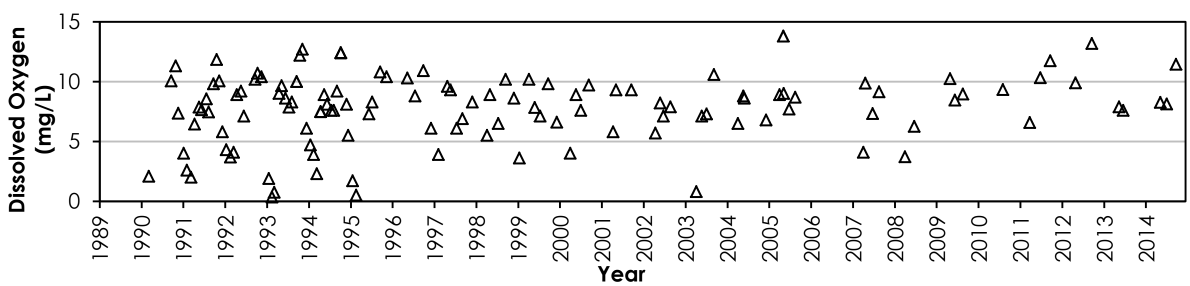


Figure 4-2 Total Dissolved Solids, Turbidity, and Dissolved Oxygen Levels at the Hay River Border Site, 1989 to 2014

4.2.2.1.2 Major Ions

Concentrations of major cations (calcium, magnesium, sodium, potassium) and anions (sulphate, chloride) are higher during the base flow period than during the open water season at the HR-BORDER site, suggesting greater relative proportions of groundwater inputs under ice (Hatfield 2009; Environ 2012; HDR 2015). Figure 4-3 shows data for hardness, alkalinity, calcium, and sulphate at the HR-BORDER site between 1989 and 2014.

Hardness ranges from 51 to 421 mg/L (as $CaCO_3$) with a median of 166 mg/L (Environ 2012; HDR 2015) and water at the HR-BORDER site is considered hard (defined as 120 to 180 mg/L; Health Canada 2014) with high buffering capacity. A statistically significant decrease in hardness (and also its major constituents, calcium and magnesium) over time was identified by Environ (2012) but not by HDR (2015). Interim triggers have not been set for hardness.

Total alkalinity ranges from 14 to 305 mg/L (as $CaCO_3$) with a median of 110 mg/L (Environ 2012; HDR 2015), and with low sensitivity to acid deposition (alkalinity greater than 40 mg/L; Saffran and Trew 1996). Interim triggers (50^{th} and 90^{th} percentiles) for alkalinity are 93 and 127 mg/L during the open water season and 191 and 272 mg/L under ice (AB-NWT 2015).

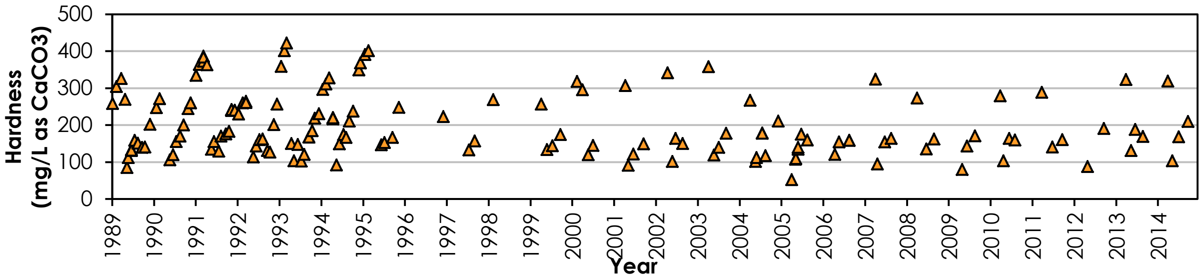
Calcium is the predominant cation, followed by sodium, magnesium, and potassium. Calcium ranges from 10 to 135 mg/L, with a median of 45 mg/L (Environ 2012; HDR 2012). Sodium concentrations range up to 35.1 mg/L, magnesium to 32.6 mg/L, and potassium to 4.8 mg/L (HDR 2015). Interim triggers for calcium, sodium, magnesium, and potassium for open water and under ice are reported in Appendix A (Table A2).

Sulphate is the predominant anion, followed by chloride. Sulphate ranges from 11.8 to 151 mg/L, with a median of 72 mg/L (Environ 2012; HDR 2015). Chloride ranges from 1.3 to 24.4 mg/L, with a median of 4.2 mg/L (cited by Environ 2012) or 3.8 mg/L (cited by HDR 2015), reflecting differences in data selected for analysis. Interim triggers for sulphate and chloride during open water and under ice are described in Appendix A (Table A2). Bicarbonate, carbonate, hydroxide, and fluoride are also measured, but have not been treated statistically.

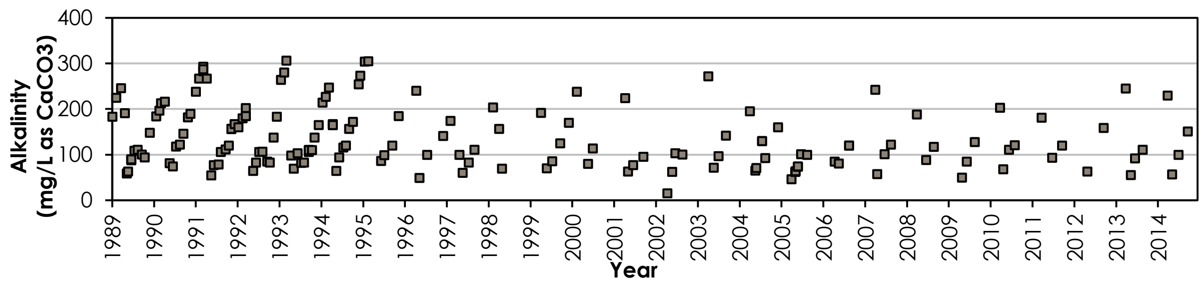
The two studies of temporal trends identified similar trends for the most part for major cations and anions; any differences were related to differences in the statistical tools used and the data included in the trend analysis (discussed in Appendix A1):

- Environ (2012) identified statistically significant trends for alkalinity, hardness, calcium, magnesium, and sulphate (decrease) over the 1989 to 2010 period studied that were not evident for the more recent 2000 to 2010 period; however, the HDR (2015) study did not identify any significant temporal trends considering data over the entire period (to 2014) for any of these parameters.
- For data analyzed by season, HDR (2015) identified a statistically significant decreasing trend for chloride in the open water season, whereas Environ (2012) identified an increasing trend over the base flow period and a decreasing trend during the recession period. Environ (2012) identified an increasing trend for sodium during the baseflow period, but HDR (2015) did not identify any trends for sodium.

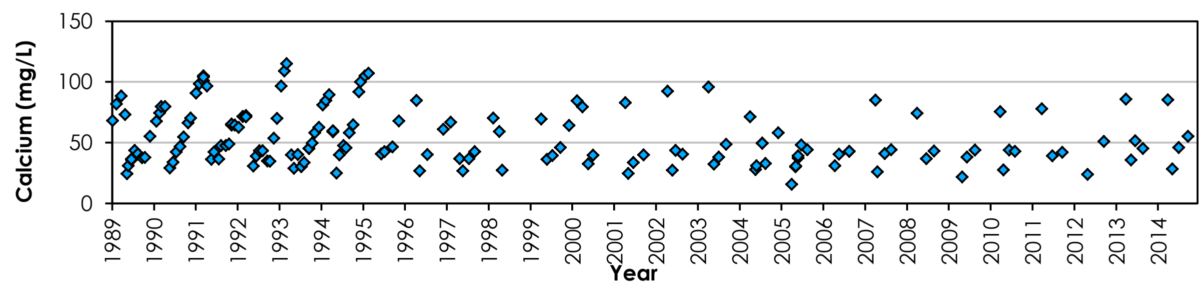
a) Total Hardness (as $CaCO_3$)



b) Total Alkalinity (as $CaCO_3$)



c) Calcium



d) Sulphate

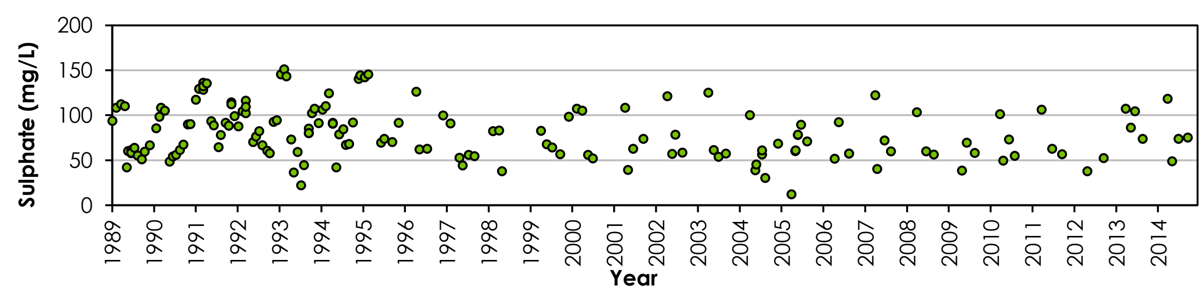


Figure 4-3 Hardness, Alkalinity, Calcium, and Sulphate at the Hay River Border Water Chemistry Station, 1989 to 2014

4.2.2.1.3 Nutrients and Organic Carbon

Nitrogen and phosphorus data provide insight into the nutrient and trophic status of waters in the lower Hay River. Algae and macrophytes (plants at the base of the aquatic food web) require both nutrients for growth. Guidelines provided by CCME and others are derived to protect aquatic life from toxic effects, and seldom provide guidance on protection from eutrophication (increased plant productivity related to human activities that add nutrients), which can occur at much lower concentrations than toxic effects. A system may be naturally oligotrophic (poorly nourished, low nutrient concentrations), mesotrophic (moderately nourished), or eutrophic (well nourished, high nutrient concentrations). Eutrophication may occur through introduction of nutrients from agricultural or residential use of fertilizers or from effluent discharges from municipal wastewater treatment plants, pulp mills, and other industrial sources. The CCME (2004) and Gartner Lee (2006) classify trophic status and describe trigger ranges for total phosphorous concentrations in Canadian lakes and rivers. Other literature provides information about ranges for nitrogen (e.g., Carlson and Simpson 1996; Dodds et al. 1998; Alexander and Smith 2006).

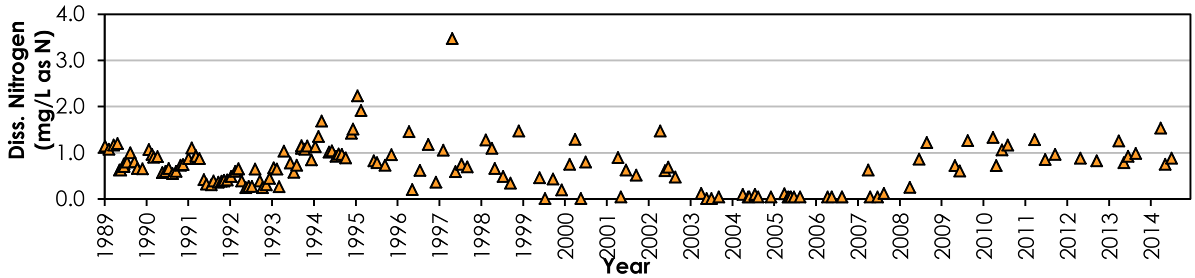
At the HR-BORDER site, nitrogen is measured as ammonia, nitrate, and total dissolved and total particulate fractions, and reported in mg/L as N. The majority of nitrogen occurs in the dissolved fraction at the HR-BORDER site (Hatfield 2009). Nitrogen concentrations between 1989 and 2014 are shown in Figure 4-4 and are summarized as follows (HDR 2015):

- Total dissolved nitrogen ranges from less than detection to 3.47 mg/L, with a median of 0.690 mg/L; there is a statistically significant decrease for the open water and ice-covered seasons (but not on an annual basis).
- Particulate nitrogen ranges from 0.003 to 2.09 mg/L as N, with a median of 0.140 mg/L; there is a statistically significant increase on an annual basis and for the ice-covered season.
- Nitrate plus nitrite range from less than detection to 1.73 mg/L, with a median of 0.080 mg/L; all values are below the CCME WQG for nitrate (550 mg/L short-term, 13 mg/L long-term).
- Ammonia ranges from less than detection to 0.938 mg/L, with a median of 0.021 mg/L; there are no trends identified on an annual or seasonal basis.

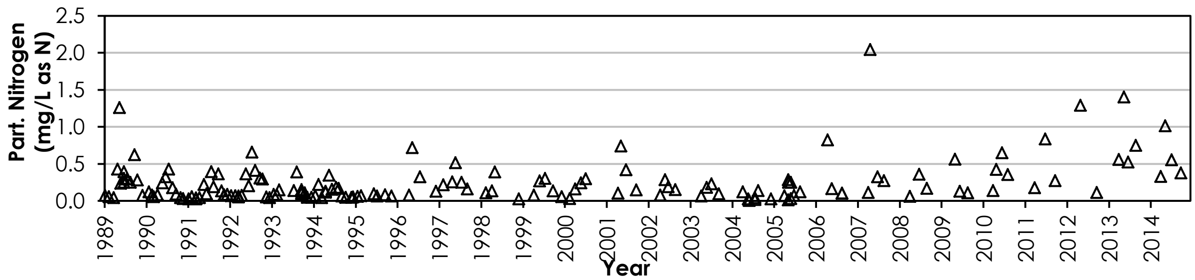
Environ (2012) reported slightly different summary statistics for nitrate plus nitrate, with a range up to 2.5 mg/L, a median of 0.101 mg/L, and a statistically significant increasing trend over time annually and during the recession; these trends were not identified by HDR (2015). These differences in the interpretation of the long-term dataset and long-term trends appear to be related to differences in the dates selected and statistical methods used in the two studies. The studies did not identify any obvious sources of nutrient enrichment.

Interim triggers (50^{th} and 90^{th} percentiles) for dissolved nitrogen are 0.617 and 1.009 mg/L during the open water season and 0.924 and 1.498 mg/L under ice. Seasonal triggers for nitrate/nitrite are not available but annual triggers are 0.090 and 0.587 mg/L (AB-NWT 2015).

a) Total Dissolved Nitrogen



b) Total Particulate Nitrogen



c) Nitrate plus Nitrite

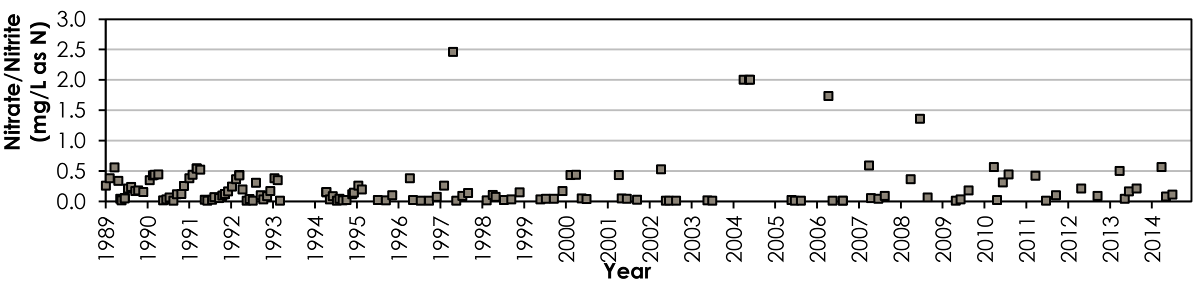


Figure 4-4 Total Dissolved Nitrogen, Total Particulate Nitrogen, and Nitrate Plus Nitrite at the Hay River Border Water Chemistry Site, 1988 to 2015

Total phosphorus trends were assessed by both Environ (2012) and HDR (2015). Figure 4-5 shows data for 1989 to 2014 at the HR-BORDER site, with concentrations reported in mg/L as P. Overall, total phosphorus ranges from less than detection (less than 0.010 mg/L) to 0.760 mg/L, with a median of 0.080 mg/L (Environ 2012; HDR 2015). Maximum concentrations generally occur during May to July, corresponding to higher TSS and turbidity levels during spring freshet (Hatfield 2009). The majority of samples had peak concentrations of 0.200 mg/L or less (Figure 4-5). There are no numerical CCME WQGs for total phosphorus; however, Hatfield (2009) commented that 93 of 140 samples had values higher than the Alberta WQG in place at that time (0.050 mg/L, which has since been superceded with narrative guidance to prevent detrimental changes to algal and aquatic plant communities, aquatic biodiversity, oxygen levels, and recreational quality; AESRD 2014). Environ (2012) identified a statistically significant trend of increasing total phosphorus over the entire period of record, but not during individual seasons or for recent data from 2000 to 2010. In contrast, HDR (2015) did not identify any temporal trends in total phosphorus. Interim triggers (50^{th} and 90^{th} percentiles) have been set at 0.107 and 0.256 mg/L during the open water season and 0.054 and 0.113 mg/L under ice (AB-NWT 2015).

Total dissolved phosphorus trends were assessed by HDR (2015). Concentrations range from less than detection (less than 0.002 mg/L) to 0.447 mg/L (Figure 4-5), with a median of 0.026 mg/L, and a significant decreasing trend over time for the open water season (HDR 2015). Interim triggers (50^{th} and 90^{th} percentiles) have been set at 0.025 and 0.050 mg/L during the open water season and 0.027 and 0.04 mg/L under ice (AB-NWT 2015).

Trophic status is identified using both total phosphorus and dissolved nitrogen concentrations, as plants require both nutrients for growth (more nitrogen than phosphorus). The atomic ratio of nitrogen to phosphorus in aquatic plants is 16:1, known as the Redfield ratio, which corresponds to a mass ratio of 7:1 (Jarvie et al. 1999). On the basis of median total phosphorus concentrations of approximately 0.080 mg/L (Environ 2012; HDR 2015) and median total dissolved nitrogen of 0.69 mg/L (HDR 2015) at the HR-BORDER site, the Hay River appears to be mesotrophic to eutrophic, or moderately to highly productive (Carlson and Simpson 1996; Alexander and Smith 2006; Gartner Lee 2006).

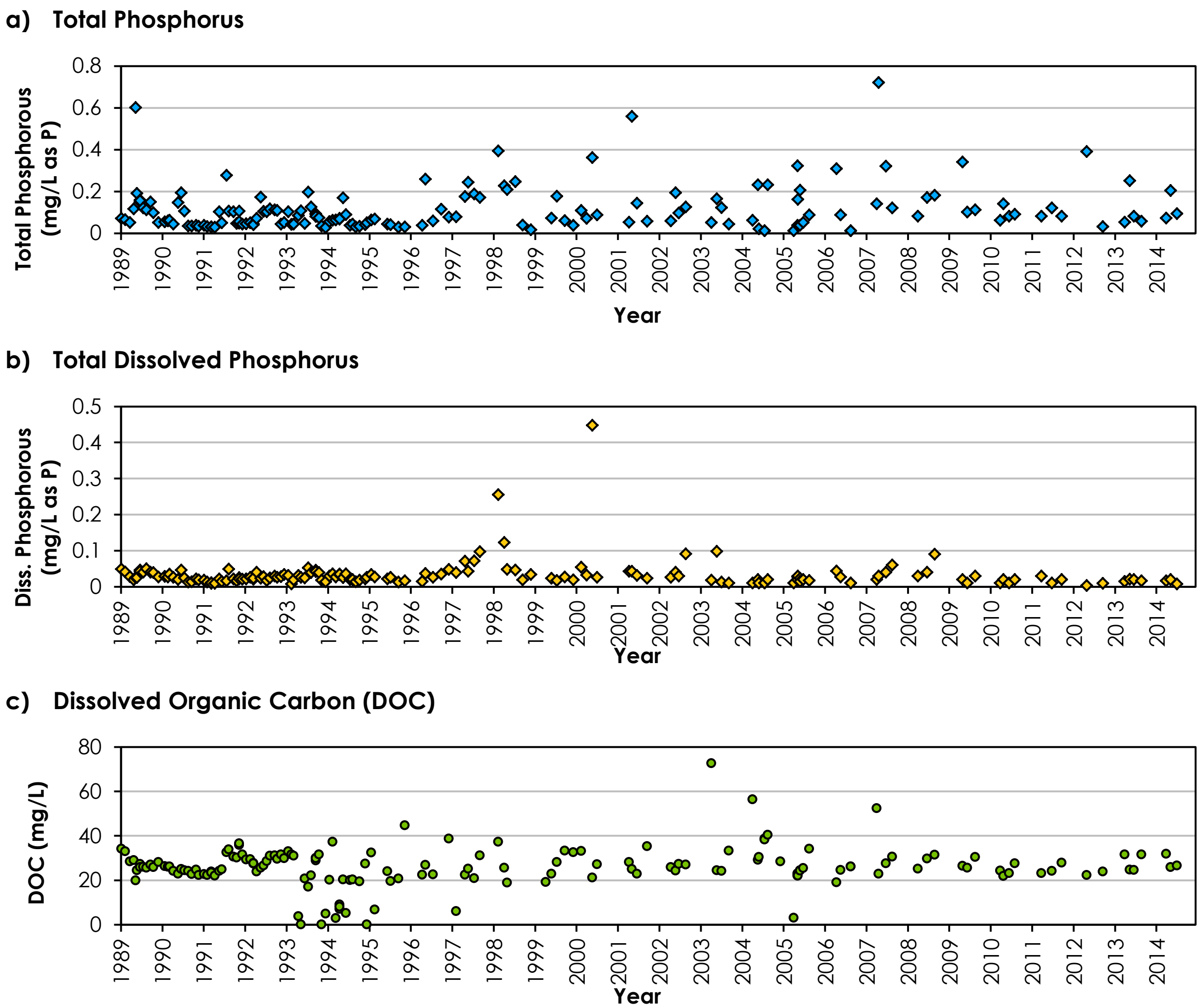


Figure 4-5 Total Phosphorus, Total Dissolved Phosphorus, and Dissolved Organic Carbon at the Hay River Border Water Chemistry Sites, 1989 to 2014

Maximum total phosphorus and particulate nitrogen concentrations occur during spring freshet (May/June), when high flows, TSS, and turbidity are not conducive to algal growth, and the river is transporting large amounts of suspended matter. The datasets identified as "summer" and "fall" by HDR (2015) reflect concentrations during the active growing period ("post-freshet", roughly July through September). Post-freshet median total phosphorus concentrations range up to 0.108 mg/L (HDR 2015), which is in the range for eutrophic waters (0.035 to 0.100 mg/L; CCME 2004), and reflects natural conditions in this river. Post-freshet median dissolved nitrogen concentrations range up to 0.73 mg/L, which suggest mesotrophic conditions, based on a comparison to trophic state classification described by Alexander and Smith (2006), who recommend 0.7 mg/L total N as the boundary between oligotrophic and mesotrophic, and 1.5 mg/L total N as the boundary between mesotrophic and eutrophic. Because trophic status is governed by the nutrient in lowest relative supply, nitrogen appears to be the nutrient limiting plant growth in the Hay River post-freshet, so small increases in phosphorus are unlikely to stimulate algal or macrophyte growth.

The Hay River contains relatively high levels of total and dissolved organic carbon (TOC and DOC) and colour compared to other northern rivers (Hatfield 2009). The source is thought to be from leaching of organic soils in the low-lying wetlands that occur throughout the basin (GNWT and GOC 1984; North/South Consultants et al. 2007; Culp et al. 2005). The DOC concentrations range from 2.6 to 73 mg/L at the HR-BORDER site (Figure 4-5), with a median of 26 to 27 mg/L and no identified temporal trends (Environ 2012; HDR 2015). In contrast, DOC ranges from 1.5 to 40.4 mg/L in the Slave River at Fitzgerald, from 0.1 to 33 mg/L in the Liard River, and from 0.3 to 24.6 mg/L in the Peel River (AANDC 2012b). Interim triggers (50^{th} and 90^{th} percentiles) for DOC at the HR-BORDER site are 25.6 and 32.7 mg/L during the open water season, and 28.2 and 37.2 mg/L under ice (AB-NWT 2015).

4.2.2.1.4 Metals

Metals concentrations reflect the underlying geology of the Hay River Basin, and may also increase as a result of land disturbance. Total and dissolved fractions are measured at the HR-BORDER site. Particulate forms of metals are associated with sediment in the river.

Hatfield (2009) summarized data on the full suite of analyzed metals (1998 to 2008), while Environ (2012) analyzed trends for 14 target (routinely measured) metals (1988 to 2010), and HDR (2015) analyzed trends for 24 metals (select periods between 1988 and 2014). Most of the 24 metals analyzed are frequently present at detectable levels; HDR (2015) indicated 30% or fewer non-detect values (depending on the metal) for total and dissolved metals. Ranges and medians for total and dissolved concentrations of 14 metals are summarized in Table 4-3, along with applicable CCME WQGs and any identified temporal trends. Ranges and medians for all 24 metals are reported in Appendix A (Table A3-1).

For metals with CCME WQGs, exceedances are relatively common at the HR-BORDER site, attributed to the naturally elevated suspended sediment load, typically with maximum concentrations during spring freshet (North/South Consultants 2007; Hatfield 2009). Updates to CCME WQGs for beryllium, cadmium, silver, and uranium since 2010 are not reflected in the Hatfield (2009) and Environ (2012) reports. Many metals meet Canadian Council of Ministers of Environment water quality guidelines (CCME WQGs) for protection of aquatic life, except for total iron (60% of samples), cadmium (23%), copper (15%), zinc (4%), and, on one occasion each, arsenic, chromium, and lead (Table 4-3).

Table 4-3 Descriptive Statistics and Temporal Trends for Select Metals in Surface Water Analyzed at the Hay River Border Site

Parameter	CCME WQG (µg/L)[1]		n_{ND} / n[2]	Concentrations (µg/L)			# > CCME WQG[3]		Temporal Trend[4]	
	Short Term	Long Term		Minimum	Maximum	Median	Short Term	Long Term	Environ (2012)	HDR (2015)
Total Aluminum	–	–	0 / 144	11	7,950	25	–	–	–	↔
Dissolved Aluminum	–	–	0 / 41	6.5	91.7	27	–	–	–	↔[7]
Total Arsenic	–	5	0 / 71	0.19	5.90	1.42	–	1	↔	↔[7]
Dissolved Arsenic	–	–	0 / 184	0.10	1.60	0.50	–	–	↑[8]	↔[7]
Total Boron	29,000	1,500	0 / 77	9.1	66.2	31.5	0	0	–	↔
Dissolved Boron	–	–	0 / 41	17.1	60.9	29	–	–	–	↔[7]
Total Cadmium[5]	3.5	0.24	24 / 215	0.014	2.56	0.157	0	50	↔	↔
Dissolved Cadmium	–	–	0 / 41	0.015	0.186	0.028	–	–	↔	↓[7]
Total Chromium[6]	–	8.9	4 / 150	0.010	12.2	0.544	–	1	↔	↔
Dissolved Chromium	–	–	0 / 41	0.090	0.342	0.152	–	–	–	↔[7]
Total Copper[5]	–	3.65	0 / 215	0.55	24.7	2.5	–	33	↔	↔
Dissolved Copper	–	–	0 / 41	1.3	5.6	2.5	–	–	–	↔[7]
Total Iron	–	300	0 / 150	200	21,800	2,015	–	91	↔	↓
Dissolved Iron	–	–	0 / 41	237	3,170	500	–	–	–	↓[7]
Total Lead[5]	–	6.07	39 / 215	0.088	11.3	0.700	–	1	↔	↔
Dissolved Lead	–	–	0 / 41	0.026	0.915	0.151	–	–	–	↓[7]
Total Molybdenum	–	73	2 / 150	0.05	1.90	0.73	–	0	–	↔
Dissolved Molybdenum	–	–	0 / 41	0.54	1.29	0.77	–	–	–	↔[7]
Total Nickel[5]	–	141	0 / 215	0.74	27.3	3.91	–	0	↔	↔
Dissolved Nickel	–	–	0 / 41	2.27	7.78	3.19	–	–	–	↓[7]

Table 4-3 Descriptive Statistics and Temporal Trends for Select Metals in Surface Water Analyzed at the Hay River Border Site

Parameter	CCME WQG (µg/L)[1]		n_{ND} / n[2]	Concentrations (µg/L)			# > CCME WQG[3]		Temporal Trend[4]	
	Short Term	Long Term		Minimum	Maximum	Median	Short Term	Long Term	Environ (2012)	HDR (2015)
Total Selenium	–	1	0 / 71	0.06	0.51	0.24	–	0	–	↔
Dissolved Selenium	–	–	4 / 184	0.05	0.60	0.20	–	–	–	↔[7]
Total Silver	–	0.25	23 / 109	0.001	0.200	0.044	–	0	–	↔
Dissolved Silver	–	–	1 / 41	0.001	0.047	0.004	–	–	–	↔[7]
Total Thallium	–	0.8	0 / 77	0.003	0.209	0.019	–	0	–	↔
Dissolved Thallium	–	–	0 / 41	0.006	0.021	0.008	–	–	–	↑[7]
Total Zinc	–	30	0 / 215	0.5	93.3	5.8	–	9	↔	↔
Dissolved Zinc	–	–	0 / 41	0.3	14.4	1.3	–	–	–	↔[7]

NOTES:

1 CCME WQG = Canadian Council of Ministers of the Environment (CCME) water quality guidelines for Freshwater Aquatic Life, short-term and long-term

2 n_{ND} / n = number of non-detect data points over total number of data points

3 # > CCME WQG = number of data points greater than the CCME WQG short-term and long-term values

4 Temporal trends identified for entire data record by Environ (2012) and HDR (2015); ↑ = increasing, ↓ = decreasing, ↔ = no trend, – = not assessed

5 CCME WQG for these metals are hardness-dependent; WQGs calculated based on a median hardness value of 166 mg/L $CaCO_3$

6 Total chromium guideline provided for trivalent chromium

7 Trends identified based on a dataset with less than 30 data points (HDR 2015), who recommend the trends be viewed with caution until the dataset can be expanded.

8 Trends identified included high proportion of censored (non-detect) values at start of monitoring period, which likely biased the result to show a trend.

SOURCE: Environ 2012; HDR 2015

Metals in their dissolved form are more bioavailable and toxic than those in particulate form. When dissolved concentrations are compared to the CCME WQGs for total metals, the number of guideline exceedances is much lower than for total metals. This indicates that guideline exceedances for many of the metals would not pose a toxicity concern; the exceptions are copper and iron (dissolved copper has exceeded the CCME WQG on a few sampling dates and dissolved iron has more frequently exceeded the CCME WQG). These concentrations reflect background conditions, to which aquatic organisms are adapted.

The ability to detect statistically significant long-term changes in water quality can be challenging when the dataset includes a high proportion of values reported as below detection limits, particularly when detection limits change over time (for example, lower limits for cadmium and selenium), and when there are few measurements. As a result, both Environ (2012) and HDR (2015) recommended caution in interpreting temporal trends for some parameters and stressed the importance of ongoing monitoring to add to the baseline dataset, to increase confidence in the ability to identify long-term trends. Metals for which trends were evaluated but did not show a trend are listed in Appendix A (Table A3-1) and include the total and/or dissolved fraction of 26 metals. Trends were not assessed for the dissolved fraction of five metals (cobalt, manganese, strontium, uranium, and vanadium).

Concentrations of the majority of metals do not show any statistically significant trends over time on an annual basis. Table 4-3 and Appendix A (Table A3-1) identify the following trends:

- A decreasing trend for total iron (identified by HDR only); it might be expected that similar trends would be identified for total aluminum, TSS, and turbidity, given the high proportion of iron and aluminum in fine sediment, but this was not the case (HDR 2015)
- A decreasing trend for total lithium (identified by HDR) and an increase for total vanadium (identified by Environ and HDR)
- Several parameters for which the authors recommend caution in interpretation, due to a high number of non-detect values (e.g., dissolved arsenic and total vanadium; Environ) or a relatively low number of data points used in the analysis (e.g., dissolved cadmium, cobalt, iron, lead, nickel, thallium; HDR)

Long-term trends in data analyzed by season were also identified. The HDR (2015) study separated the data into two groups: under ice and open water season. The Environ (2012) study separated the data into three groups: base flows (under ice), freshet, and recession. HDR (2015) identified statistically significant trends over time for total lead (decrease under ice), total lithium (decrease under ice and in open water), total cadmium (decrease in open water), total manganese (increase in open water), total uranium (increase under ice) and total zinc (increase under ice). The HDR study also identified trends where the number of data points was small (i.e., less than 30; caution to be used in interpretation), including decreases in dissolved aluminum, arsenic, antimony, cadmium, cobalt, iron, lead, vanadium, and zinc. Environ (2012) identified an increase in dissolved arsenic during recession and in total zinc during base flows. See Appendix A (Table A3-1) for details.

It is possible that the identified long-term annual and seasonal trends in total and dissolved metals also reflect variations in composition and sources of suspended sediment over time (e.g., from disturbance of land during development in various sub-basins). However, there are insufficient data at this time to confirm trends (e.g., for dissolved metals) and there are no monitoring data in the Upper Hay or Chinchaga sub-basins to characterize water quality on a sub-basin level. A review of these trends suggests the risk to aquatic life and other water users from elevated metals levels is low and unchanged from baseline conditions, given that there are no parameters that display both a long-term increasing trend based on a sufficient dataset and an exceedance of CCME WQGs.

The interim triggers for metals are listed in Table A2 of Appendix A. Seasonal (i.e., open water and under ice) site-specific triggers (50th and 90th percentiles) have been set for total aluminum, barium, beryllium, cadmium, chromium, cobalt, copper, iron, lead, lithium, manganese, molybdenum, nickel, strontium, vanadium, and zinc. Annual triggers have been developed for total antimony, arsenic, bismuth, boron, selenium, silver, thallium, and uranium and 24 dissolved metals; many of these are considered preliminary given the small number of data points available for calculation of triggers (HDR 2015).

4.2.2.2 Suspended Sediments

Suspended sediment samples are collected at the HR-BORDER site using a centrifuge process and analyzed for particle size, nutrients, and metals (Environ 2012). The centrifuge separates suspended sediment from water, concentrating the constituents to make their presence easier to detect. The dataset reviewed by Environ (2012) largely included data from 1995 to 1999, 2004, and 2005, while the Hatfield (2009) review focused on data from 2004 and 2005 (one sample each). For this report, Stantec compiled data provided and collected by the Government of the Northwest Territories (previously AANDC) between 1995 and 2014 and developed the discussion below using this full dataset, with temporal trends identified by Environ (2012) for 1995 to 2005. Interim triggers for suspended sediment quality have not been established (AB-NWT 2015).

4.2.2.2.1 Particle Size

Particle size of suspended sediment is reported as percent clay, silt, and sand, and was analyzed in six samples collected from the HR-BORDER site in 2005, 2011, and 2014. Silt and clay are predominant (median values of 41% and 40%, respectively), with lesser amounts of sand (median of 14%). Proportions range from of 27 to 47% silt, 21 to 69% clay, and 4 to 45% sand. Proportions of sand are greatest during spring freshet; however, the dataset contains fewer samples from this time of year, which may bias the summary statistics.

4.2.2.2.2 Nutrients and Organic Carbon

Particulate nitrogen, phosphorus, and carbon can be transformed and degraded during transport and settling in the river. As such these nutrients can contribute to overall nutrient supply. Total concentrations of phosphorus, and inorganic and organic particulate nitrogen and carbon were reviewed (see Table 4-4 and also Table A3-2 in Appendix A).

Table 4-4 Descriptive Statistics and Temporal Trends for Select Nutrients and Metals in Suspended Sediments Analyzed at the Hay River Border Station, Over the Period 1995 to 2014

Parameter	Units	CCME SQG[1]		n_{ND} / n[2]	Concentration			# > CCME SQG[3]		Temporal Trends[4]
		ISQG	PEL		Minimum	Maximum	Median	ISQG	PEL	
Carbon, Inorganic	%	–	–	1 / 13	<0.1	0.43	0.31	–	–	–
Carbon, Organic	%	–	–	0 / 12	2.0	10.0	3.1	–	–	↔
Nitrogen, Inorganic	%	–	–	0 / 1	0.31	0.31	–	–	–	–
Nitrogen, Organic	%	–	–	0 / 6	0.17	0.85	0.25	–	–	–
Phosphorus, Total	mg/kg	–	–	0 / 10	875	1,730	1,170	–	–	–
Arsenic	mg/kg	5.9	17	0 / 14	12.5	19.6	16	14	5	↔
Cadmium	mg/kg	0.6	3.5	4 / 14	0.66	<1.00[5]	0.90	14	0	–
Chromium	mg/kg	37.3	90	0 / 14	26.8	118	68	9	1	↔
Copper	mg/kg	35.7	197	0 / 14	17.0	43.0	25.9	1	0	↔
Lead	mg/kg	35	91.3	0 / 14	10.0	17.7	15.4	0	0	↔
Mercury	mg/kg	0.170	0.486	0 / 14	0.062	0.092	0.078	0	0	↔
Zinc	mg/kg	123	315	0 / 14	110	158	142	0	0	↔

NOTES:

1 CCME SQG = Canadian Council of Ministers of the Environment (CCME) sediment quality guidelines for freshwater environments; ISQG = interim sediment quality guidelines; PEL = probable effects level

2 n_{ND} / n = number of non-detect data points over total number of data points

3 # > CCME SQG = number of data points greater than the CCME SQG ISQG and PEL

4 Temporal trends identified for entire data record by Environ (2012); ↑ = increasing, ↓ = decreasing, ↔ = no trend, – = not assessed

5 Maximum value for cadmium in suspended sediments due to high detection limits in 1990s; maximum detected value is 0.91 mg/kg (September 2011 and July 2014)

Over the period 1995 to 2014, inorganic nitrogen was analyzed in one sample (0.31%). Organic nitrogen was analyzed in eight samples (range from 0.17 to 0.85%, median of 0.21%). Total phosphorus was analyzed in 10 samples (range from 875 to 1,730 mg/kg, median of 1,170 mg/kg). Organic carbon and inorganic carbon were analyzed in 14 and 15 samples, respectively. Concentrations of organic carbon were notably higher (range of 2.0 to 10.0%, median of 3.0%) than for inorganic carbon (range of < 0.1 to 0.43%, median of 0.31%). Environ (2012) did not analyze temporal trends for nitrogen, phosphorus, or inorganic carbon (1995 to 2005). Trends for organic carbon were assessed but no temporal trends were identified; however, correlations between suspended sediment organic carbon and flow (negative) and total organic carbon (positive) were identified (Environ 2012).

4.2.2.2.3 Metals

From 1995 to 2014, metals were analyzed in 14 samples, with the number of metals analyzed per sample varying over time (see Table 4-4 and also Table A3-2 in Appendix A). Of the 24 metals analyzed, 22 were detected in all samples in which they were analyzed, with cadmium and molybdenum reported at below detection limits in some samples.

Given that there are no guidelines for suspended sediments, results were compared to CCME guidelines for benthic sediments. The interim sediment quality guidelines (ISQGs) represent concentrations below which adverse biological effects are expected to occur rarely, whereas probable effect levels (PELs) represent concentrations above which adverse biological effects occur frequently (CCME 2001). Both levels are derived from available literature, though at present, guidelines for metals are considered interim due to a lack of data. The guidelines are generic and do not take into account elevated metals levels in areas where soil and rock are naturally enriched in metals. In the Hay River samples, concentrations were higher than the ISQG for arsenic and cadmium (14 of 14 samples each), chromium (9 of 14 samples), and copper (1 of 14 samples); concentrations were higher than the PEL for arsenic (5 of 14 samples) and chromium (1 of 14 samples), as shown in Table 4-4.

Environ (2012) did not identify any statistically significant temporal trends for metals in suspended sediment over the 1995 to 2005 data record.

4.2.3 Differences between Hay River at the Border and the Town of Hay River

Differences in water quality at the HR-BORDER and HR/WC sites were examined (Environ 2012). Because samples were collected on different dates for two separate programs (i.e., Environment Canada and GNWT), some differences in water quality may be due to short-term variability in river conditions. To minimize such confounding influences, data collected on similar dates were analyzed using a paired t-test that provided a balanced statistical design. Using this approach, statistically significant higher concentrations were identified for TDS, total chromium, magnesium, pH, and sodium at HR/WC than at HR-BORDER (Environ 2012).

4.2.4 Summary for General Water Quality

Surface water chemistry has been monitored consistently at the HR-BORDER station since late 1988, with programs conducted by Environment Canada and the Government of the Northwest Territories. Since 1995, suspended sediment and centrifugate water samples have also been analyzed. Elsewhere in the Hay River Basin, water quality is monitored at the Town of Hay River, near the mouth of the river, but there are no monitoring sites in the Upper Hay and Chinchaga sub-basins from which to identify spatial trends across the basin.

Water at the HR-BORDER site is slightly alkaline (median pH of 7.7), hard (median hardness of 166 mg/L as $CaCO_3$), with highest total dissolved solids concentrations during winter, reflecting the higher relative proportion of groundwater inputs during the minimum flow period. The major ions are calcium, magnesium, sodium, potassium, sulphate, and chloride. The Hay River carries a moderate load of suspended sediment, with a median TSS level of 12.5 mg/L. The TSS levels are lower than for other northern rivers (Slave, Liard, and Peel rivers). Dissolved oxygen levels during winter can fall below the recommended minimum threshold for cold water aquatic biota, which is a natural condition under ice.

Nutrient concentrations are highest during freshet, associated with transport of particulate matter. The water at HR-BORDER is considered naturally productive on the basis of dissolved nitrogen concentrations (mesotrophic) and total phosphorus concentrations (eutrophic), with nitrogen likely to limit algal growth during the growing season. Levels of TOC and DOC and colour are high compared to other northern rivers, presumed to be related to leaching from organic soils in the many low-lying wetlands throughout the basin.

Metal concentrations reflect the underlying geology of the Hay River Basin and the levels of suspended sediment in the river, with highest concentrations typically occurring during spring freshet. Total metal concentrations that frequently exceed their CCME WQGs for protection of aquatic life are aluminum (57% of samples), cadmium (23%), copper (15%), and iron (60%). The dissolved concentrations, which are more bioavailable, seldom exceeded the CCME WQGs for total metals, although dissolved copper occasionally exceeds, and dissolved iron more frequently exceeds their guidelines. These concentrations reflect background conditions, to which aquatic organisms have likely adapted.

Two assessments of water quality trends in the Hay River have been undertaken, and the authors of the two reports reached similar conclusions for some, but not all, results. Both reports recommended caution in interpreting trends, especially for parameters with many values below detection (e.g., for some metals) or for which there were few data. No long-term statistically significant trends on an annual basis were identified for routine parameters, or the majority of nutrients and metals (decreasing trend for total iron), although there were some trends on a seasonal basis.

4.3 STATUS OF ORGANIC CONTAMINANTS

Organic contaminants are of interest because some compounds persist and bioaccumulate, so can be of potential concern for aquatic and human health. They may come from sources within the Hay River Basin or from long-range transport in the atmosphere. Organic contaminant monitoring for the Hay River began in 1994, and some data reviews have been published for the Hay River (AANDC 2014) and Slave River (AANDC 2012b). The information presented below provides an integrated review of all organic data collected for the Hay River Basin up to 2015.

An organic compound is any member of a large class of gaseous, liquid, or solid chemical compounds that contain carbon. Many organic compounds are encountered daily and are essential to human functioning. Some, both natural and synthetic, are considered contaminants. Examples include pesticides, herbicides, solvents, coolants, and petroleum products. They can come from local sources and enter the aquatic environment through discharge, leakage, spills, and run-off from inhabited areas, or they can come from global sources and enter the aquatic environment through atmospheric deposition. Many of the contaminants analyzed in water and suspended sediment in the Hay River come from global sources. For example, many synthetic contaminants analyzed have been banned for many years in North America (e.g., various pesticides and polychlorinated biphenyls [PCBs]) or are not used in the Hay River Basin (many of the pesticides and fluorocarbons [organofluorines; used as refrigerants, solvents, and anesthetics]). Others, such as polycyclic aromatic hydrocarbons (PAHs), come from both natural sources (e.g., natural petroleum seeps, breakdown of vegetation, forest fires) and human activities (e.g., burning of fuels, discharge from industrial sources, spills, and municipal effluent).

Organic contaminants (including PAHs, PCBs, and pesticides) are analyzed in water and suspended sediment samples collected at the HR-BORDER site. Comparisons have been made to similar data collected from the Slave River where appropriate, to provide context for two basins with different levels of development and suspended sediment loads. For example, the Slave River Basin is known for vast natural oil reserves and intense oil sands development in Alberta, while the Hay River Basin has a lower level of development, with less oil sector activity.

Where possible, results for water were compared to the CCME WQGs for the protection of freshwater aquatic life (CCME 2016). As guidelines do not exist for suspended sediment, these results were compared to CCME ISQGs and PELs developed for benthic (bottom) sediment.

4.3.1 Overview of Contaminants

4.3.1.1 Polycyclic Aromatic Hydrocarbons

Polycyclic aromatic hydrocarbons are widely distributed organic compounds that contain two or more benzene rings. They are found naturally in fossil fuels (crude oils and coal) and certain plant fractions but also can be a product of human activities (from incomplete combustion in forest fires, internal combustion engines, wood stoves, and coal coking) (CCME 1999a). The major human activities that release PAHs to freshwater are oil spills and refinery effluents, with domestic sewage, stormwater runoff, and landfills also contributing (CCME 1999a).

These hydrocarbons are nonpolar and most are hydrophobic (i.e., avoid water), with low solubility. As a result, in water they tend to adsorb onto solid phases like sediment (Neff 1979; National Research Council of Canada 1983; Eisler 1987; Slooff et al. 1989). Adsorption to benthic sediments plays an important role in PAH transport and distribution (Smith et al. 1978; United States Environmental Protection Agency [USEPA] 1982; Broman et al. 1991). Solubility of PAHs decreases as molecular weight increases (BC Ministry of Environment, Lands, and Parks 1993).

Related aromatic compounds include heterocycles (with a nitrogen or sulphur atom replacing a carbon atom in the benzene ring) and biphenyl (two unfused but linked benzene molecules). Examples include acridine and quinolone (nitrogen hydrocycles), dibenothiophene (sulphur hydrocycle), biphenyl, and alkylated biphenyls. These compounds occur naturally in crude oil and coal tars, behave similarly to PAHs, and can be useful tracking tools for the presence of petroleum sources.

There are parent (unsubstituted) and alkylated PAHs (with alkyl groups attached). Parent PAHs can be divided into low molecular weight compounds, with two or three aromatic rings, and high molecular weight compounds, with four to six rings. The high molecular weight PAHs degrade more slowly than low molecular weight PAHs and are less soluble in water, so tend to adhere to sediment and settle onto bottom sediments. Alkylated PAHs degrade more slowly than their parent compounds.

The PAHs produced during incomplete combustion of fossil fuels (pyrogenic sources) are predominantly the parent PAHs, with an abundance of high molecular weight PAHs such as chrysene, pyrene and benzo(a)pyrene (Yender et al. 2002). Sources of pyrogenic PAHs can be natural (e.g. forest fires) or human-made (e.g. municipal incineration). In contrast, PAHs in petroleum-derived oils (petrogenic sources) contain a higher proportion of alkylated compounds and relatively low concentrations of the high molecular weight PAHs (Yender et al. 2002). Sources of petrogenic PAHs can be natural (e.g. bitumen/oil seeps) or human-made (e.g. oil sands effluent). Profiles of PAH compounds and relative abundance of parent and alkylated compounds can be used to differentiate the various sources such as petrogenic or pyrogenic (natural or otherwise).

Many factors influence PAH concentrations in river water, including the source (e.g., natural vs. human activity, continuous vs. accidental spill-related), weathering behavior (e.g., solubility, volatility, photo-degradation), and biological degradation pathways by microbes (CCME 1999a; Dupuis and Ucan-Marin 2015). For example, naphthalene is a common component in fossil fuels (unrefined and refined oils, coal deposits), and being a low molecular weight PAH with high solubility, is often measurable in surface water. Although it degrades quickly compared to other PAHs, naphthalene may remain in river water because of a continuous source (e.g., natural oil seeps, effluent discharge, atmospheric deposition) or its high solubility compared to other PAHs. In general, most of the naphthalene that enters a river or lake will be gone within two weeks (United States Department of Health and Human Services 2005).

There are CCME WQGs, ISQGs, and PELs for several of the parent PAHs (CCME 1999a; CCME 2016), but few guidelines for the numerous alkylated PAHs. The guidelines were derived from toxicity studies of a wide range of sensitive aquatic organisms, including rainbow trout (*Oncorhynchus mykiss*), brown trout (*Salmo trutta)*, and the invertebrate *Daphnia magna*.

4.3.1.2 Naphthenic Acids

Naphthenic acids are water soluble weak acids, mainly monocarboxylic acids (carboxylic acid with a single carboxyl group), that biodegrade slowly and persist in the environment. They occur naturally in crude oils and bitumen, and are the primary toxicants identified in wastewaters associated with oil refineries and oil sands extraction (Dalmia 2013).

Naphthenic acids are of interest because of their association with oil sector activities, persistence in the environment, and identified aquatic toxicity at concentrations found in tailings pond waters (MacKinnon and Boerger 1986). However, due to a lack of sufficient chronic toxicity data regarding long-term exposure of aquatic biota (CEATAG 1998), there are currently no water quality guidelines for naphthenic acids in Canada or the United States.

4.3.1.3 Pesticides

A pesticide is any substance or mixture of substances used to destroy, suppress, or alter the life cycle of any pest. Pesticides can be naturally derived or synthetically produced and include fungicides, herbicides, insecticides, and repellents. They are used in commercial, domestic, urban, and rural environments.

The fate of pesticides released into the environment varies: some are released to the air and subsequently move into soil or water; others are applied directly to soil or plants and can be washed off into nearby waterbodies. Worldwide distribution of dichlorodiphenyltrichloroethane (DDT) and the presence of pesticides in waters far from their primary use areas are examples of the potential for long distance transport (Kannan et al. 2006).

Some pesticides are of concern because they persist and can accumulate and magnify in the food chain (e.g., organochlorines and organophosphates). Many have been banned. For example, DDT use in Canada was severely restricted in the early 1970s due to evidence linking it to adverse effects in many wildlife species (Canadian Council of Resource and Environment Ministers 1987). While banned pesticides are still a concern due to their persistence, currently used pesticides can also cause toxicity to aquatic organisms (Kannan et al. 2006). Current-use pesticides are those currently registered for use in Canada under the *Pest Control Products Act* administered by the Pest Management Regulatory Agency of Health Canada (Environment Canada 2011).

Water and sediment guidelines (WQGs, ISQGs, and PELs) are available for 9 pesticides for sediment and 37 for water (CCME 2016). Similar to PAHs, the guidelines for pesticides were derived from toxicity studies of a wide range of sensitive aquatic organisms.

4.3.1.4 Polychlorinated Biphenyls

Polychlorinated biphenyls are chlorinated organic compounds that include 209 congeners (similar compounds) that can be toxic to aquatic biota. The PCB congeners are classified into similar groups according to the number of chlorine atoms they contain (CCME 1999b). They were produced commercially as complex mixtures of chlorobiphenyl congeners in North America, marketed under the trade name Aroclor (Moore and Walker 1991) and had many industrial applications. Although not manufactured in Canada, approximately 40,000 t of PCBs were imported and used commercially between 1929 and 1977 (Canadian Council of Resource and Environment Ministers 1986). Canada prohibited import of PCBs in 1980 (Strachan 1988).

The majority of PCBs introduced into the aquatic environment become incorporated into benthic sediments (Baker et al. 1985), making sediments an important exposure route for aquatic biota. As environmental exposure is predominantly via sediment, soil, and/or tissue, there are no CCME WQGs for PCBs. Instead, CCME ISQG and PELs can be used to evaluate the degree to which adverse biological effects are likely to occur as a result of exposure to PCBs.

4.3.1.5 Other Contaminants

Perfluorocarbons are organofluorine compounds used in refrigerants, solvents, surfactants, firefighting materials, anaesthetics, fabric treatments, and other common consumer goods. They can be released to the aquatic environment in effluent from wastewater treatment plants, industrial waste, and biosolids (Rahman et al. 2014). They are soluble, both hydrophobic and hydrophilic, and persistent (Rahman et al. 2014). Water and sediment guidelines have not been developed for perfluorocarbons.

Polybrominated diphenyl ethers (PBDEs) are organobromine compounds, commonly used as flame retardants and incorporated in many consumer goods, including building materials, electronics, textiles, furniture, and plastics. They are similar in structure to PCBs, and are persistent, hydrophobic, relatively insoluble, and tend to bioaccumulate in the food web (USEPA 2014). The PBDEs can enter the aquatic environment through atmospheric deposition, leachate from waste disposal sites, and wastewater treatment plant effluent discharges (USEPA 2014). Water and sediment guidelines have not been developed for PBDEs.

4.3.2 Sample Type, Location, and Sampling Frequency

Organic contaminants have been collected and analyzed in samples collected from the Hay River in surface water, centrifugate, suspended sediment, and polyethylene membrane devices (PMDs), as shown in Table 4-5. See Section 4.2.1 for a general introduction to sampling programs for the Hay River Basin and Figure 4-1 for locations of monitoring sites. The routinely analyzed parameters are PAHs, PCBs, and pesticides, with others (naphthenic acids, PBDEs, and perfluorinated compounds [PFCs]) added periodically because they are emerging contaminants of potential concern.

Table 4-5 Organic Compounds Monitoring Program in the Hay River, Types, and Years Sampled

Sampling Site	Matrix	Type of sample	Contaminant Class			
			PAHs	PCBs	Pesticides	Other
HR-BORDER	Water	Surface Water	1994–2010, 2012–2014, 2004, 2011, 2012, 2015	1994, 1996–1998, 2005, 2007, 2015	1994, 1996–2010, 2012–2014, 2004, 2005, 2015	2004, 2005 (VOCs) 2015 (naphthenic acids)
		Centrifugate Water	2004, 2005 2011–2015	2014, 2015	2013–2015	2004, 2005 (VOCs) 2013, 2014 (naphthenic acids) 2015 (PFCs, PBDEs)
	Suspended Sediment	Suspended Sediment	1995–1999 2004, 2005 2011–2015	1995–1999 2004, 2005 2011–2015	1995–1999 2004, 2005 2011–2015	2004, 2005 (n-alkanes) 2011–2014 (naphthenic acids) 2015 (PFCs, PBDEs)
HR-01	Water	PMDs	2012–2014	—	—	—
HR-02	Water	PMDs	2013	—	—	—

NOTES:

— = not sampled

PMDs = Polyethylene membrane device, VOCs = volatile organic compounds, PFCs = perfluorinated compounds, PBDEs = polybrominated diphenyl ethers

Years listed in black were for samples collected by Government of the Northwest Territories (previously by AANDC).

Years listed in red were for samples collected by Environment Canada.

Years listed in blue were for samples collected by Environment Canada and AANDC.

4.3.2.1 Surface Water

Surface water samples are collected from just below the river surface and contain both water and suspended sediment. Surface water samples are sometimes referred to as "grab" samples. Environment Canada and the Government of the Northwest Territories, have collected samples for analysis of organic contaminants at the HR-BORDER site since 1994. Similar programs have been conducted on the Slave River at Fitzgerald (SR-FITZ) since 1979 (Figure 4-1); because the sampling protocols and laboratory analyses are the same, contaminant concentrations can be compared for these two rivers that have different levels of human activity in their basins.

4.3.2.1.1 Suspended Sediment and Centrifugate Water Samples

Because large northern rivers typically carry a relatively high load of suspended sediment (Hatfield 1999), and because many organic contaminants have low solubility in water and tend to adhere to sediment, it is useful to examine organic contaminants in the suspended sediment fraction. A centrifuge is used to collect sufficient sediment for the required analyses, separating out the water (centrifugate) and sediment. Analysis of the individual fractions allows compounds associated with suspended sediments to be differentiated from those associated with water.

Centrifuge sampling has been carried out at the HR-BORDER site since 1995, by Environment Canada (1995 to 1999) and by the GNWT (formerly by AANDC) since 2004. Similar programs have been conducted on the Slave River since 1990 at Fort Smith (SR-SMITH; Figure 4-1). Since 2013, centrifuge sampling efforts in the two rivers have been coordinated, to improve the ability to compare results for water and suspended sediment.

4.3.2.1.2 Polyethylene Membrane Devices

Polyethylene membrane devices are passive samplers placed in the river for up to one month and are used to detect very low concentrations of hydrocarbons (PAHs) in water. The GNWT initiated the PMD program to address community concerns related to upstream oil sands development, municipal dumps, historical spills, and boat docking activity. Two sites in the Hay River were sampled using PMDs: one at Hay River upstream of West Channel (HR-01) from 2012 to 2014, and one at the mouth of Great Slave Lake (HR-02) in 2013, shown in Figure 4-1. They were also used in the Slave River at Fort Smith below the rapids (SMITH-01, which is within 100 m of the centrifuge site SR-SMITH). Data from the two rivers were compared where appropriate.

4.3.3 Polycyclic Aromatic Hydrocarbons

Surface water, centrifugate, suspended sediment, and PMD samples from the Hay and Slave rivers were analyzed for PAHs. Concentrations were lowest in the surface water, similar or slightly higher in centrifugate water, and highest in the suspended sediment, as would be expected, given that PAHs, are hydrophobic and tend to adsorb onto particles.

Laboratory detection limits have been lowered over time, which has led to an increase in the number of detectable PAHs. In addition, the laboratory analysis was expanded in recent years to include alkylated as well as parent PAHs, to increase the ability to evaluate trends and identify PAH sources. The results are discussed for parent, alkylated, and total parent plus alkylated PAHs, where appropriate. A conservative approach has been followed for the detection limits, given that many PAHs are present at low concentrations or are not detectable: when calculating values for total parent, alkylated, and all PAHs combined, the full detection limits for individual PAHs are used. To provide context on how much PAH is actually measured, the sum of all the detection limits is provided, where appropriate.

4.3.3.1 PAHs in Surface Water

At the HR-BORDER site, PAHs were analyzed in 32 surface water samples collected by Environment Canada between 1994 and 2014 (Table 4-5). The concentration in surface water reflects presence of PAHs in the water phase, including suspended matter, so is higher than in the centrifugate portion of a sample. Samples were collected in May to September from 1994 to 2008, then annually in May from 2009 to 2014. Up to 22 compounds were analyzed (mainly parent PAHs). Laboratory detection limits were 5 to 10 times lower after 2007, resulting in a greater number of PAHs detected, but at very low concentrations. Results for the HR-BORDER site are as follows:

- There were low but detectable levels of PAHs in 9 of the 32 samples (less than three times their detection limit, except perylene, which was up to 12 times higher than the lowest analytical detection limit [0.166 µg/L in May 1997])
- Concentrations were well below their applicable CCME WQGs
- Naphthalene was the most frequently detected PAH (in seven samples) and ranged from 0.006 µg/L (April 2008) to 0.027 µg/L (July 2004); in comparison, the maximum concentration for the Slave River at SLAVE-FITZ was five times higher at 0.134 µg/L (December 2005)

Five additional surface water samples were collected at HR-BORDER in 2004 by Environment Canada (parent PAH, all non-detects) and in 2011 and 2012 by the GNWT (parent plus alkylated PAHs, using lower detection limits than in 2004). The four samples analyzed between August 2011 and September 2012 provided more detailed information about very low concentrations of PAHs:

- Depending on the parameter, concentrations were 3 to 300 times lower than any applicable CCME WQGs.
- The maximum concentration recorded for a parent PAH was for naphthalene (0.039 µg/L, September 2011), well below the CCME WQG of 1.1 µg/L.
- Of the 232 measurements of parent and alkylated PAH, 88% were recorded as non-detects; the July 2012 sample had the highest number of detectable PAHs (17 compounds).
- Alkylated PAHs were generally below the detection limit, except in July 2012, when the maximum concentration was recorded for C2 phenanthrenes/anthracenes (0.013 µg/L).

Table 4-6 shows maximum concentrations recorded in surface water at the HR-BORDER site between 1994 and 2014 for PAHs that have a CCME WQG. Maximum concentrations were well below these guidelines.

Table 4-6 Maximum PAH Concentrations in Surface Water Samples Collected at HR-BORDER between 1994 and 2014 Compared to Water Quality Guidelines

PAH compound	CCME WQG[1] (µg/L)	Maximum Concentration[2] (µg/L)	Ratio (times below the WQG)
Acenaphthene	5.8	< 0.00517	> 1000
Acridine[3]	4.4	< 0.001	> 4000
Anthracene	0.012	< 0.00612	> 2
Benz(a)anthracene	0.018	< 0.00996	> 2
Benzo(a)pyrene	0.015	< 0.00942	> 1.6
Fluoranthene	0.04	0.00839	5
Fluorene	3.0	0.00837	360
Naphthalene	1.1	0.0271	40
Phenanthrene	0.4	0.0447	9
Pyrene	0.025	0.00764	3
Quinoline[3]	3.4	< 0.001	> 3000

NOTES:

[1] Canadian Council of Ministers of Environment Water Quality Guideline for Protection of Freshwater Aquatic Life, Interim (CCME 1999a)

[2] < = less than the lowest analytical detection limit. Detection limits varied over time but were consistently well below WQGs

[3] Acridine and quinolone are hydrocycles (they incorporate a nitrogen atom in the ring structure) that occur naturally in coal tars and crude oils.

Concentrations of PAHs in surface water samples from the Slave River generally were higher than those from the Hay River, but they also were consistently below CCME WQGs, with many PAHs below or close to their detection limits. Consistent use of lower detection limits and analysis of alkylated as well as parent PAHs will increase the ability to evaluate trends in PAHs over time.

4.3.3.2 PAHs in Centrifugate Water

Centrifuged water samples were collected from the HR-BORDER site and analyzed for PAHs twice a year between May and September in 2004 and 2005 (parent PAHs) and, using lower detection limits, in 2011 and 2012 (parent and alkylated PAHs). Concentrations in centrifugate samples were similar to those in surface water (Table 4-7), except for one date (twice as high in centrifugate, August 2011).

Table 4-7 Comparison of Total PAH Concentrations in Centrifugate and Surface Water Samples Collected from the HR-BORDER Site between 2004 and 2012

Sample Date	Number of PAH Compounds Analyzed	Total PAH (µg/L)[1]	
		Centrifugate	Surface Water
Jun 2004	17	0.20 (sum of DLs = 0.17)	0.17 (same as sum of DLs)
Jul 2004	17	0.17 (same as sum of DLs)	NA
May 2005	17	0.27 (sum of DLs = 0.17)	NA
Jun 2005	17	0.17 same as sum of DLs)	NA
Aug 2011	52	0.936 (sum of DLs = 0.412 µg/L)	0.439 (sum of DLs = 0.412 µg/L)
Sep 2011	52	0.476 (sum of DLs = 0.412 µg/L)	0.462 (sum of DLs = 0.412 µg/L)
Jul 2012	52	0.234, 0.279 (duplicates) (sum of DLs = 0.137 µg/L)	0.200 (sum of DLs = 0.137 µg/L)
Sep 2012	52	0.413, 0.412, 0.412 (triplicates) (sum of DLs = 0.412 µg/L)	0.418 (sum of DLs = 0.412 µg/L)

NOTES:
NA = not analyzed, DL = detection limit
Underlined = total PAH is higher than detection limit
[1] The concentration is the sum of individual PAH concentrations and/or DL (if not detected). Where a concentration was reported as less than the DL the full DL was used to calculate total PAH). The sum of the DLs is included to provide context to the reported values.

Of the 432 PAH analyses performed on centrifugate during this period, 374 (86%) were recorded as non-detects. Observations were as follows:

- All concentrations were below applicable CCME WQGs
- Many PAH concentrations were close to or below the detection limits
- Methylnaphthalenes (0.020 µg/L) and naphthalene (0.030 µg/L) were detected in 2004
- Acenaphthene (0.020 µg/L), fluorene (0.030 µg/L), methylnaphthalenes (0.040 µg/L) and phenanthrene (0.050 µg/L) were detected in 2005
- More parameters were detected in 2011 and 2012 (11 and 21, respectively) than in 2004 and 2005, due to the use of lower detection limits; maximum concentrations detected were for naphthalene (0.382 µg/L, which is below the CCME WQG of 1.1 µg/L)

From 2013 to 2015, centrifugate samples were collected monthly during the summer from the HR-BORDER and SR-SMITH sites. Samples were analyzed for up to 75 parent and alkylated PAHs using ultra-low detection limits to identify trends in PAH levels and to support more precise identification of PAH sources. The maximum concentrations recorded were for the alkylated C2-

biphenyls, C2-naphthalenes, and C4-phenanthrenes/anthracenes and the parent naphthalene, which were present at levels many times higher than their detection limits (Table 4-8).

Table 4-8 Maximum PAH Concentrations in Centrifugate Water Samples Collected at the HR-BORDER and SR-SMITH Sites between July 2013 and August 2015

Sampling Site	PAH Compound	Sampling Date	Maximum Concentration (µg/L)[1]	Detection Limit (µg/L)[1]
HR-BORDER	C2-biphenyls[1]	Jul 2013	0.0239	0.00043
		Jun 2014	0.0160	0.00029
		Jul 2014	0.00522	0.00020
	C2-naphthalenes	Aug 2014	0.00431	0.00012
	Naphthalene	Aug 2013	0.01370	0.00035
		Jun 2015	0.00274	0.00011
SR-SMITH	C2-biphenyls[1]	Jul 2013	0.0234	0.00045
		Jul 2014	0.00690	0.000071
	C2-naphthalenes	Aug 2014	0.00363	0.00016
		Jun 2015	0.00823	0.000074
		Aug 2015	0.05450	0.00053
	Naphthalene	June2014	0.0175	0.00026
	C4-phenanthrenes/ anthracenes	Aug 2013	0.0084	0.00036
		Jul 2015	0.00901	0.000097

NOTES:
The average concentrations of duplicate and triplicate samples are presented in this table.
[1] Biphenyls consist of two aromatic rings but are not true PAHs; they can by alkylated (e.g., C2-biphenyls). They occur naturally in coal tars and crude oils.

Other details of the sampling program are as follows:

- PAHs with CCME WQGs were notably lower than their guidelines (e.g., maximum naphthalene levels in Hay River of 0.0137 µg/L and Slave River of 0.0175 µg/L were about 50 times lower than the CCME WQG of 1.1 µg/L); there are no CCME WQGs for alkylated PAHs.
- The ultra-low detection limits allowed quantification of many previously undocumented alkylated PAHs which facilitates the assessment of long term trends in the future. The alkylated and parent PAHs were well above their detection limits which highlights the importance of low detection limits for environmental monitoring.

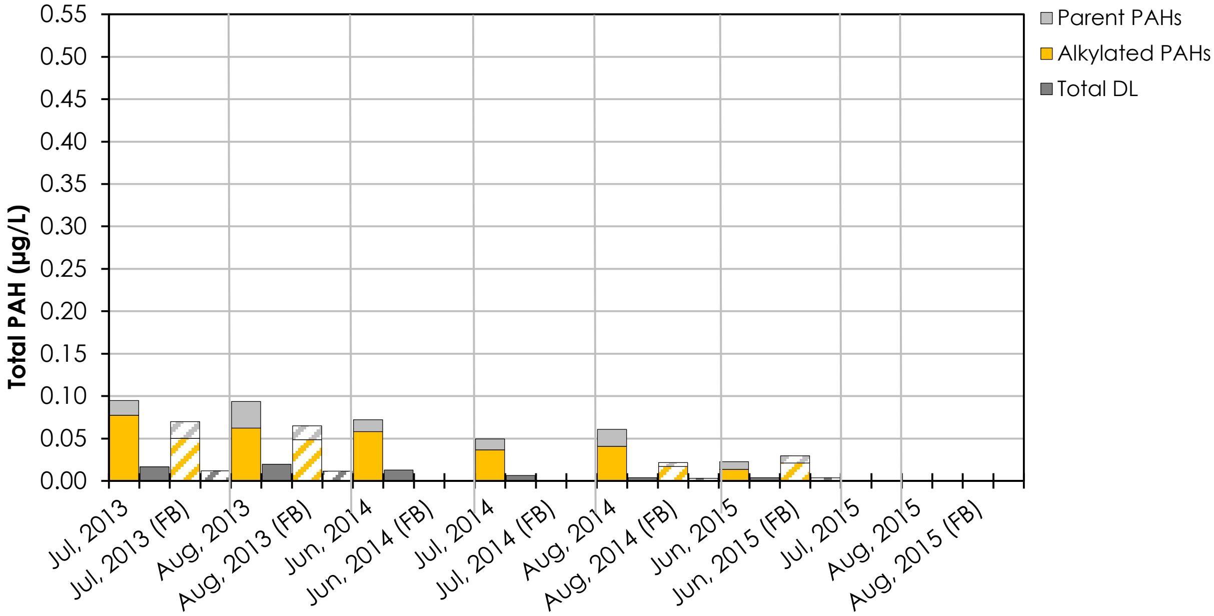
The centrifugate samples from the HR-BORDER and SR-SMITH sites contained higher proportions of alkylated PAHs than parent PAHs, i.e., ratio higher than 1:1 (Figure 4-6), which suggests the hydrocarbon source was mainly petrogenic rather than pyrogenic in both rivers (Yender et al. 2002; Wang and Fingas 2003; Wang and Stout 2007; Stogiannidis and Laane 2015). This suggests a higher proportion of PAHs from petroleum-derived sources (oils) entering the aquatic environment and lower proportion from combustion sources. There are no WQGs available for alkylated PAHs; however, concentrations measured in the surface water samples are low (Wang and Fingas 2003; Wang and Stout 2007) and may reflect the natural background presence of PAHs. For example, there are recognized oil reserves in the Hay-Zama Lakes area, in the Upper Hay sub-basin within Alberta (Section 7.2). Total PAH concentrations, in particular total alkylated PAHs, were generally higher at SR-SMITH than at HR-BORDER, which would be expected given the large natural upstream oil deposits and more intense oil sector activities in the Slave River Basin.

Figure 4-6 shows two other relevant aspects—first, the concentrations reported for centrifugate water are well above their detection limits and, second, the field blanks indicate the presence of PAHs for the samples. Several field blanks were collected and analyzed at the same time as centrifugate samples, as part of the quality assurance/quality control program Appendix B). On several occasions, the field blanks had PAH concentrations similar to or greater than the centrifugate samples (e.g., July and August 2013 for Hay River, August 2014 for Slave River). This indicates PAHs can be introduced during sampling (e.g., cross-contamination in sampling equipment or from another source) or in the laboratory (laboratory blanks also contained measurable PAH concentrations). The August 2014 field blank for the Slave River had a higher total PAH concentration and different composition (a greater proportion of parent PAHs) than the corresponding centrifugate sample, suggesting cross-contamination in the field. Results for field and laboratory blanks point to the ubiquitous presence of hydrocarbons in the environment (even in ultra-clean laboratory conditions), challenges when working with very low detection limits, and potential for other sources to confound the analyses. Even a blank, which is intended to be pure water, can be “contaminated” by PAHs in the air during sample collection or in the laboratory during analysis.

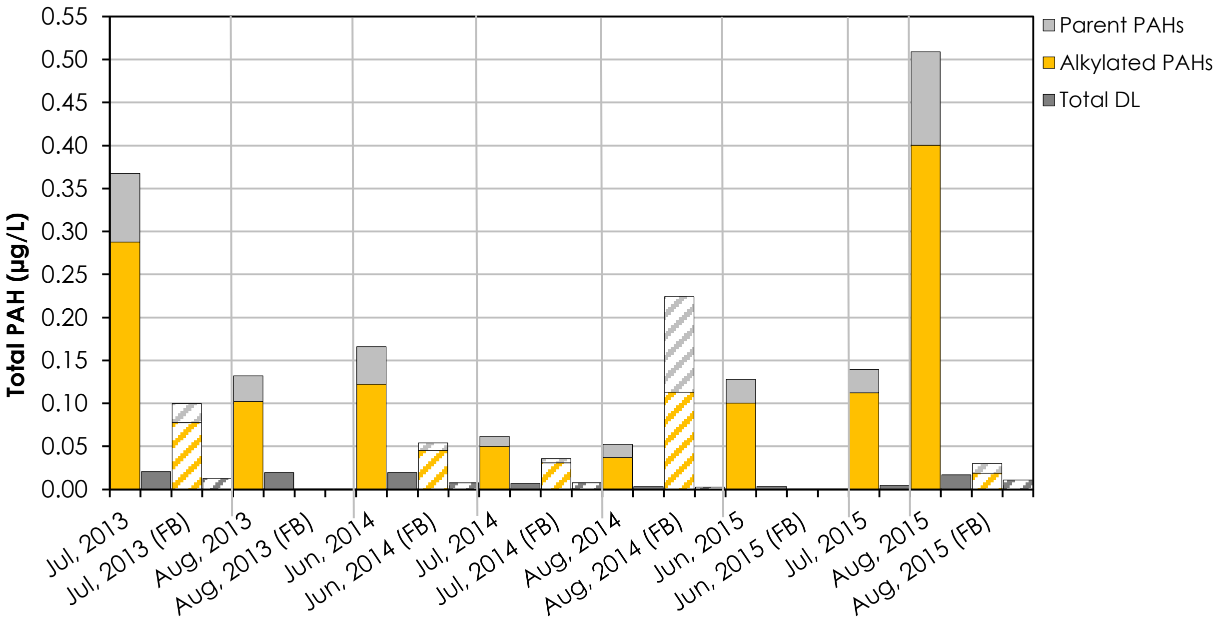
In July and August 2015, surface water samples were collected at HR-BORDER because turbidity levels in the river were too low to obtain sediment and centrifugate samples. A laboratory blank sample was analyzed both months and a field blank was analyzed in August (Appendix B). The results from August suggest, using very low detection limits, that small amounts of PAHs may have been introduced into the samples in the field.

Maximum PAH concentrations in the surface water sample (mean for triplicate samples) were recorded for C4-phenanthrenes/anthracenes (0.0136 µg/L, July 2015) and C2-naphthalenes (0.02 µg/L, August 2015). Similar to the centrifugate samples, results for these surface water samples indicate higher concentrations of alkylated PAHs than parent PAHs at HR-BORDER. Concentrations in all samples were below applicable CCME WQGs.

a) Hay River (HR-BORDER)



b) Slave River (SR-SMITH)



NOTE: The total height of each bar represents total PAH concentrations while the coloured sections of each bar represent contributions from parent and alkylated PAHs. In sample dates on X-axis, FB = field blank sample (shown in cross-hatching for reported value and total detection limit). Full detection limits were used to calculate the sum of all analytical detection limits (i.e., Total DL), as shown in bars adjacent to sample values. The average concentrations of duplicate and triplicate samples are presented in this figure.

Figure 4-6 Parent Versus Alkylated PAH Concentrations (µg/L) in Centrifugate Samples from a) Hay River and b) Slave River, July 2013 to June 2015

4.3.3.3 PAHs in Suspended Sediment

Between 1995 and 2012, 12 suspended sediment samples were collected at the HR-BORDER site and analyzed for PAHs. Between 1995 and 1999, samples were collected once a year, during the spring freshet; samples were collected twice a year in 2004 (June and July) and 2005 (May and June), including three duplicate samples (Appendix B). Samples were also collected in August and September 2011 and July 2012. In the absence of guidelines for suspended sediment, results were compared to available CCME interim freshwater bottom sediment guidelines to provide some context to what the values means. It is important to note that given the different nature of bottom and suspended sediment, the guidelines can be used for comparative purposes only; it is difficult to draw any definitive conclusions with respect to effects on biota. Concentrations in all samples were below relevant CCME sediment quality guidelines (the ISQGs and PELs). All values are reported as µg/kg dry weight (dw).

From 1998 to 2005, PAHs were below detection limits with the exception of perylene (which comes from peat, plants, coal, and crude oil) and 1-methylnaphthalene (common in crude oil):

- Perylene in 1997, 1998, and 1999; concentrations ranging from 131 µg/kg (June 1999) to 236 µg/kg (May 1998)
- Perylene in June 2004 (193 µg/kg)
- 1-methylnaphthalene in May 2005 (30 µg/kg) and June 2005 (10 µg/kg)

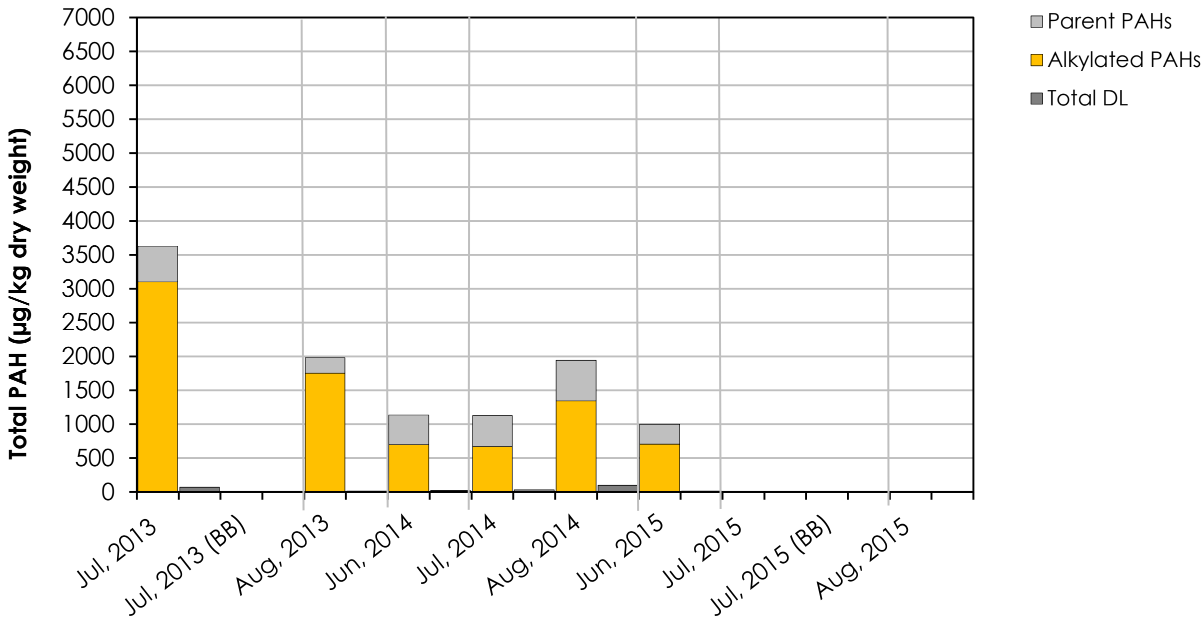
In 2011 and 2012, alkylated PAHs were added to the monitoring program and detection limits were lowered. As a result, more PAHs were detected. Alkylated PAH concentrations tended to be higher than parent PAHs, with the exception of perylene. Perylene concentrations ranged from 264 to 390 µg/kg and were higher in 2011 and 2012 than in previous years. The maximum alkylated PAH concentration recorded was for C2 naphthalenes in September 2011 (819 µg/kg). Several PAHs were present at levels several times higher than their detection limits. The sum of the parent PAHs ranged from 453 to 611 µg/kg (sum of the DLs ranged from 12 to 201 µg/kg) and alkylated PAHs ranged from 1,002 to 2,476 µg/kg (sum of the DLs ranged from 42 to 802 µg/kg).

Between July 2013 and August 2015, suspended sediment samples were analyzed for parent and alkylated PAHs in six samples from HR-BORDER and eight samples from SR-SMITH (Figure 4-7).

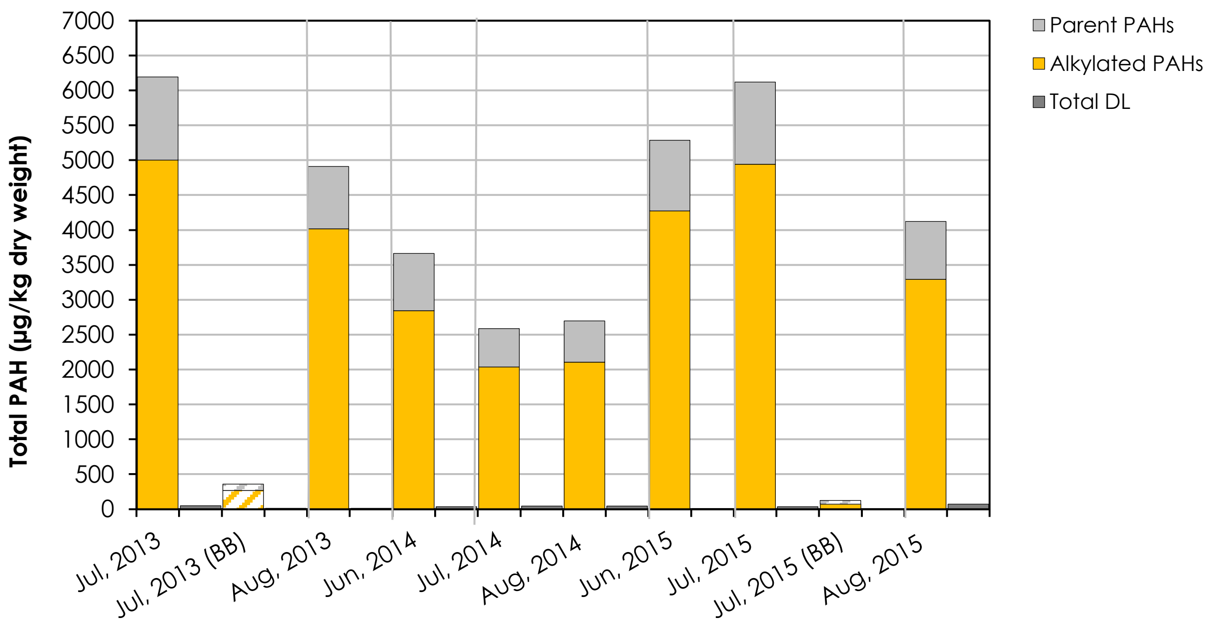
Concentrations of alkylated PAHs were generally higher than parent PAHs at both sites. Concentrations of total PAH were higher at SR-SMITH than at HR-BORDER:

- At HR-BORDER, the sum of all PAH concentrations ranged from 999 µg/kg in June 2015 (sum of the DLs = 11 µg/kg) to 3,629 µg/kg in July 2013 (sum of the DLs = 70 µg/kg)
- At SR-SMITH, the sum of PAH concentrations ranged from 2,585 µg/kg in July 2014 (sum of the DLs = 45 µg/kg) to 6,193 µg/kg in July 2013 (sum of the DLs = 47 µg/kg)

a) Hay River (HR-BORDER)



b) Slave River (SR-SMITH)



NOTE: The total height of each bar represents total PAH concentrations while the coloured sections of each bar represent contributions from parent and alkylated PAHs. In sample dates on X-axis. In sample dates on the X-axis, BB = bowl blank sample. Full detection limits were used to calculate the sum of detection limits (i.e. Total DL). The average concentrations of duplicate and triplicate samples are presented in this figure.

Figure 4-7 Parent Versus Alkylated PAH Concentrations in Suspended Sediment Samples from a) Hay River and b) Slave River, July 2013 to June 2015

In the Hay River samples, the most abundant PAHs were the parent PAH perylene and the alkylated C3-phenanthrenes/anthracenes, present at concentrations several times higher than their detection limits (Table 4-9). In contrast, the most abundant PAHs in the Slave River samples were C-2 naphthalenes and C4-phenanthrenes/anthracenes (Table 4-9), suggesting a different profile from the Hay River samples.

Table 4-9 Maximum PAH Concentrations in Suspended Sediment Samples Collected at the HR-BORDER and SR-SMITH Sites between July 2013 and August 2015

Sampling Site	PAH Compound	Sampling Date	Maximum Concentration (µg/kg) dry weight	Detection Limit (µg/kg) dry weight
HR-BORDER	C3-phenanthrenes/ anthracenes	Jul 2013	791	3.23
	Perylene	Aug 2013	336	1.33
		Jun 2014	259	0.45
		Jul 2014	267	0.79
		Aug 2014	306	5.51
		Jun 2015	164	0.30
SR-SMITH	C2-naphthalenes	Jul 2013	399	0.55
		Jun 2015	423	0.06
		Jul 2015	441	0.15
	C4-phenanthrenes/ anthracenes	Aug 2013	363	0.44
		Jun 2014	255	1.11
		Jul 2014	203	1.70
		Aug 2014	202	2.27
		Aug 2015	265	3.57

NOTE:
The average concentrations of duplicate samples are presented in this table.

In the absence of guidelines for suspended sediment, comparisons were made to available CCME guidelines for parent PAHs in benthic sediments. Observed concentrations in all HR-BORDER samples were below the CCME ISQGs and PELs; however, 2-methylnaphthalene, anthracene, chrysene, fluorene, dibenz[a,h]anthracene, naphthalene, and phenanthrene were above their ISQGs (but below PELs) in one or more samples from SR-SMITH (Table 4-10). There are no alkylated PAH guidelines, aside from that for 2-methylnaphthalene.

Table 4-10 Maximum PAH Concentrations in Suspended Sediment Samples Collected at HR-BORDER and SR-SMITH between 2013 and 2015 Compared to Sediment Quality Guidelines

Sampling Site	PAH Compound	Sediment Quality Guidelines		Maximum Concentration (µg/kg) dry weight							
		ISQG	PEL	Jul 2013	Aug 2013	Jun 2014	Jul 2014	Aug 2014	Jun 2015	Jul 2015	Aug 2015
HR-BORDER	2-methylnaphthalene	20.2	201	7.08	5.98	3.6	3.39	6.68	3.8	—	—
	Acenaphthene	6.71	88.9	0.393	2.53	1.81	1.68	2.62	1.42	—	—
	Acenaphthylene	5.87	128	0.393	0.088	0.084	0.081	0.989	0.051	—	—
	Anthracene	46.9	245	0.663	0.442	0.14	0.232	0.513	0.248	—	—
	Benz[a]anthracene	31.7	385	1.67	2.9	1.75	1.43	2.08	1.28	—	—
	Benzo[a]pyrene	31.9	782	4.14	5.06	3.49	3.22	4.23	2.5	—	—
	Chrysene	57.1	862	14.5	15.8	9.94	11.3	17.7	8.46	—	—
	Dibenz[a,h]anthracene	6.22	135	1.96	2.38	1.47	1.85	2.99	1.53	—	—
	Fluoranthene	111	2355	6.39	7.77	4.55	5.07	9.28	4.33	—	—
	Fluorene	21.2	144	3.01	2.29	1.18	1.44	2.76	1.65	—	—
	Naphthalene	34.6	391	2.7	2.79	1.99	1.9	3.62	1.98	—	—
	Phenanthrene	41.9	515	10.5	10.7	6.28	6.46	15.2	7.22	—	—
	Pyrene	53	875	11.5	12.8	8.15	7.81	12.2	5.89	—	—
SR-SMITH	2-methylnaphthalene	20.2	201	**151**	**80.2**	**90.2**	**53.6**	**58.3**	**164**	**154**	**83.1**
	Acenaphthene	6.71	88.9	6.3	3.36	2.76	2.26	2.27	3.58	3.88	2.89
	Acenaphthylene	5.87	128	0.255	0.186	0.139	0.118	0.11	0.136	0.191	0.153
	Anthracene	46.9	245	2.28	2.19	**66.7**	1.4	1.01	1.7	2.32	1.57
	Benz[a]anthracene	31.7	385	14.6	10.5	8.68	4.9	5.80	9.37	13.6	7.99

Table 4-10 Maximum PAH Concentrations in Suspended Sediment Samples Collected at HR-BORDER and SR-SMITH between 2013 and 2015 Compared to Sediment Quality Guidelines

Sampling Site	PAH Compound	Sediment Quality Guidelines		Maximum Concentration (µg/kg) dry weight							
		ISQG	PEL	Jul 2013	Aug 2013	Jun 2014	Jul 2014	Aug 2014	Jun 2015	Jul 2015	Aug 2015
SR-SMITH (con't)	Benzo[a]pyrene	31.9	782	21.5	14.4	10.3	7.22	7.28	9.91	12.1	12.2
	Chrysene	57.1	862	56	53.5	35	27.3	29.30	51.1	**65.3**	40.4
	Dibenz[a,h]anthracene	6.22	135	**8.61**	**6.92**	4.22	3.19	3.86	5.57	**7.34**	4.97
	Fluoranthene	111	2355	24.4	19.7	10.8	8.91	10.46	14.7	20.4	12.4
	Fluorene	21.2	144	21.1	11.5	9.08	6.4	7.76	15.9	**24**	8.98
	Naphthalene	34.6	391	**70.3**	31.9	**44.9**	25.1	27.4	**74.2**	**66**	**39.2**
	Phenanthrene	41.9	515	**106**	**82.6**	**69.1**	**42.7**	**51.4**	**125**	**140**	**72.3**
	Pyrene	53	875	40.8	33.9	21	15.7	16.8	24.9	31.3	22

NOTES:
The average concentrations of duplicate and triplicate samples are presented in this table.
Concentrations bold and underlined exceed the ISQG.
— = no sample collected

The risk of toxicity of PAHs to bottom-dwelling organisms can be assessed using an approach developed by the USEPA (USEPA 2003). This approach uses data for 18 parent and 16 alkylated PAHs, normalized for organic carbon content of the sediment, combined with information about their bioavailability, to calculate an equilibrium partitioning based sediment benchmark toxicity unit (ESB-TU). An ESB-TU greater than 1.0 is the threshold for predicting toxicity to benthic invertebrates. Data for the HR-BORDER sample with the highest total parent plus alkylated PAH concentration (July 2013) were used to calculate the ESB-TU. The result, 0.045, is well below the 1.0 threshold identified by the USEPA for toxicity effects on benthic invertebrates, and from this it can be assumed that levels of parent and alkylated PAHs present in Hay River water will not pose a toxicity risk to aquatic biota. A similar calculation made for a sample collected from SR-SMITH in September 2010 yielded an ESB-TU of 0.079, higher than for the Hay River, but also well below the toxicity threshold (AANDC 2012b).

4.3.3.4 Polyethylene Membrane Device Water Chemistry

Polyethylene membrane devices passively sample for dissolved hydrocarbons over time, allowing detection of very low concentrations of hydrocarbons in the river that could be missed in routine grab water sampling. The PMDs are installed within the top 2 m of the water column on a mooring and left for about 30 days. The samplers are analyzed for more than 40 parent and alkylated PAHs. For the Hay River program, HR-01 was sampled once in 2012, twice in 2013 and three times in 2014 (plus one duplicate), while HR-02, downstream at the mouth of the river, was sampled once in 2013 (Table 4-5). For the Slave River program, SMITH-01 was sampled once in 2012, five times in 2013, and three times in 2014 (plus one duplicate).

Total dissolved PAH concentrations ranged from 0.0037 µg/L to 0.0123 µg/L in samples from HR-01, and were higher in the Slave River, ranging from 0.0095 µg/L to 0.0214 µg/L at SMITH-01 (Table 4-11). These concentrations are on a per sample basis (entire exposure period, ranging from 14 to 40 days). At both sites, total dissolved PAH concentrations were higher in 2014 than in 2012 and 2013. Total dissolved PAH concentrations for all HR-01 PMD samples were below those measured in various northern Canadian rivers (0.015 µg/L; Yunker et al. 2002), and much lower than those that can affect fish health (0.4 µg/L; Carls et al. 1999). Although concentrations were higher in the SMITH-01 samples, these also were generally within the range reported for northern rivers, except in June 2014 (0.0214 µg/L) and August 2014 (0.0156 µg/L), and were well below concentrations that can affect fish health.

On one occasion, PMDs were deployed at both HR-01 and HR-02 (33 days, from June 19 to July 22, 2013) to evaluate spatial differences. Total PAH concentrations were higher at HR-02 (0.0119 µg/L) than HR-01 (0.0037 µg/L), but were still below levels of concern for fish health.

Table 4-11 Parent Versus Alkylated PAH Concentrations in PMD Samples Collected at the HR-01 and SMITH-01 Sites between 2012 and 2014

Sampling Site	Sampling Dates	Duration (days)	Concentration (µg/L)			% Parent
			Total Parent plus Alkylated PAHs	Total Parent PAHs	Total Alkylated PAHs	
HR-01	Aug 22 to Sep 25, 2012	33	0.0076	0.0027	0.0049	36%
	Jun 19 to Jul 22, 2013	33	0.0037	0.0006	0.0031	16%
	Jul 22 to Aug 27, 2013	35	0.0045	0.0014	0.0031	32%
	Jun 2 to Jun 24, 2014	22	0.0079	0.0055	0.0024	69%
	Jun 24 to Jul 28, 2014	34	0.0123	0.0093	0.0030	75%
	Jul 28 to Sep 8, 2014	40	0.0123	0.0047	0.0076	39%
SMITH-01	Sep 25 to Oct 25, 2012	30	0.0102	0.0019	0.0082	19%
	Jun 18 to Jul 10, 2013	22	0.0120	0.0014	0.0106	12%
	Jul 10 to Aug 13, 2013	33	0.0186	0.0042	0.0144	22%
	Aug 13 to Aug 27, 2013	14	0.0095	0.0025	0.0070	26%
	Aug 13 to Sep 10, 2013	27	0.0114	0.0021	0.0093	18%
	Sep 10 to Oct 9, 2013	29	0.0098	0.0013	0.0085	13%
	Jun 26 to Jul 24, 2014	28	0.0214	0.0134	0.0081	63%
	Jul 24 to Aug 20, 2014	26	0.0133	0.0070	0.0062	53%
	Aug 20 to Sep 24, 2014	34	0.0157	0.0116	0.0040	74%

NOTES:
The average concentrations of duplicate samples are presented in this table.
Full detection limits were used to calculate the total values when parameters were reported as less than the detection limits.

Parent versus alkylated PAH concentrations for the HR-01 and the SMITH-01 PMD samples were compared (Table 4-11). Samples collected in 2012 and 2013 had low proportions of parent PAHs (16 to 36% for HR-01 and 19 to 26% for SMITH-01) compared to alkylated PAHs, suggesting a petrogenic source (similar to results for surface water, centrifugate, and suspended sediment). Samples collected in 2014 had higher proportions of parent PAHs (69 and 75% in two samples from HR-01 and 53 to 74% in three samples from SMITH-01), suggesting a pyrogenic source. The higher concentrations of parent PAHs in 2014 samples from both rivers were due to naphthalene (up to 0.0072 µg/L at HR-01 and 0.0122 µg/L at SMITH-01).

Samples collected in 2014 differed from those collected in 2012 and 2013 for both the Hay River and Slave River samples, with higher amounts of naphthalene and of total parent plus alkylated PAHs in 2014. While this might be related to the high number of forest fires that occurred in northern Alberta and the Northwest Territories in 2014 (A. Czarnecki, pers. comm.), it is also possible that cross-contamination affected those samples. Field blanks and travel blanks analyzed at the same time as the PMD samples (Appendix B) had concentrations similar to or greater than the PMD samples collected in 2014, also associated with elevated naphthalene concentrations (up to 0.0114 µg/L in the SMITH-01 travel blank sample and up to 0.0065 µg/L in the HR-01 field blank sample, both in September 2014). This indicates how easily PAHs can be introduced in the field (e.g., cross-contamination in sampling equipment or from another source) or in the laboratory (laboratory blanks also contained measurable PAH concentrations), and the care needed from sample collection through data analysis.

4.3.4 Naphthenic Acids

Naphthenic acids are of interest because of their association with crude oil deposits and oil extraction activities (there are identified oil reserves in the Hay-Zama Lakes area; Section 7.2). They were occasionally analyzed in centrifugate and suspended sediment samples in 2011, 2012, and 2013, with concentrations generally less than their detection limits. In 2014 and 2015, naphthenic acids were analyzed using lower detection limits. When reporting the sum of all naphthenic acids (totals), the full detection limit was used for values reported as less than the detection limit.

Naphthenic acids tend to be soluble, and are expected to have higher concentrations in the water than the suspended sediment fraction. There are no water or sediment quality guidelines for naphthenic acids, and little information available about levels in suspended sediment. However, background concentrations of naphthenic acids in surface water are typically less than 1 mg/L (Headley and McMartin 2004).

4.3.4.1 Naphthenic Acids in Surface Water

Surface water samples from HR-BORDER were analyzed on two occasions (July and August 2015) because turbidity levels in the river were too low to collect centrifugate and suspended sediment (Table 4-5). Average detected concentrations of individual naphthenic acid in surface water samples (mean of July and August 2015 samples) ranged from 0.0052 µg/L ($C_{21}H_{36}O_2$) to 0.305 µg/L ($C_{20}H_{30}O_2$). Total naphthenic acid concentrations were 2.01 µg/L (compared to a total detection limit of 0.36 µg/L) for July 2015 and 1.36 µg/L (compared to a total detection limit of 0.30 µg/L) for August 2015.

4.3.4.2 Naphthenic Acids in Centrifugate Water

Centrifugate samples collected in June, July, and August 2014 at the HR-BORDER and SR-SMITH sites were analyzed for 60 individual naphthenic acids, along with two samples from SR-SMITH collected in July and August 2015 (Table 4-5). For quality assurance/quality control purposes, two field blank and five laboratory blank samples were analyzed (Appendix B).

Naphthenic acids were detected in all samples collected in 2014 and 2015. Concentrations were higher on average at SR-SMITH than HR-BORDER (Table 4-12). The maximum concentration for the sum of all naphthenic acids was 8.45 µg/L (compared to the sum of the DLs, 0.797 µg/L), reported for SR-SMITH in July 2014. The maximum concentration for HR-BORDER samples was also reported in July 2014, with a value of 2.07 µg/L (sum of the DLs = 0.488 µg/L).

Table 4-12 Comparison of the Sum of All Naphthenic Acid Congeners in Surface Water, Centrifugate Water, and Suspended Sediment Samples Collected From the HR-BORDER and SR-SMITH Sites between 2014 and 2015

Sampling Site	Sampling Date	Surface Water µg/L		Centrifugate Water µg/L		Suspended Sediment µg/kg	
		Sum of NAs[1]	Sum of DLs	Sum of NAs[1]	Sum of DLs	Sum of NAs[1]	Sum of DLs
HR-BORDER	Jun 2014	—	—	1.24	0.33	5,413	283
	Jul 2014	—	—	2.07	0.49	2,850	244
	Aug 2014	—	—	1.89	0.36	12,834	1,197
	Jul 2015	2.01	0.36	NS1	NS1	NS1	NS1
	Aug 2015	1.36	0.30	NS1	NS1	NS1	NS1
SR-SMITH	Jun 2014	—	—	6.40	0.42	3,976	328
	Jul 2014	—	—	8.45	0.80	3,101	159
	Aug 2014	—	—	2.75	0.29	7,717	3,192
	Jul 2015	—	—	1.86	0.30	NS2	NS2
	Aug 2015	—	—	1.59	0.30	NS2	NS2

NOTES:
NAs = naphthenic acids, DLs = detection limits
NS1 = no centrifugate or suspended sediment, insufficient turbidity to collect sample.
NS2 = no sample results available at the time of report preparation
[1] Where a concentration was reported as less than the DL the full DL was used to calculate the sum of all NA congeners. The sum of the DLs is included to provide context to the reported values.

Average concentrations for June to August 2014 (n = 3) for individual naphthenic acids were calculated for the HR-BORDER and SR-SMITH samples, and overall ranges were similar at the two sites. The HR-BORDER averages ranged from 0.0050 µg/L ($C_{21}H_{36}O_2$) to 0.222 µg/L ($C_{20}H_{30}O_2$), and the SR-SMITH averages ranged from 0.0049 µg/L ($C_{18}H_{34}O_2$) to 0.279 µg/L ($C_{18}H_{24}O_2$). However, the number of individual naphthenic acids detected was higher in the SR-SMITH samples (46 to 49 compounds of the 60 analyzed) than the HR-BORDER samples (28 to 30 compounds, resulting in the higher overall concentrations for the SR-SMITH samples.

4.3.4.3 Naphthenic Acids in Suspended Sediment

Suspended sediment samples were collected in June, July, and August 2014 at the HR-BORDER and SR-SMITH sites and analyzed for naphthenic acids (Table 4-5). Data were reported on a dry weight basis.

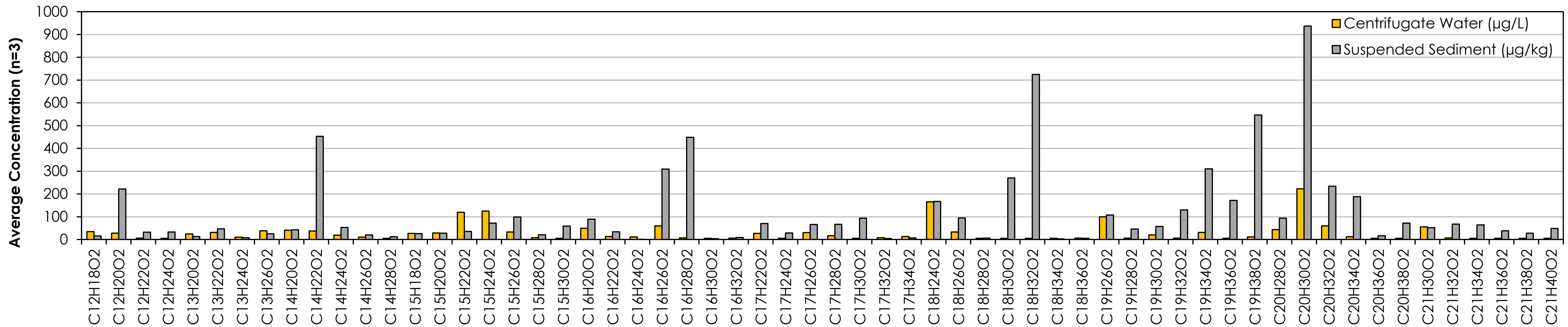
The sum of all individual naphthenic acids in suspended sediment was higher in samples from HR-BORDER (range of 2,850 to 12,834 µg/kg) than from SR-SMITH (3,101 to 7,717 µg/kg). At both sites, concentrations were highest in August 2014 and lowest in July 2014 (Table 4-12). The sums listed in the table include the full detection limit for all compounds reported as less than the detection limit, with the sum of the detection limits provided for comparison to measured values.

The average concentrations for June to August 2014 (n=3) for individual naphthenic acids were calculated (Table 4-12). The HR-BORDER averages ranged from 1.1 µg/kg ($C_{16}H_{24}O_2$) to 936.7 µg/kg ($C_{20}H_{30}O_2$). The SR-SMITH averages ranged from 0.82 µg/kg dw ($C_{18}H_{28}O_2$) to 489.1 µg/kg dw ($C_{18}H_{32}O_2$). The number of individual naphthenic acids detected was similar in the samples from SR_SMITH and HR-BORDER (43 to 48 compounds of the 60 analyzed).

Naphthenic acid concentrations were higher in suspended sediment than centrifugate samples at both the HR-BORDER and SR-SMITH sites, suggesting many of these compounds bind to particulate matter (Figure 4-8). In centrifugate, concentrations were higher in SR-SMITH than HR-BORDER samples, but in suspended sediment, they generally were lower in the SR-SMITH samples, which would not be expected, given their association with crude oil reserves and development activities (Table 4-12). Additional monitoring of naphthenic acids in both water and suspended sediment and comparison to total suspended sediment levels is recommended to understand the levels of these compounds in the different media of both rivers.

The types of naphthenic acids were similar in the two rivers. The highest average concentrations of individual naphthenic acids in suspended sediment samples were recorded for $C_{20}H_{30}O_2$, $C_{18}H_{32}O_2$, and $C_{19}H_{38}O_2$ for samples from both HR-BORDER and SR-SMITH (Figure 4-8). However, concentrations were notably higher in the HR-BORDER samples. In the centrifugate samples the highest average concentrations of naphthenic acids were recorded for $C_{20}H_{30}O_2$, $C_{18}H_{24}O_2$, and $C_{15}H_{24}O_2$ at both sites (Figure 4-8).

a) Hay River (HR-BORDER)



b) Slave River (SR-SMITH)

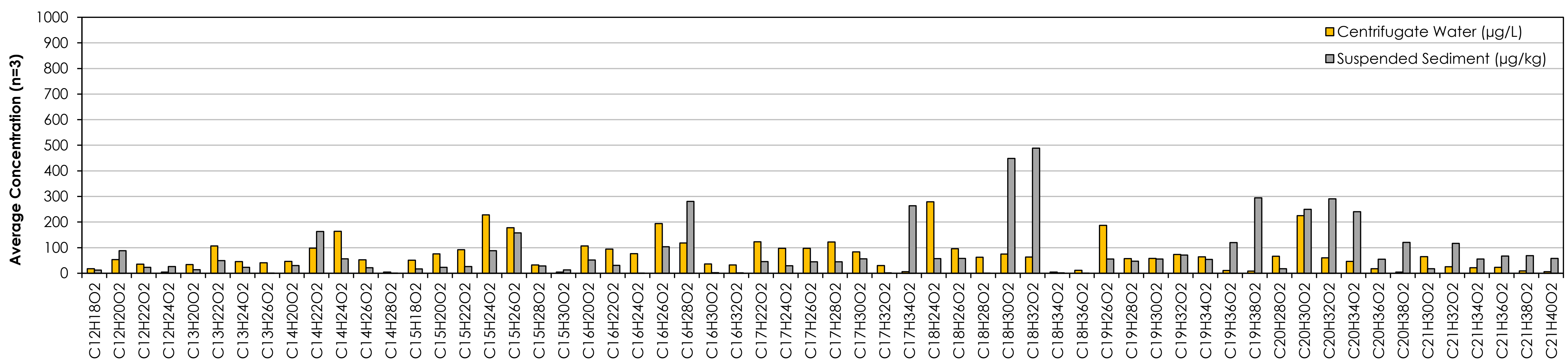


Figure 4-8 Average Naphthenic Acid Concentrations (June, July, August 2014; n=3) for Each Congener for the a) HR_BORDER and b) SR-SMITH Sites

4.3.5 Pesticides

Pesticides were analyzed in surface water, centrifugate, and suspended sediment samples, and similar compounds were detected in all three sample types. Up to 37 compounds were analyzed, including currently used (i.e., multi-residue) pesticides and those that have been banned for many years (e.g., organochlorines and other persistent organic pollutants). The majority of pesticides present are presumed to originate from long range transport from outside the Hay River Basin, given the low levels of activities in the basin that would use pesticides. Results were compared to CCME water and sediment quality guidelines, where available.

When dealing with parameters reported at or near the detection limit, it is particularly important to consider the accuracy of the measurements. Laboratory "accuracy" is measured as percent difference from the true value or certified target for reference materials and, for pesticide analyses, can range from 130% to150% (i.e., 30 to 50% higher than the true value). As a general rule, reporting limits (minimum concentration of an analyte that can be measured within specified limits of precision and accuracy) are 5 to 10 times the detection limit. Other potential complications include changing detection limits over time and potential cross-contamination in the field or laboratory (evident in the blanks). As a result, there is lower confidence in reported results that are close to the detection limit, and it is useful to simply report that trace amounts were detected. For this review, particular note is made of values at least 10 times higher than the detection limits.

4.3.5.1 Pesticides in Surface Water

At the HR-BORDER site, 28 water samples were collected for pesticide analysis: during May to September from 1994 to 2008, then once a year in May from 2009 to 2014, and in July and August 2015 (Table 4-5). Up to 37 compounds were analyzed in each sample, but some were analyzed on only one or two occasions. The majority of pesticides were below detection limits. In total, pesticides were detected in 8 of the 28 samples (Table 4-13).

For the organochlorine pesticides (historically used, banned for several years) detected in the samples, there are no CCME WQGs for protection of aquatic life for comparison; however, all except 2 compounds were present in low concentrations, less than 10 times their lowest detection limit. The exceptions were for hexachlorobenzene, in June 1999 (14 times higher than July 2003), and as the form gamma-benzenehexachloride in July 2003 (10 times higher than the detection limit). The maximum concentration of 0.00397 µg/L (June 1999) is well below the CCME WQG for livestock watering (0.52 µg/L; CCME 1999c) and preliminary guidance provided by the USEPA ("does not cause significant adverse effects on the survival, growth, and reproduction of freshwater aquatic life at or below the water solubility limit of approximately 6 µg/L" (USEPA 1994). Hexachlorobenzenes were used mainly as fungicides, notably on wheat seeds, until they were banned. In 2015, laboratory blanks were also analyzed each month and a field blank was analyzed. All compounds in the laboratory blanks were reported as below their detection limits.

Table 4-13 Detectable Organochlorine Pesticide Compounds in Surface Water Samples Collected at the HR-BORDER between 1994 and 2015

Sample Date	Concentration (µg/L)			
	1,3-dichlorobenzene (LDL not listed)	**Alpha-benzenehexachloride (LDL = 0.0002)**	**Gamma-benzenehexachloride (LDL = 0.00015)**	**Hexachlorobenzene (LDL = 0.00029**
May 1997	0.00534	—	—	—
Jun 1999	—	—	—	0.00397
Jul 1999	—	—	0.00134	—
Sep 1999	—	0.00024	0.00144	—
May 2000	—	—	0.00045	—
Sep 2002	—	—	0.00075	—
Jul 2003	—	—	0.00157	—

NOTES:
— = not detected/not sampled
LDL = lowest detection limit

Surface water samples, were collected at the HR-BORDER site in July (one sample) and August 2015 (triplicate samples), and analyzed for multi-residue, i.e., current-use, pesticides. No comparable samples were collected from the Slave River. Laboratory blanks analyzed in both months did not show detectable pesticides, except for MCPA (2-methyl-4-chlorophenoxyacetic acid) in August 2015 (0.154 ng/L; three times the detection limit). Triclopyr (herbicide and fungicide), MCPA (herbicide), and 2,4,5-T (herbicide) were detected in surface water samples at levels greater than 10 times their detection limit on the two dates sampled (Table 4-14).

Table 4-14 Detectable Current-use Pesticides in Surface Water Samples Collected at the HR-BORDER and SR-SMITH Sites between June 2014 and August 2015

Sampling Site	Pesticide Compound	Maximum Concentration (µg/L)	
		Jul 2015	**Aug 2015**
HR-BORDER	MCPA	0.00170	0.00073
	Triclopyr	0.00081	0.00130
	2,4,5-T	<0.000056	0.00036

NOTE:
August 2015 data are means of triplicate samples

Toxaphene was analyzed in surface samples collected in July and August 2015. All results for HR-BORDER, SR-SMITH, and laboratory blanks were below the detection limits.

Pesticides were also analyzed in surface water from SR-SMITH from 1979 to 2010. In the majority of samples, pesticides were below detection limits. A few pesticides were close to their detection limit on one or two occasions. The exception was alpha-benzenehexachloride (29 of 56 samples, up to eight times higher than the detection limit). This compound was not detected from 2004 onwards even after the detection limit was lowered from 0.001 µg/L to 0.0002 µg/L.

4.3.5.2 Pesticides in Centrifugate Water

Centrifugate water samples were collected at the HR-BORDER station in July and August 2013 and at the HR-BORDER and SR-SMITH stations in June 2014 and June, July and August 2015 and analyzed for pesticides (Table 4-5). From 2014 onwards, laboratory blanks were analyzed each month that a field sample was analyzed. All pesticides in the field and laboratory blanks were reported as non-detectable (Appendix B). Results are presented in Table 4-15.

Table 4-15 Detectable Pesticides in Centrifugate Samples Collected at the HR-BORDER and SR-SMITH sites between June 2014 and August 2015

Sampling Sites	Pesticide Compound	Maximum Concentration (µg/L)					
		Jun 2014	Jul 2014	Aug 2014	Jun 2015	Jul 2015	Aug 2015
HR-BORDER	Dicamba	—	0.00012	—	—	—	—
	Hexachlorobenzene	—	0.00002	0.00007	—	—	—
	MCPA	0.00137	0.00262	0.00147	0.00135	0.00170	0.00107
	Triclopyr	0.00041	0.00039	0.00016	0.00064	0.00081	0.0013
SR-SMITH	2,4-D	—	0.00134	0.00058	—	—	—
	Aldrin	—	—	0.00014	—	—	—
	Chlorothalonil	—	0.00016	—	—	—	—
	Dicamba	0.00010	—	—	—	0.00006	—
	Hexachlorobenzene	—	0.00002	0.00019	—	—	—
	MCPA	0.00099	0.00173	0.00064	0.00044	—	—
	MCPP	0.00021	—	—	—	—	—
	Triclopyr	0.00073	0.00037	0.00053	—	0.00036	0.000058

NOTES:
The average concentrations of triplicate samples are presented in this table.
— = not detected/not sampled

Multi-residue and organochlorine pesticides were analyzed in samples collected from both sites in 2014 and 2015. Similar to surface water samples, most were recorded as below detection limits. The exceptions were dicamba, MCPP (methylchlorophenoxypropionic acid), MCPA, and triclopyr, and occasionally chlorothalonil and the banned pesticides hexachlorobenzene and aldrin, typically present at less than 10 times their detection limits (Table 4-15). Pesticides reported at more than 10 times the detection limit were MCPA (twice at HR-BORDER and twice at SR-SMITH; ranging from 0.00099 to 0.00137 μg/L) and triclopyr (one occasion; SR-SMITH in June 2014; 0.00073 μg/L). All multi-residue pesticides were well below applicable CCME WQGs.

4.3.5.3 Pesticides in Suspended Sediment

Between 1995 and 2013, 13 suspended sediment and 3 field duplicate samples were collected at the HR-BORDER site for pesticide analysis (Table 4-5). Laboratory detection limits were lower in 2011 to 2013 compared to previous years. Concentrations are reported on a dry weight basis. All concentrations were recorded as below detection limits except for the herbicide triallate (23.1 μg/kg) in July 2012. There are no CCME sediment quality guidelines for the detected pesticides that can be used for comparison.

Multi-residue (current-use) pesticides were analyzed in the June, July, and August 2014 samples at the HR-BORDER and SR-SMITH sites (Table 4-16):

- The majority of pesticides in samples from both sites were recorded as below detection limits.
- Dicamba, MCPP, and triclopyr were present at less than 10 times their detection limit in some samples.
- MCPA was present at more than 10 times the detection limit in June 2014 at HR-BORDER (0.568 μg/kg dw; 27 times the detection limit); this value was associated with detectable levels in the laboratory blank (2.37 μg/kg), suggesting cross-contamination in the analysis of the field sample.
- Hexachlorobenzene was present at more than 10 times the detection limit in July and August 2014 at HR-BORDER and SR-SMITH (up to 0.105 μg/kg dw; 26 times the detection limit).
- Concentrations were similar in samples from HR-BORDER and SR-SMITH, except for MCPA (higher at HR-BORDER in all months sampled).

Toxaphene was analyzed in suspended sediment samples collected in June 2014 and June 2015. All results for HR-BORDER, SR-SMITH, and laboratory blanks were below the detection limits.

Table 4-16 Detectable Pesticide Compounds in Suspended Sediment Samples Collected at HR-BORDER and SR-SMITH in June, July, and August 2014

Sampling Site	Pesticide Compound	Maximum Concentration (μg/kg)		
		Jun 2014	Jul 2014	Aug 2014
HR-BORDER	Dicamba	0.028	—	—
	Hexachlorobenzene	—	0.051	0.105
	MCPA	0.568	0.118	0.454
	MCPP	0.044	0.043	0.28
	Triclopyr	0.021	—	—

Table 4-16 Detectable Pesticide Compounds in Suspended Sediment Samples Collected at HR-BORDER and SR-SMITH in June, July, and August 2014

Sampling Site	Pesticide Compound	Maximum Concentration (µg/kg)		
		Jun 2014	Jul 2014	Aug 2014
SR-SMITH	Dicamba	0.022	—	0.051
	Hexachlorobenzene	—	0.045	0.052
	MCPA	0.17	0.091	0.226
	MCPP	—	0.051	—
	Triclopyr	0.065	—	—

NOTES:
The average concentrations of triplicate samples are presented in this table.
— = not detected/not sampled

4.3.6 Polychlorinated Biphenyls

Surface water, centrifugate and suspended sediment samples were analyzed for PCBs. There are no CCME WQGs for PCBs as aquatic exposure is predominantly via sediment. Results for suspended sediment were compared to CCME guidelines for Aroclor 1254 (ISQG = 60 µg/kg and PEL = 340 µg/kg) and total PCBs (ISQG = 34.1 µg/kg and PEL = 227 µg/kg). Typically, the laboratory reported results for PCB Aroclor mixtures and for total PCB in both water and suspended sediment samples; however, the 2015 samples were also analyzed for numerous individual PCB congeners using ultralow detection limits.

4.3.6.1 PCBs in Surface Water

Between 1994 and 2007, nine samples collected at the HR-BORDER site were analyzed for total PCBs (Table 4-5). In seven of the nine samples, all parameters were reported as non-detects, with detection limits ranging from 0.00021 µg/L to 0.0219 µg/L. The two samples with detectable levels of total PCBs (0.011 µg/L and 0.0127 µg/L) were collected in 1994. Although local and atmospheric sources of PCBs are possible, contamination from the laboratory is most likely, given that PCBs had not been detected in any water samples collected since 1994 (AANDC, 2014). PCBs analyzed from 2005 to 2010 in samples collected at the SLAVE-FITZ site had concentrations below detection limits (detection limits ranged from 0.00021 µg/L to 0.00034 µg/L).

In July and August 2015, two surface water samples collected at the HR-BORDER site were analyzed for PCBs using ultra-low detection limits (highest detection limit was 8.88 pg/L or 0.0000088 µg/L). The following compounds were recorded at greater than 10 times their detection limits: Aroclor 1242 and 3'-dichlorobiphenyl (DiCB) in July, and Aroclor 1242, 3'-DiCB and 2,2',5,5'-tetrachlorobiphenyl (TeCB) in August 2015.

4.3.6.2 PCBs in Centrifugate Water

In July and August 2014, PCBs were analyzed in centrifugate samples collected at the HR-BORDER site (Table 4-5). All congeners were recorded as less than their detection limits, with detection limits ranging from 0.01 µg/L to 0.05 µg/L.

In June 2015, HR-BORDER was sampled, and analyzed for a larger suite of PCB congeners at ultra-low concentrations (note: reported in picograms instead of micrograms [1 pg = 0.000001 µg]). Results were compared to those for triplicate samples collected in June at SR-SMITH. Most of the PCBs were reported as non-detects, except for those listed in Table 4-17. Similar levels of Aroclor 1242 and 3,3'-DiCB were detected at both sites and in the laboratory blank (Appendix B), suggesting cross-contamination in the laboratory. Aroclor 1254, Aroclor 1260 and 2,4-DiCB were also detected at both sites (but not in laboratory blanks). In general, the types and concentrations of detectable PCBs were similar at both sites. The total PCB concentration was 289 pg/L at HR-BORDER and 506 pg/L at SR-SMITH (mean of triplicates).

Table 4-17 Detectable PCB Compounds in Centrifugate Water Samples Collected at the HR-BORDER and SR-SMITH Sites in June 2015

PCB Compound	Maximum Concentration (pg/L)	
	HR-BORDER	SR-SMITH[1]
2,4- Dichlorobiphenyl (DiCB)	—	38.4
3,3'- Dichlorobiphenyl (DiCB)	60.5	62.8
Aroclor 1242	152	178
Aroclor 1254	74.6	156
Aroclor 1260	9.4	68.1
Decachlorobiphenyl	1.6	—
TOTAL PCBs	289	506

NOTES:
— = not detected/not sampled
1. Mean of triplicate samples

4.3.6.3 PCBs in Suspended Sediment

Between 1995 and 2014, 12 suspended sediment samples were collected at HR-BORDER and analyzed for Aroclors and total PCBs. All concentrations were recorded as below detection limits, which ranged from 0.01 µg/kg to 0.148 µg/kg. Aroclor 1254 and total PCB concentrations were considerably lower than their CCME ISQGs. Results are reported on a dry weight basis.

In June 2015, one sample was collected at HR-BORDER and analyzed for a larger suite of PCBs at ultra-low concentrations. Results were compared to those obtained in June at SR-SMITH. A laboratory blank was also analyzed (Appendix B). The majority of PCBs had concentrations below the detection limit, with the exception of those listed in Table 4-18. Aroclor 1242 and Aroclor 1260 were detected in samples from both sites and in the laboratory blank (lower in the blank). 3,3'-DiCB was detected in the two river samples and the laboratory blank; concentrations were three times higher in the HR-BORDER sample than in the SR-SMITH and blank samples (suggesting some cross-contamination in the laboratory). The total PCB concentration was higher at HR-BORDER (108 pg/g dw) than at SR-SMITH (56.3 pg/g dw) and many orders of magnitude below the CCME ISQG (34.1 µg/kg or 34,100,000 pg/g).

Table 4-18 Detectable PCB Compounds in Suspended Sediment Samples Collected at the HR-BORDER and SR-SMITH Sites in June 2015

PCB Compound	Maximum Concentration (pg/kg)	
	HR-BORDER	SR-SMITH[1]
3,3'-Dichlorobiphenyl (DiCB)	19.7	5.74
Aroclor 1242	46.8	21.1
Aroclor 1254	10.3	19.2
Aroclor 1260	—	4.24
Decachlorobiphenyl	0.44	0.266
TOTAL PCBs	108	56.3

NOTES:
— = not detected/not sampled
1. Mean of triplicate samples

4.3.7 Others Contaminants

Emerging contaminants of concern were analyzed from time to time in surface water, centrifugate, and suspended sediment samples in 2014 and 2015. Results were generally lower than detection limits.

Perfluorocarbons were measured in suspended sediment and centrifugate samples at HR-BORDER, SR-SMITH, and in laboratory blanks in June 2015. Samples were analyzed for 13 compounds. With the exception of trace concentrations of perfluorobutanoic acid (PFBA, 4.35 ng/L, at less than two times the detection limit), all perfluorocarbons were reported as below the detection limits. At this time, there are no CCME WQGs for perfluorocarbons.

Poly-brominated diphenyl ethers (PBDEs) were also measured in suspended sediment and centrifugate samples at HR-BORDER, SR-SMITH, and in laboratory blanks in June 2015. Samples were analyzed for 46 compounds. Concentrations of all PBDE compounds were below the detection limit in all samples and laboratory blanks.

4.3.8 Summary for Organic Contaminants

The organic contaminant data reflect low concentrations in surface water, centrifugate, and suspended sediment samples at HR-BORDER, below any applicable water and sediment guidelines and not indicating concerns for aquatic biota. Concentrations of pesticides and PCBs reflect mainly long range transport from sources outside the Hay River Basin, whereas concentrations of PAHs and naphthenic acids appear to reflect background sources in the basin (natural and from human activities) and, for PAHs, some long range transport sources.

Over time, decreasing detection limits and increasingly complex analytical tools have produced a more detailed understanding of the status of PAHs, pesticides, PCBs and other contaminants. However, these analytical changes make it challenging to identify any increasing or decreasing trends over time. Also, with use of more sensitive analytical tools comes greater potential for interference from other sources of contaminants in the field or the laboratory that can confound the interpretation of the results. Even a blank, which is intended to be pure water, can become contaminated during sample collection, transport, or analysis.

The PAH concentrations in surface water were low, with many compounds below even the ultra-low detection limits used in 2013 to 2015. Concentrations of individual parent PAHs were 3 to 300 times lower than their CCME WQGs. Naphthalene was the most commonly reported and most abundant parent PAH in water; this low molecular weight PAH has high solubility in water. Alkylated PAHs were present, typically in higher proportions than parent PAHs. There are no CCME WQGs for alkylated PAHs for comparison, but concentrations were lower than those reported for the Slave River which were also low.

The use of centrifuged samples to separate suspended sediment from water provided additional information, given that many PAHs bind to particles. The PAH concentrations in centrifugate samples were similar to those for surface grab samples. The suspended sediments contained low concentrations of parent PAHs compared to CCME ISQGs (with no suspended sediment guidelines, benthic sediment guidelines were used). The risk of toxicity of parent and alkylated PAHs to aquatic biota in the Hay River was predicted to be low using an analytical tool developed by the USEPA (a calculated ESP-TU of 0.045 for the suspended sediment sample with the highest total PAH content, compared to a threshold value of 1.0). Proportions of alkylated PAHs were higher than those of parent PAHs.

Samples obtained using a passive PMD left in the river for up to 30 days provided an indication of longer term presence and concentrations of PAHs, which might otherwise be missed in grab samples. Total dissolved PAH concentrations for all HAY-01 PMD samples were below those measured in various northern Canadian rivers (0.015 µg/L; Yunkers et al. 2002), and much lower than those that can affect fish health. Although concentrations were higher in the SMITH-01 samples, these also were generally within the range reported for northern rivers. Samples collected in 2012 and 2013 had higher proportions of alkylated PAHs, as noted for surface water samples, but those collected in 2014 had higher proportions of parent PAHs. These differences were attributed to possible cross-contamination in 2014 (elevated parent PAHs, particularly naphthalene, in field blanks) and possible influence of forest fires in the area in 2014.

Samples of all types (e.g., surface water, centrifugate water, PMD water, suspended sediment) collected from the Slave River (SR-SMITH) generally had higher PAH concentrations compared to those from HR-BORDER, as would be expected for a river with large natural oil deposits, and associated developments, upstream. In surface water samples from the Slave River, parent PAH concentrations were lower than the CCME WQGs; however, in some suspended sediment samples, some parent PAHs were higher than the ISQGs (but below the PELs).

The concentrations of PAHs at HR-BORDER appear to reflect a natural background presence, with the higher proportions of alkylated than parent PAHs in both water and suspended sediment suggesting a petrogenic (petroleum) rather than a pyrogenic (combustion) source. This may be related to natural hydrocarbon sources in the Hay River Basin (e.g., the identified oil reserves in the Hay-Zama Lakes area; Section 7.2), which could be investigated using additional fingerprinting tools (ratios and indices for specific PAHs). Data for the suspended sediment fractions will be most useful for examining sources of PAHs, given that these samples are concentrated and that the majority of PAHs have low solubility.

Naphthenic acids were measurable in all samples collected from HR-BORDER in 2014 and 2015. There are no CCME WQGs for naphthenic acids; however, concentrations in water were low compared to levels identified in the literature as posing a risk to aquatic biota. In centrifugate samples, the total concentration of naphthenic acids was lower in samples from HR-BORDER than SR-SMITH; while concentrations of specific compounds were similar in the two rivers, there were many more detected compounds in the SR-SMITH samples. This might be expected, given the higher amounts of upstream oil reserves and activities in the Slave River watershed. In suspended sediment samples, however, the total concentration of naphthenic acids was greater in samples from HR-BORDER than SR-SMITH, which is counter-intuitive which highlights that continued monitoring is important to understand these relationships further.

There were measurable concentrations of current use (multi-residue) and banned organochlorine pesticides in some surface water, centrifugate, and suspended sediment samples collected from HR-BORDER. The majority of pesticides were not detectable and those that were detected were present in low levels, well below any associated CCME WQGs for protection of aquatic life. Given the low levels of agricultural activity and pesticide use in the Hay River Basin, these concentrations reflect mainly long range transport from sources beyond the basin. Ultra-low detection limits used in the analysis of samples collected in 2014 and 2015 confirmed that trace levels of some pesticides were present, notably MCPA, triclopyr, and hexachlorobenzene. Similar results were reported for samples from SR-SMITH.

Concentrations of PCBs were low or not detectable in samples of surface water, centrifugate, and suspended sediment. Use of PCBs has been banned for several decades, and their presence reflects long-range transport from sources beyond the Hay River Basin. Because PCBs have low solubility in water, they are most reliably sampled in bottom (or benthic) sediment or suspended sediment. Concentrations of total PCBs in the suspended sediment samples were well below the CCME ISQG. Although several PCB congeners were detected in the lab blank from the 2015 Hay River suspended sediment sample, the values (levels) were below the established acceptance criteria for this analytical method. Samples from SR-SMITH had low or non-detectable levels of PCBs similar to those reported for HR-BORDER.

Concentrations of perfluorocarbon and PBDE compounds are not currently of concern and were near or below the detection limits in samples from HR-BORDER and SR-SMITH.

5.0 AMBIENT AQUATIC ECOSYSTEM CONDITION

The Hay River Basin provides extensive habitat for aquatic biota and for wildlife that depend on aquatic habitat. Fish provide commercial, recreational, and subsistence resources. Numerous wetlands provide habitat for migratory birds and other wildlife. Many of the aquatic wildlife species also have significant cultural value for local Indigenous people (e.g., furbearers for trapping, moose and waterfowl as a food source).

Section 5.1 describes information about aquatic biota (plankton, benthic invertebrates and macrophytes), fish and fish habitat, and aquatic wildlife in the basin. Section 5.2 describes contaminant levels in fish tissue, from studies conducted in the late 1980s and early 1990s.

5.1 CURRENT CONDITIONS

Few aquatic habitat surveys have been conducted in lakes and watercourses in any of the sub-basins and, aside from some fish surveys, none have been reported for the Hay River itself. Within the Alberta portion of the basin, a study conducted 10 years ago concluded there were insufficient data on non-fish biota for an assessment of Basin health (North/South Consultants Inc. 2007), and little new information has been obtained since (C. Sherburne, pers. comm.). In the portions of the basin within British Columbia and the Northwest Territories, even less information is available. Although information may have been collected for individual projects or permit applications, there do not appear to be provincial or territorial databases that store such information for public access.

5.1.1 Community Structure

5.1.1.1 Plankton

Plankton are microscopic plants (phytoplankton), animals (zooplankton), and bacteria that live in the water column of lakes and rivers. Phytoplankton are the primary producers, and include algae and cyanobacteria. They form the base of the aquatic food chain and can provide information about trophic (nutrient) status and stressors on the aquatic ecosystem. Zooplankton are the secondary producers. They consume plankton or organic matter, and in turn are consumed by larger organisms, including fish. Composition of the plankton community changes throughout the growing season in response to changing light, temperature, nutrient regimes, and food availability (Blomqvist et al. 1994).

Information on plankton communities in the Hay River Basin is sparse. A 1992 study of Hutch Lake, an impoundment in the Alberta portion of the Lower Hay sub-basin, reported a mean chlorophyll a concentration of 17.9 µg/L (mean of three sampling events during summer) (North/South Consultants Inc. 2007). An August 1975 survey of Rainbow Lake, in the Alberta portion of the Upper Hay sub-basin, indicated a variety of phytoplankton species, predominantly the cyanobacterium *Aphanizomenon flos-aquae* (Walty 1976), a species typical of lakes with adequate to high nutrient supply (Ferber et al. 2004). High abundance of cyanobacteria in the summer is typical in waterbodies of the Boreal Plains (which includes a portion of the Chinchaga sub-basin) (Zhang and Prepas 1996) compared to the Boreal Shield (Planas et al. 2000). The 1975 Rainbow Lake study identified common zooplankton groups such as rotifers (*Keratella* sp.), daphids (*Daphnia* sp.), and copepods (*Calanoida* sp.) (Walty 1976), which are commonly reported in North American lakes (Gliwicz 2003).

5.1.1.2 Benthic Invertebrates

Benthic invertebrates in both lakes and watercourses are secondary producers, feeding on algae, organic matter, or other invertebrates, and providing food for fish and wildlife. They are good indicators of environmental conditions and stressors, as they have been well-studied.

There is little information available about benthic invertebrate communities in the Hay River. Environment Canada sampled erosional (flowing) habitat in the Hay River West Channel, near the Town of Hay River, Northwest Territories, in August 2015 using the Canadian Aquatic Biomonitoring Network (CABIN) protocols (Environment Canada 2016; P. Redvers, pers. comm.). Data were unavailable at the date of this report, but are expected to form a good monitoring baseline and provide an assessment of conditions in the lower Hay River.

Elsewhere in the basin, four studies were identified, two for Alberta streams, one for an Alberta lake, and one for a British Columbia lake (data summarized in Table 5-1). These studies primarily reported on species presence and abundance, but did not comment on other aspects of community structure (e.g., diversity and evenness).

Table 5-1 Benthic Invertebrates Reported in the Hay River Basin

Sampling Location	Major Taxa Identified	Location[1]
Upper Hay Sub-basin, Alberta August and September 1973 (Griffiths and Ferster 1974)		
Melvin River	Ephemeroptera, Plecoptera, Diptera, Hemiptera (Cordidae)	16-117-21-W5
Slavey Creek	Ephemeroptera, Plecoptera, Diptera, Trichoptera	22-117-21-W5
Little Rapids Creek	Ephemeroptera, Plecoptera, Diptera, Trichoptera	19-116-15-W5
James Creek	Ephemeroptera, Plecoptera, Diptera, Trichoptera, Annelida (Hirudinea), Coleoptera, Mollusca (Bivalvia)	14-119-13-W5 04-120-14-W5 13-121-16-W5 10-124-17-W5
Amber River	Ephemeroptera, Plecoptera, Diptera, Trichoptera, Annelida (Hirudinea), Crustacea (Amphipoda)	13-117-08-W6
Steen River	Ephemeroptera, Plecoptera, Diptera, Trichoptera, Annelida (Hirudinea, Naididae), Coleoptera, Mollusca (Gastropoda), Crustacea (Amphipoda, Hemiptera (Gerridae), Ondonata	21-119-02-W6 26-19-22-W5 08-122-19-W5
Jackpot Creek	Ephemeroptera, Plecoptera, Diptera, Trichoptera, Annelida (Oligochaeta), Mollusca (Gastropoda), Hemiptera (Gerridae), Nematoda	01-124-22-W5 28-126-20-W5 06-126-19-W5

Table 5-1 Benthic Invertebrates Reported in the Hay River Basin

Sampling Location	Major Taxa Identified	Location[1]
Lower Hay sub-basin, Alberta, August 1975 (Walty 1976)		
Rainbow Lake (water depths to 10 m)	Crustacea (Amphipoda), Diptera (Chironomidae, Ceratopogonidae, Chaoboridae),Annelida (Hirudinea, Oligochaeta), Nematoda, Mollusca (Bivalvia, Gastropoda)	107-08-W6
Upper Hay sub-basin, British Columbia, August 1982, (Coombes and Jesson 1982)		
Kotcho Lake (shoreline habitat)	Crustacea (Amphipoda), Odonata, Mollusca (Gastropoda), Annelida (Hirudinea), Coleoptera	59° 3' 58" N 121° 9' 0" W
Chinchaga sub-basin, Alberta, late May-early June 2011 (Alberta Environment and Parks 2015c)		
Weirnuk Creek	Plecoptera, Diptera (incl. Chironomidae), Trichoptera, Hemiptera, Annelida (Hirudinea)	57° 13' 38" N 119° 35' 10" W
Unnamed Tributary	Trichoptera, Coleoptera	57° 12' 58" N 119° 3' 40" W

NOTE:

[1] Sampling locations from Griffiths and Fersters (1974) and Walty (1976) are reported using the Alberta legal land description (i.e., section, township, range and meridian). Sampling locations from Coombes and Jesson (1982) and AEP (2015) are reported in latitude and longitude (degrees, minutes, seconds).

Stream surveys were conducted by Griffiths and Ferster (1974) and Alberta Environment and Parks (2015c). The most comprehensive dataset for benthic invertebrates in the Basin is that provided by Griffiths and Ferster (1974), who conducted surveys of seven streams In August and September 1973 to assess fisheries potential. The streams were located in the Upper Hay and Lower Hay sub-basins within Alberta. Benthic invertebrate taxa typical of unpolluted/undisturbed conditions in erosional habitat (Mandeville 2002) were present. These included larvae of mayflies (*Ephemeroptera*), stoneflies (*Plecoptera*), caddisflies (*Trichoptera*), dragonflies (*Ondonata*), and true bugs (*Hemiptera*), as well as true flies (*Diptera*, including *chironomids*), leeches (*Hirudinea*), molluscs (bivalves and gastropods), and amphipods (see Table 5-1). From an Arctic grayling (*Thymallus arcticus*) assessment of two creeks in the Chinchaga sub-basin within Alberta (Werniuk Creek and a nearby unnamed tributary), conducted in late May and early June 2011, the presence of stoneflies, caddisflies, true bugs, leeches, and true flies, including chironomids, was reported (Alberta Environment and Parks 2015c).

Lake surveys were conducted by Walty (1976) and Coombes and Jesson (1982). The survey of Rainbow Lake (Upper Hay sub-basin in Alberta) conducted in August 1975 included benthic invertebrate sampling at various depths in the lake; results are considered typical of lake sediments (RAMP 2016a). Amphipods (*Crustacea*) and non-biting midges (*Chironomidae, Diptera*) were the dominant taxa in waters 1.5 to 3 m deep; chironomids and pea clams (*Sphaeridae*) were typically the dominant taxa below 3 m deep; and aquatic worms (*Oligochaeta*) became common below 8 m (Walty 1976). Leeches (*Hirudinae*) and nematodes (*Nematoda*) were present in waters up to 3 m deep, and biting midges (*Ceratopogoniidae*) were present in waters up to 4.5 m depth. Phantom midges (*Chaoboridae*) and snails

(*Valvatidae*) were present at various depths in the lake. At Kotcho Lake, in the Upper Hay sub-basin in British Columbia, an August 1982 survey of littoral (shoreline) habitat indicated the presence of gastropods (snails), leeches, amphipods, water beetles, and dragonfly larvae (Coombes and Jesson 1982), which are typically found in nearshore areas.

5.1.1.3 Macrophytes

Aquatic macrophytes (vascular plants) are common in shoreline areas of lakes and slow-moving watercourses, and provide valuable habitat for benthic invertebrates and fish. Information on macrophyte presence in the Hay River Basin is scarce, and was provided in two studies.

The August 1982 survey of Kotcho Lake, in the British Columbia portion of the Upper Hay sub-basin, listed nine macrophyte species in the shoreline area (Coombes and Jesson 1982). These were pond weed (*Potamogeton* spp., *P. richardsonii*, *P. amphibium*,), variegated pond-lily (*Nuphar variegatum*), bur-reed (*Sparganium* spp.), common spike-rush (*Eleocharis palustris*), mare's-tail (*Hippuris vulgaris*), water parsnip (*Sium sauve*), and water milfoil (*Myriophyllum exalbescens*). These are common species in lakes of the northern boreal forest (Archibold 2007)

Wallis (1995) delineated vegetation community types in the Hay-Zama wetland complex (Upper Hay sub-basin in Alberta) in efforts to define the boundaries of lakes, river channels, and levees (elevated channel belts formed by sediment deposits). Community types are listed in Table 5-2.

Table 5-2 Aquatic vegetation community types in the Hay-Zama Wetland Complex

Habitat Type		Aquatic Vegetation Community
Lakes	Around the periphery of large ephemeral lake basins	Sedge/yellow cress-small bedstraw
	In the central part of large ephemeral lake basins	Water smartweed-bulrush-water foxtail
	In frequently flooded lake basins and small wetlands with high water tables	Cattail-bulrush-sedge
River Channels and Levees	On fluvial deposits along river channels and floodplains	Aspen-balsam poplar/red osier-willow/dewberry-horsetail
SOURCE: Wallis (1995)		

5.1.1.4 Fish and Fish Habitat

Fish are common in the lakes and watercourses of the Hay River Basin. Several species are of commercial, recreational, and/or of Aboriginal importance for traditional subsistence purposes. Forage species (small minnows, dace, and shiners) provide food for other fish and for wildlife.

There is little information available about fish distribution and movement in the Hay River Basin (Hatfield 2009). However, studies conducted by Nelson and Paetz (1992), McPhail et al. (1998), Stewart and Low (2000), Alberta Environment and Parks (2015c), and Government of British Columbia (2016a) provide information about species presence in lakes and watercourses in the three sub-basins.

The list of 26 fish species includes 8 species considered to be of management concern in at least one of the jurisdictions of the basin, but does not include species listed federally under the *Species at Risk Act* (Table 5-3). The species of management concern are Arctic grayling (*Thymallus arcticus*), walleye (*Sander vitreus*), inconnu (*Stenodus leucichthys*), lake trout (*Salvelinus namaycush*), pearl dace (*Margariscus margarita*), northern redbelly dace (*Phoxinus eos*), cisco (*Coregonus artedi*), and spottail shiner (*Notropis hudsonius*).

The number of identified fish species is lowest in the Chinchaga sub-basin (14 species) and highest in the Lower Hay sub-basin (22 species). Four species present in the Lower Hay are not reported in the Upper Hay sub-basin (Table 5-3), possibly due to differences in habitat and to barriers to fish movement (McPhail et al. 1998). Two impassible barriers (the Louise and Alexandra falls), 32 km upstream from Great Slave Lake, isolate the lower river from the upper reaches. Below the falls, the river has been colonized by species travelling upstream from Great Slave Lake, including chum salmon (*Onchorhynchus keta*), Arctic lamprey (*Lampetra japonica*), inconnu, and lake trout (Stewart and Low 2000; McPhail et al. 1998). These species spawn in the Hay River and return to rear in Great Slave Lake (Nursall and Buchwald 1972). Inconnu are considered a rare visitor in the Hay River; chum salmon are known to travel from the Mackenzie River to the Hay River during the fall spawning migration (Stewart and Low 2000). In October 2015, a local fisherman caught a chum salmon in the lower Hay River (Fabien 2015).

A 1997 survey of 18 lakes and 3 rivers (Little Buffalo, Shekilie, and Kotcho Rivers) in the Upper Hay sub-basin within British Columbia provided information on fish presence (McPhail et al. 1998). Nine species were captured (lake chub [*Couesius plumbeus*], finescale dace [*Phoxinus neogaeus*], longnose sucker [*Catostomus catostomus*], white sucker [*Catostomus commersonii*], northern pike [*Esox lucius*], trout-perch [*Percopsis omiscomaycus*], burbot [*Lota lota*], brook stickleback [*Culaea inconstans*], and walleye). No lacustrine (lake) species (e.g., spottail shiner, lake whitefish) were captured, attributed to a lack of suitable habitat: the lakes were typically 2 m deep or less and likely experience very low oxygen levels during winter (McPhail et al. 1998).

Table 5-3 Fish Species Known to Occur in the Hay River Basin

Common Name	Scientific Name	Sub-basin[1]						Conservation Status[7]
		Upper Hay		Lower Hay		Chinchaga		
		AB	BC	AB	NWT	AB	BC	
Longnose sucker	*Catostomus catostomus*	X[2,3]	X[4,6]	X[2,3]	X[5]	X[2,3]	X[6]	Secure (AB, NWT), Yellow (BC)
White sucker	*Catostomus commersonii*	X[2,3]	X[4,6]	X[2,3]	X[5]	X[2,3]	X[6]	Secure (AB, NWT), Yellow (BC)
Lake whitefish	*Coregonus clupeaformis*	–	–	X[2,3]	X[5]	–	–	Secure (AB, NWT), Yellow (BC)
Slimy sculpin	*Cottus cognatus*	X[2,3]	–	X[3]	–	X[3]	–	Secure (AB, NWT), Yellow (BC)
Lake chub	*Couesius plumbeus*	X[2,3]	X[4,6]	X[2,3]	X[5]	X[2,3]	X[6]	Secure (AB, NWT), Yellow (BC)
Cisco	*Coregonus artedi*	–	–	X[2]	–	–	–	Red listed (BC) Secure (AB, NWT)
Brook stickleback	*Culaea inconstans*	X[2,3]	X[4,6]	X[2,3]	X[5]	X[2,3]	–	Secure (AB, NWT), Yellow (BC)
Northern pike	*Esox lucius*	X[2,3]	X[4,6]	X[2,3]	X[5]	X[2,3]	X[6]	Secure (AB, NWT), Yellow (BC)
Burbot	*Lota lota*	X[2,3]	X[4,6]	X[2,3]	X[5]	X[3]	–	Secure (AB, NWT), Yellow (BC)
Pearl dace	*Margariscus margarita*	X[2,3]	–	X[2]	–	X[2,3]	–	Blue listed (BC) Secure (AB, NWT)
Emerald shiner	*Notropis atherinoides*	X[2]	X[6]	–	–	X[2]	–	Secure (AB, NWT), Unknown (BC)
Spottail shiner	*Notropis hudsonius*	–	–	X[3]	X[5]	X[2]	–	Red listed (BC) Secure (AB, NWT)
Rainbow trout	*Onchorhynchus mykiss*	X[2]	–	–	–	X[3]	–	Exotic (AB, NWT), Yellow (BC)
Trout-perch	*Percopsis omiscomaycus*	X[2,3]	X[4,6]	X[2,3]	X[5]	X[2,3]	–	Secure (AB, NWT), Yellow (BC)
Northern redbelly dace	*Phoxinus eos*	X[2,3]	X[6]	–	–	–	–	Blue listed (BC) Secure (AB, NWT)
Finescale dace	*Phoxinus neogaeus*	X[2,3]	X[4,6]	X[2]	X[5]	–	–	Secure (AB, NWT), Yellow (BC)
Fathead minnow	*Pimephales promelas*	–	–	X[2]	–	–	–	Undetermined (AB, NWT), Exotic (BC)
Flathead chub	*Platygobio gracilis*	–	X[6]	X[2]	–	–	–	Secure (AB, NWT), Yellow (BC)
Ninespine stickleback	*Pungitius pungitius*	X[3]	–	X[3]	X[5]	–	–	Undetermined (AB) Secure (NWT),

Table 5-3 Fish Species Known to Occur in the Hay River Basin

Common Name	Scientific Name	Sub-basin[1]						Conservation Status[7]
		Upper Hay		Lower Hay		Chinchaga		
		AB	BC	AB	NWT	AB	BC	
								Unknown (BC)
Longnose dace	*Rhinichthys cataractae*	X[2]	–	–	X[5]	–	–	Secure (AB, NWT), Yellow (BC)
Walleye	*Sander vitreus*	X[2,3]	X[4,6]	X[2,3]	X[5]	X[2,3]	–	Sensitive (AB and NWT) Yellow (BC)
Arctic grayling	*Thymallus arcticus*	X[2,3]	–	X[2,3]	X[5]	X[2,3]	X[6]	Sensitive (AB and NWT) Yellow (BC)
Chum salmon	*Onchorhynchus keta*	–	–	–	X[5]	–	–	Undetermined (NWT), Yellow (BC)
Arctic lamprey	*Lampetra japonica*	–	–	–	X[5]	–	–	Undetermined (NWT)
Inconnu	*Stenodus leucichthys*	–	–	–	X[5]	–	–	Sensitive (NWT) Blue-listed (BC)
Lake trout	*Salvelinus namaycush*	–	–	–	X[5]	–	–	Sensitive (AB) Secure (NWT), Yellow (BC)
Total species		**17**	**12**	**18**	**18**	**14**	**5**	

NOTES:

1 Jurisdictions include: AB = Alberta, BC = British Columbia, NWT = Northwest Territories

2 Alberta Environment and Parks 2015c

3 Nelson and Paetz 1992

4 McPhail et al. 1998

5 Stewart and Low 2000

6 Government of British Columbia 2016a

7 Conservation Status: In all three jurisdictions, "secure" or "yellow" means a species that is not at risk or sensitive. In Alberta and Northwest Territories, "sensitive" means a species is not at risk of extinction but require conservation effort to prevent them from becoming at risk. In British Columbia, "blue listed" means a species is at risk due to their vulnerability to human activities and natural events but are not threatened or endangered, while "red listed" means a species is threatened, endangered or extinct and are candidates to become protected under the *British Columbia Wildlife Act*.

Additional reports on fish distribution, movements and stocks are available but were not received in sufficient time for review and inclusion in this report. These include:

- An assessment in the Chinchaga River (Lucko and Wagner 1982)
- A fishery inventory in the Caribou Mountains and the Lower Hay in Alberta (Lyttle et al. 2012)
- A fish distribution and habitat study of the Chinchaga River and tributaries (Shroeder 1987)
- An Arctic grayling assessment in the Hay River (Lyttle and Wilcox 2012)
- A walleye assessment in Hutch Lake (Rees and Wilcox 2012)
- A fishery inventory in the Melvin River (Steenbergen et al. 2012)
- A walleye stock assessment in Rainbow Lake (Sherburne 2009)

Low DO concentrations during winter may limit available overwintering habitat for fish communities in some parts of the Hay River Basin. If resident fish are unable to move to other suitable overwintering habitat, the winter low flows and poor nutrient input in the Chinchaga River, as well as low DO levels measured in the Hay River at the Alberta/Northwest Territories border, could pose a risk to some resident fish communities, as suggested by Hatfield (2009). The low DO levels are considered natural, however, and in some waterbodies may be due to decomposition of the large amounts of organic matter present (North/South Consultants 2007).

Several fish species present in the basin have significant value for traditional subsistence purposes, residents, and sports fishermen, and can be considered species of commercial, recreational, or Aboriginal importance. In the Upper Hay sub-basin of British Columbia, walleye, burbot, northern pike, longnose sucker, and white sucker are known to be used by the Fort Nelson First Nation (LGL Limited 2003). Lake whitefish are the primary species harvested for subsistence purposes at the mouth of the Hay River at Great Slave Lake (Town of Hay River in the east and west channels around Vale Island), although other species captured as by-catch (e.g., burbot, inconnu, lake trout, longnose sucker, northern pike, and walleye) are also harvested for subsistence. Walleye are the main species targeted by recreational fishers in the Hay River, along with burbot and northern pike (Stewart and Low 2000).

In the 1990s, the Town of High Level, Alberta, stocked yellow perch (*Perca flavescens*) in a lake north of the town. At that time, there was some concern that yellow perch could find its way into Great Slave Lake but this has not occurred (G. Low, pers. comm.).

Surveys of walleye fishers in the Hay River (Lower Hay sub-basin in the Northwest Territories), conducted by Fisheries and Oceans Canada (DFO) between 1972 and 1986, indicated that over this period, fishing effort increased substantially while catch per unit effort decreased 30%, from 1.2 to 0.84 walleye per angler hour (Stewart and Low 2000). However, fish length and age increased during the same period and recruitment was considered adequate for stock replacement (Stewart and Low 2000). In 1989, a recommendation was made to conduct a creel census (documenting the number of fish caught by sport fishermen) and biological sampling program every three years, along with a tagging program to assess walleye movements (Stewart and Low 2000), but it is not known if this occurred.

The creel surveys conducted between 1972 and 1986 were the last known studies conducted on fish stocks in the Hay River in the Lower Hay sub-basin in the Northwest Territories. Fishing pressure in that section of river is lower than in the 1980s, and there are no records of local concerns about inadequate fish stocks (G. Low, pers. comm.). One approach to estimating domestic fishing pressure could be to review available fishing licence data for the Hay River Basin.

5.1.1.5 Aquatic Wildlife

Aquatic habitats in the Hay River Basin support 97 aquatic wildlife species: 4 amphibian, 12 mammal, and 81 bird species (Table C1 to C3 in Appendix C). These species were defined as aquatic wildlife based on their habitat and/or life cycle requirements, depending on water for all or part of their life cycle. Of the 97 species, 38 (mainly birds) are considered species of management concern in at least one of the jurisdictions of the Hay River Basin.

Many of the aquatic wildlife species also have significant cultural value for local Indigenous people. Furbearers such as American mink, short-tailed weasel, muskrat, American beaver, and northern American otter are important resources for trapping by the Dehcho and Métis people in the Lower Hay sub-basin of the Northwest Territories and the Dene Tha' in Alberta and British Columbia. Other species, such as moose and various waterfowl, are hunted and consumed as a food source (DLUPC 2006; Stevenson 2011).

Sensitive zones for aquatic wildlife overlap with the basin. In Alberta, Alberta Environment and Parks have designated key wildlife biodiversity zones and identified trumpeter swan (*Cygnus buccinator*) habitat in all three sub-basins. The key wildlife biodiversity zones are sensitive areas identified as having high biodiversity potential and/or being key winter habitat for ungulates such as moose, deer, elk, and caribou (AESRD 2012a, 2015). There are restrictions on timing of development activities for projects that occur within the key wildlife biodiversity zones and trumpeter swan habitat (AESRD 2012a, 2015) to prevent activities from occurring during sensitive life stages (e.g., giving birth, nesting). Due to its status as a species of management concern in Alberta, identified trumpeter swan habitat has been protected to support recovery efforts.

The Hay-Zama Lakes wetland complex, within the Hay-Zama Lakes Wildland Provincial Park and Upper Hay sub-basin in Alberta, is another sensitive area. It is an internationally-recognized Ramsar 'wetland of importance' and a globally-recognized Important Bird Area because of the density of congregatory species and waterfowl concentrations (Bird Life IBA Canada 2015a). The Ramsar convention recognizes the importance of wetland conservation but does not grant protection status (Ramsar 2014). Waterfowl use lakes in the wetland complex as staging areas during their spring and fall migrations. An estimated 2.6% (approximately 130,000) of the global snow goose (*Chen caerulescens*) population and 1% of the global Canada goose (*Branta canadensis*) population use the lakes during migrations. Ducks Unlimited estimates up to one million waterfowl use the lakes during fall migration. Yellow rail (*Coturnicops noveboracensis*), American avocet (*Recurvirostra americana*), lesser yellowleg (*Tringa flavipes*), hudsonian godwit (*Limosa haemastica*), and common tern (*Sterna hirundo*) are other aquatic bird species recorded as using the Hay-Zama Lakes wetland complex (Bird Life IBA Canada 2015a).

In the Northwest Territories, the Hay River Basin overlaps with the ranges of four bird species of management concern: rusty blackbird (*Euphagus carolinus*), horned grebe (*Podiceps auritus*), red-necked phalarope (*Phalaropus lobatus*), and yellow rail (Government of the Northwest Territories 2015a). Important wildlife areas for beaver and moose have been identified as consistently providing habitat for large numbers of both species (Wilson and Haas 2012).

In British Columbia, Kotcho Lake in the Upper Hay sub-basin is located within the Kotcho Lake Ecological Reserve and is another Important Bird Area recognized as nationally significant because of the concentrations of waterfowl that use the lake during fall migration. Trumpeter swan, canvasback (*Aythya valisineria*), American widgeon (*Anas americana*), blue-winged teal (*Anas discors*), northern shoveler (*Anas clypeata*), green-winged teal (*Anas carolinensis*), bufflehead (*Bucephala albeola*), common goldeneye (*Bucephala clangula*), and northern pintail (*Anas acuta*) are some of the species that have been recorded at Kotcho Lake (Bird Life IBA Canada 2015b).

5.2 CONTAMINANTS IN TISSUE

Two studies have been published on levels of contaminants in fish tissue within the Hay River Basin (Grey et al. 1995; Bujold 1995 as summarized in Hatfield 2009), but information on contaminant levels in other aquatic organisms (e.g., benthic invertebrates, macrophytes, aquatic wildlife) has not been identified. In the Lower Hay sub-basin in the Northwest Territories, studies on contaminants in fish tissue have not been completed since the mid-1990s (G. Low, pers. comm.).

Mercury in fish tissue is of interest, given that elevated concentrations can result in concerns for human consumption, especially when fish is a mainstay of the diet. Fish in many areas of Canada have naturally elevated levels of mercury, unrelated to human activities. A review of total mercury levels in edible fish muscle from lakes in the Northwest Territories, Nunavut, and Yukon Territory showed that walleye, northern pike, and lake trout usually exceeded the mercury tissue guideline for subsistence consumers (200 ng/g) and often exceeded the 500 ng/g Health Canada (2007) total consumption guideline for the sale of commercial fish (Lockhart et al. 2005).

In 1989 and 1990, mercury levels in edible fish tissue (muscle) were analyzed in 40 lake whitefish, 35 walleye, and 21 northern pike caught in the Hay River, from the east side of Vale Island near the Town of Hay River, NWT (Grey et al. 1995). Over the two-year study, mean mercury concentrations were 70 ng/g in lake whitefish, 220 ng/g in walleye, and 320 ng/g in northern pike (Table 5-4). Mean concentrations in walleye and northern pike were greater than the 200 ng/g advisory level for subsistence or frequent consumers but below the Health Canada 500 ng/g commercial advisory level (Grey et al. 1995).

In 1994, metals levels in muscle of walleye, northern pike, longnose sucker, and white sucker caught in the Hay River within the Northwest Territories (approximately the first 25 km of the river, north of the Alberta/Northwest Territories border) were studied (Bujold 1995). Mercury, cadmium, copper, lead, zinc, iron, manganese, selenium, and arsenic, were analyzed. Mean mercury concentrations in all four species were below the Health Canada commercial advisory level (500 ng/g) but the mean concentration in walleye were at the Health Canada subsistence advisory level (200 ng/g) (Table 5-4; Bujold 1995). Tissue mercury results for northern pike were lower than those reported by Grey et al. (1995); see Table 5-4. The other metals analyzed do not have federal tissue guidelines for human or wildlife consumption.

Table 5-4 Metals Concentrations in Muscle Tissue of Fish Species Captured in the Hay River, Northwest Territories

Metal	Muscle Tissue Concentrations (Mean [Range]; ng/g)				
	Walleye	Northern Pike	Lake Whitefish	Longnose Sucker	White Sucker
Hay River near Vale Island, Northwest Territories, 1989/1990 (Grey et al. 1995)[1]					
Mercury (Hg)	220 (100–320)	320 (190–590)	70 (30–130)	n/a	n/a
Hay River, near AB/NWT border, 1994 (Bujold 1995)[2]					
Arsenic (As)	–[3] (<50–80)	<50 (all < DL)[4]	n/a	–[3] (<50–102)	50 (<50–80)
Cadmium (Cd)	–[3] (<1–1)	–[3] (<1–1)	n/a	<1 (<1–6)	<1 (<1–2)
Copper (Cu)	274 (105–544)	259 (119–589)	n/a	369 (219–738)	420 (220–519)
Iron (Fe)	2,040 (890–5,440)	2,000 (950–4,500)	n/a	2,550 (1,460–4,570)	2,890 (1,280–3,940)
Lead (Pb)	<30 (all < DL)[4]	<30 (all < DL)[4]	n/a	<30 (all < DL)[4]	<30 (all < DL)[4]
Manganese (Mn)	200 (107–402)	417 (132–2,178)	n/a	538 (264–1,127)	243 (178–287)
Mercury (Hg)	202 (107–441)	183 (51–501)	n/a	110 (61–191)	100 (74–116)
Selenium (Se)	330 (220–430)	190 (<50–450)	n/a	450 (270–620)	430 (250–550)
Zinc (Zn)	2,790 (2,300–3,410)	3,240 (2,700–3,960)	n/a	2,950 (1,890–4,140)	2,390 (1,970–2,890)

NOTES:

1 Grey et al. (1995): 35 walleye, 21 northern pike, and 40 lake whitefish

2 Bujold (1995): 11 walleye, 15 northern pike, 9 longnose sucker, and 3 white sucker.

3 '–' = mean value not calculated

4 < DL = less than the detection limit

The 1994 study included analysis of PAHs in muscle and bile of walleye and northern pike to provide baseline information (Bujold 1995). Concentrations were orders of magnitude higher in bile than muscle (Table 5-5), making bile the preferred tissue for analysis. Naphthalene and methylnaphthalene were the most commonly detected PAHs; these low molecular weight PAHs are commonly reported in the Hay River (Section 4.3.3). There are no Canadian tissue guidelines for PAHs, aside from benzo(a)pyrene (BC Ministry of Environment 1993); muscle concentrations were not detectable and the detection limit was 100 times lower than the most conservative of the guidelines (1 ng/g for consumption of 200 g of fish per week).

Table 5-5 Mean Concentrations of Polycyclic Aromatic Hydrocarbons in Muscle and Bile of Walleye and Northern Pike Captured in the Hay River, NWT

Polycyclic Aromatic Hydrocarbons	Concentration			
	Walleye		Northern Pike	
	Muscle (ng/g) (n=1)	Bile (ng/mL) (n=3)	Muscle (ng/g) (n=5)	Bile (ng/mL) (n=3)
Napthalene	2.78	80.8	2.24	39.38
2-methylnapthalene	0.37	55.54	0.20	27.94
1-methylnapthalene	0.16	23.17	0.08	11.54
Biphenyl	0.29	25.11	0.20	5.87
Dibenzofuran	0.27	8.40	0.21	3.57
Acenaphthylene	0.00	0.00	0.01	0.00
Acenaphthene	0.00	0.00	0.11	0.00
Fluorene	0.00	4.00	0.00	0.00
Phenanthrene	0.40	10.65	0.33	5.35
Anthracene	0.07	0.05	0.04	0.03
o-terphenyl	0.00	0.00	0.00	0.00
m-terphenyl	0.00	0.00	0.00	0.00
Fluoranthene	0.22	0.00	0.15	0.00
Pyrene	0.19	1.94	0.12	0.00
p-terphene	0.00	0.00	0.00	0.00
Retene	0.00	0.00	0.00	0.00
Benzo(a)anthracene	0.00	0.00	0.00	0.00
Chrysene	0.00	0.00	0.00	0.00
Benzo(b)fluoranthene	0.00	0.00	0.00	0.00
Benzo(k)fluoranthene	0.00	0.00	0.00	0.00
Benzo(e)pyrene	0.00	0.00	0.00	0.00
Benzo(a)pyrene	0.00	0.00	0.00	0.00
Indeno(1,2,3-cd)pyrene	0.00	0.00	0.00	0.00

Table 5-5 Mean Concentrations of Polycyclic Aromatic Hydrocarbons in Muscle and Bile of Walleye and Northern Pike Captured in the Hay River, NWT

Polycyclic Aromatic Hydrocarbons	Concentration			
	Walleye		Northern Pike	
	Muscle (ng/g) (n=1)	Bile (ng/mL) (n=3)	Muscle (ng/g) (n=5)	Bile (ng/mL) (n=3)
Dibenzo(a,h)anthracene	0.00	0.00	0.00	0.00
Benzo(g,h,i)perylene	0.00	0.00	0.00	0.00
Dibenzothiophene	0.00	0.00	0.00	0.00
Perylene	0.00	0.00	0.00	0.00
SOURCE: Bujold (1995)				

The 1994 study also included analysis of organochlorine compounds (including the banned pesticides DDT and toxaphene and banned PCBs) in walleye muscle. Compared to surveys of other fish species elsewhere in the Northwest Territories, concentrations of organochlorines in Hay River walleye were among the lowest reported (Bujold 1995). The presence of these compounds reflects long-range transport of persistent organic pollutants rather than sources within the Hay River Basin (Bujold 1995).

5.3 SUMMARY

Little information is available on plankton, benthic invertebrates, and macrophytes in the Hay River Basin and most of the available studies date from the 1970s and early 1980s. There is more information available about fish: 26 species have been identified, with the greatest number of species found in the Lower Hay sub-basin. Among aquatic wildlife, there are 97 species (81 bird, 4 amphibian, and 12 mammal). The Hay-Zama Lakes wetland complex has exceptional wildlife value and is recognized internationally as a Ramsar wetland of importance and an Important Bird Area. Kotcho Lake is also recognized nationally as an Important Bird Area.

Information on contaminants in fish tissue in the basin is also scarce. Only two studies, dated from the late 1980s to the mid-1990s, contained information specific to the Hay River Basin. Mercury concentrations in walleye and northern pike muscle exceeded the advisory levels for subsistence or frequent consumers of fish (200 ng/g) but were below the advisory level for the commercial sale of fish (500 ng/g). The most common PAHs detected in walleye and northern pike tissue were naphthalene and methylnaphthalenes, which have been detected in water and suspended sediments of the Hay River (see Section 4.3.3).

6.0 EXISTING WATER USE AND ALLOCATION

Water is essential for many ecological functions and is also withdrawn for human uses, ranging from domestic and municipal water supply, to industrial uses for oil and gas, forestry, and agriculture sectors. This section describes quantities of surface water and groundwater allocated to and used by the various sectors. Section 6.1 provides the regulatory context (licences) for allocation. Sections 6.2 through 6.4 describe allocations within the individual sub-basins.

6.1 REGULATORY CONTEXT

Water withdrawal in the Hay River Basin is regulated through three pieces of legislation: the Alberta *Water Act*, the British Columbia *Water Act*, and in the Northwest Territories, through the *Waters Act.* These acts and associated regulations outline the governing bodies responsible for issuing water allocation licences/approvals in their respective jurisdictions, applicable legislative requirements, and guidance for governing bodies, proponents, and other stakeholders on water withdrawal and allocation. The types of water allocations issued by each jurisdiction are summarized in Table 6-1.

Table 6-1 Water Allocation Licences/Approvals Issued by Jurisdictions in the Hay River Basin

Water Allocation Document	Maximum Issuance Length	Data Source
British Columbia		
Water Licence	none	*British Columbia Water Act, Section 7*
Short-term Water Authorizations	24 months	*British Columbia Water Act, Section 8*
Alberta		
Water Act Licence	none	*Alberta Water Act, Section 49*
Water Act Temporary Diversion Licence	12 months	*Alberta Water Act, Section 63*
Water Act Registration	none	*Alberta Water Act, Section 73*
Water Resources Act Licence	none	Licences grandfathered from the *Alberta Water Act* predecessor
Northwest Territories		
Type A Water Licence	25 years	*Waters Act, Section 26*
Type B Water Licence	25 years	

The information discussed in the following sections may not account for all water allocations in as certain water uses, or quantities of water withdrawal, do not require a licence (see Table 6-2). Although there are no set quantities under section 42 of the British Columbia *Water Act*, a person may divert unrecorded water for domestic purposes, or for prospecting minerals, without a licence or requirement to report the withdrawal. Under the Alberta *Water Act*, a water licence is not required for use of water for domestic purposes (maximum of 1,250 m³/year), or for raising animals or applying pesticides to crops as part of a farming operation (maximum of 6,250 m³/year). In the Northwest Territories, under the *Waters Act* and regulations, for certain types of activities, withdrawal and/or storage of a limited amount of water without a licence are permitted. These exemptions are summarized in Table 6-2.

Table 6-2 Water Withdrawal Exemptions and Associated Types of Activities

Types of Exempted Activities	Maximum Water Withdrawal Limit (m³/year)	Maximum Water Storage Limit (m³ /year)	Data Source
British Columbia			
Domestic use	Not specified	Not specified	*British Columbia Water Act*, Section 42
Alberta			
Domestic use, specifically including human consumption, sanitation, fire prevention, and watering animals, gardens, lawns and trees	1,250	Not specified	*Alberta Water Act*, Section 23
Agricultural use, specifically including raising animals or applying pesticides to crops	6,250	12,500 (dugouts)	*Alberta Water Act*, Section 19
Northwest Territories			
• Industrial direct water use, including oil and gas exploration, and other • Mining and milling direct water use Agricultural, conservation, • Recreational, and miscellaneous direct water use	≤36,500	≤ 2 500	Waters Regulations, Schedule IV, V, and VIII
Municipal direct water use	≤18,250	≤ 2 500	Waters Regulations, Schedule VI

6.1.1 Data Collection

Water allocation information for British Columbia (Upper Hay and Chinchaga sub-basins) was retrieved through the online tool, the NorthEast Water Tool (BC Oil and Gas Commission 2015), through the British Columbia Ground Water Wells and Aquifer Database (Version 2.9), and through discussions with Robert Piccini, Section Head and Assistant Regional Manager of Water, and Mike D'Aloia, Senior Habitat Officer, both in the Water Stewardship Division of the British Columbia Ministry of the Environment. The volume of surface water and groundwater used annually by approved licencees is not available by sub-basin because British Columbia does not currently track this information (R. Piccini, pers. comm.). This may change with the new *Water*

Sustainability Act, which was approved and enacted in 2015. In the Hay River Basin within British Columbia, water is primarily allocated to the oil and gas sector.

Water allocation and usage data in Alberta (the three sub-basins) were provided by provincial government officials through Carmen de la Chevrotière, Transboundary Water Quantity Specialist with Alberta Environment and Parks, and through the Alberta Water Well Information Database. In Alberta, reporting requirements are specific to each licence holder. For some licence types (i.e., not major industrial), reporting is done on a voluntary basis only (N. Adhikari, pers. comm.). Reporting on the volume of water used is largely a condition only for major industrial licences and is either completed through the Alberta Environment and Parks online Water Use Reporting System, or through proponent-submitted paper or electronic documents. For the scope of this report, only water use data readily accessible from the online Water Use Reporting System were examined. As such, surface water and groundwater usage information was available for only some of the licences in the sub-basins for the period 2010 to 2014. In the Hay River Basin within Alberta, water is allocated to four major industrial sectors: oil and gas, commercial, municipal, and forestry. Other sectors are also allocated water in the Alberta portion of the basin, including transportation and government (e.g., wildlife), but this represents a relatively small proportion of allocation; for the purpose of this report, these sectors were grouped together under the "other" category.

Water allocation and usage information for the Lower Hay sub-basin within the Northwest Territories was retrieved through the Mackenzie Valley Land and Water Board (2015) Public Registry. Angela Love, with the Mackenzie Valley Land and Water Board, provided a map of current licences in the basin.

6.2 UPPER HAY SUB-BASIN

6.2.1 British Columbia

In the Upper Hay sub-basin within British Columbia, 1 surface water licence and 63 short-term surface water licences (one for groundwater and the remaining for surface water) were active as of December 2015 (Figure 6-1, Table 6-3). The surface water licence was issued in 1983 for a camp, and is still valid. The short-term surface water licences and the groundwater water licence were issued for oil and gas activity and are collectively permitted to withdraw 416,368 m^3 of surface water, and 6,000 m^3 of groundwater, annually (Table 6-4) (BC Oil and Gas Commission 2015).

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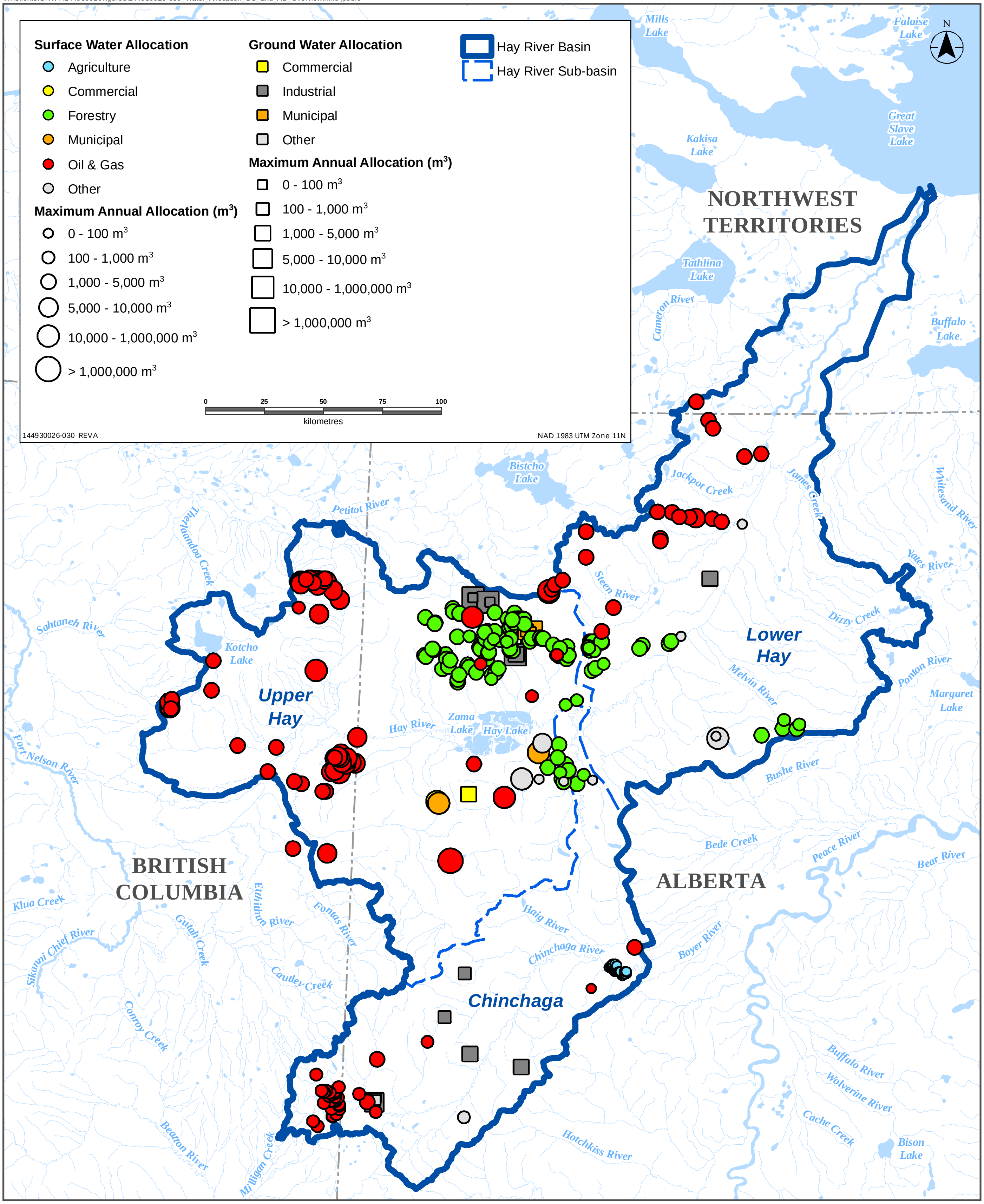

Sources: Base Data - Government of Canada; Thematic Data - the British Columbia Oil and Gas Commission (2015), and the Governments of Canada, Alberta, and the Northwest Territories (2015).

Disclaimer: This map is for illustrative purposes to support this Stantec project; questions can be directed to the issuing agency.

Hay River Basin and Sub-basins:
Overview of Surface & Groundwater Allocations

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Figure 6-1

Table 6-3 Number of Water Licences by Allocation Volume in the Upper Hay Sub-basin in 2015

Maximum Annual Allocation Volume (m^3)	British Columbia		Alberta	
	Surface Water	Groundwater	Surface Water	Groundwater
Less than 100	–	–	2	4
100 to 1,000	1	–	14	–
1,000 to 5,000	19	–	85	4
5,000 to 10,000	39	1	1	–
10,000 to 1,000,000	4	–	11	4
More than 1,000,000	–	–	1	–
Total	**63**	**1**	**114**	**12**

Overall, water allocation in the Upper Hay sub-basin of British Columbia accounts for 8% of the total 2015 surface water allocation (5,468,858 m^3) for the sub-basin, and 2% of total groundwater allocation (283,092 m^3) (Table 6-4). Annual water usage data are not available for British Columbia.

Table 6-4 Approved Water Allocation in the Upper Hay Sub-basin in 2015

Sector	Surface Water		Groundwater	
	Number of Licences[1]	Approved Allocation (m^3 year)	Number of Licences	Approved Allocation (m^3/year)
British Columbia				
Oil and gas	63	416,368	1	6,000
Total	**63**	**416,368**	**1**	**6,000**
Alberta				
Commercial	1	19,720	1	3,700
Forestry	88	231,500	0	0
Oil and gas	18	4,150,380	7	189,522
Municipal	2	602,040	4	83,870
Other	5	48,850	0	0
Total	**114**	**5,052,490**	**12**	**277,092**
Sub-basin Total	**177**	**5,468,858**	**13**	**283,092**

NOTE:
[1] Number of Licences: includes licences, approvals, and authorizations

6.2.2 Alberta

In the Upper Hay sub-basin within Alberta, 114 surface water licences and 12 groundwater licences were active as of December 2015 (Table 6-3), representing five economic sectors (Table 6-4, Figure 6-1). Collectively, these licences authorize the withdrawal of 5,052,490 m^3 of surface water and 277,092 m^3 of groundwater annually, 82% of which is approved allocation for the oil and gas sector (Table 6-4). The forestry sector had the highest number of licences issued (88), but only 5% of the total surface water allocation. Eight water licences expired in 2015 (five oil and gas and three "other") and accounted for 13,500 m^3 of surface water allocation. The one commercial licence was issued to a golf course. The municipal licences were issued to Chateh and the Town of Rainbow Lake. All licences from the forestry sector were issued to one proponent (Government of Alberta 2015). Overall, water allocation in the Upper Hay sub-basin of Alberta accounts for 92% of the total 2015 surface water allocation (5,468,858 m^3) and 98% of the total groundwater allocation (283,092 m^3) for the sub-basin (Table 6-4).

Based on online-reported water usage data for the Alberta portion of the Upper Hay sub-basin, total annual surface water usage varied from about 1.2 million to 1.5 million m^3 between 2010 and 2014, while reported annual groundwater use varied from 4,147 to 14,477 m^3, with no obvious trend over that time (Table 6-5). Water usage data for 2015 were not available at the date of this report. These quantities represent 24 to 30% of the total surface water and 1 to 5% of total groundwater allocated in 2015, suggesting that either not all the allocated water is used or is not reported. The oil and gas sector was the largest consumer of surface water, withdrawing over 1 million m^3 annually, and the only consumer of groundwater, withdrawing 41,925 m^3 annually between 2010 and 2014, as shown in Table 6-5 (Government of Alberta 2015).

Table 6-5 Annual Surface Water and Groundwater Use in the Upper Hay Sub-basin of Alberta from 2010 to 2014

Sector	Water usage (m^3 year)[1]					
	2010	**2011**	**2012**	**2013**	**2014**	**Total**
Surface Water						
Commercial	655	0	0	0	0	655
Oil and Gas	1,243,804	1,033,424	1,326,684	1,494,648	1,359,208	6,457,767
Municipal	252,206	173,833	0	0	0	426,039
Other	16,270	18,129	10,525	21,186	18,896	85,006
Total	**1,512,935**	**1,225,386**	**1,337,209**	**1,515,834**	**1,378,104**	**6,969,467**
Groundwater						
Oil and Gas	7,750	14,477	7,393	7,612	4,147	41,925
Total	**7,750**	**14,477**	**7,393**	**7,612**	**4,147**	**41,925**
Sub-basin Total	**1,520,685**	**1,239,863**	**1,344,602**	**1,523,446**	**1,422,251**	**7,011,392**

NOTE:
[1] Zeros may represent a lack of reporting, rather than no water use (C. delaChevrotiere, pers. comm.).

6.3 CHINCHAGA SUB-BASIN

6.3.1 British Columbia

In the Chinchaga sub-basin within British Columbia, there were 27 active short-term use licences and no active surface water or groundwater licences in 2015 (Table 6-6, Figure 6-1); all active licences were issued for the oil and gas sector (Table 6-7, Figure 6-1). Collectively, the licences permitted the withdrawal of 13,500 m^3 of surface water annually, but they all expired in December 2015 (Table 6-7).

Table 6-6 Number of Water Licences by Allocation Volume in the Chinchaga Sub-basin in 2015

Maximum Annual Allocation Volume (m^3)	British Columbia		Alberta	
	Surface Water	Groundwater	Surface Water	Groundwater
Less than 100	–	–	23	4
100 to 1,000	27	–	5	2
1,000 to 5,000	–	–	7	3
5,000 to 10,000	–	–	–	1
10,000 to 1,000,000	–	–	–	–
More than 1,000,000	–	–	–	–
Total	**27**	**–**	**35**	**10**

Overall, the water allocation in the Chinchaga sub-basin of British Columbia accounts for 40% of the total 2015 surface water allocation (33,381 m^3) for the sub-basin, and 0% of the total groundwater allocation (15,989 m^3) (Table 6-7). Annual water usage data are not available for the province.

Table 6-7 Approved Water Allocation in the Chinchaga Sub-basin in 2015

Sector	Surface Water		Groundwater	
	Number of Licences[1]	Approved Allocation (m^3 year)	Number of Licences[1]	Approved Allocation (m^3 year)
British Columbia				
Oil and Gas	27	13,500	0	0
BC Total	**27**	**13,500**	**0**	**0**
Alberta				
Agriculture	21	1,451	0	0
Forestry	4	6,500	0	0
Oil and Gas	8	11,500	9	15,969
Other	2	430	1	20
AB Total	**35**	**19,881**	**10**	**15,989**
Sub-basin Total	**62**	**33,381**	**10**	**15,989**

NOTE:
[1] Number of Licences: includes licences, approvals, and authorizations

6.3.2 Alberta

In the Chinchaga sub-basin within Alberta, 35 surface water licences and 10 groundwater licences were active as of December 2015, representing oil and gas, agriculture, forestry, and "other" sectors (Table 6-6, Table 6-7, and Figure 6-1). Collectively, these licences authorize withdrawal of 19,881 m^3 of surface water and 15,989 m^3 of groundwater, with 58% allocated to the oil and gas sector (Table 6-7). One "other" licence (Table 6-7) expired in 2015 and accounted for 80 m^3 of surface water allocation. All licences from the forestry sector in the Chinchaga sub-basin within Alberta were issued to one proponent (Government of Alberta 2015). Overall, water allocation in the Chinchaga sub-basin of Alberta accounts for 60% of the total 2015 surface water allocation (33,381 m^3) and 100% of the total groundwater allocation (15,989 m^3) for the sub-basin (Table 6-7).

These water allocations represent a small proportion of the average annual surface water discharge in the Chinchaga sub-basin. The 2015 annual surface water allocation for the entire sub-basin (including British Columbia) is 0.004% of the average annual surface water discharge, calculated using an average annual discharge of 914 million m^3 (28.9 m^3/s) at WSC station "Chinchaga River near High Level" (ID 07OC001 for 1970 to 2012; see Table 2-1). When considering the winter low flow period (January to March) at this station (see Section 2.2.1), the surface water allocation represents 0.14% of the winter low flow (0.75 m^3/s), assuming a constant withdrawal rate through this winter period.

Surface water usage information was not available for the Chinchaga sub-basin within Alberta. Based on reported groundwater usage, total annual usage varied from about 934 to 2,968 m³ between 2010 and 2014, with no obvious trend over that time (Table 6-8). Groundwater usage data for 2015 were not available at the date of this report. These water volumes represent 6 to 19% of the total groundwater allocated in 2015, suggesting not all of the groundwater allocated is used or reported. The oil and gas sector was the largest consumer of groundwater in the Chinchaga sub-basin within Alberta (68% of total usage), and withdrew 704 to 1256 m³ per year between 2010 and 2014 (Table 6-8) (Government of Alberta 2015).

Table 6-8 Annual Groundwater Use in the Chinchaga Sub-basin of Alberta from 2010 to 2014

Sector	Water usage (m³/year)					
	2010	2011	2012	2013	2014	Total
Groundwater						
Oil and Gas	1,098	934	1,256	704	985	4,977
Commercial	0	0	0	361	1,983	2,344
Total	**1,098**	**934**	**1,256**	**1,065**	**2,968**	**7,321**

NOTE:
[1] Zeros may represent a lack of reporting, rather than no water use (C. delaChevrotiere, pers. comm.).

6.4 LOWER HAY SUB-BASIN

6.4.1 Alberta

In the Lower Hay sub-basin within Alberta, one groundwater and 42 surface water licences were active as of December 2015 (Table 6-9, Figure 6-1).

Table 6-9 Number of Water Licences by Allocation Volume in the Lower Hay Sub-basin in 2015

Maximum Annual Allocation Volume (m³)	Alberta		Northwest Territories	
	Surface Water	Groundwater	Surface Water	Groundwater
Less than 100	3	–	–	–
100 to 1,000	5	–	–	–
1,000 to 5,000	32	1	1	–
5,000 to 10,000	1	–	–	–
10,000 to 1,000,000	1	–	–	–
More than 1,000,000	–	–	–	–
Total	**42**	**1**	**1**	**–**

These licences represent the oil and gas, forestry and "other" sectors (Table 6-10, Figure 6-1). The licences authorize the total annual withdrawal of 1,093,612 m^3 of surface water and 2,008 m^3 of groundwater, 88% allocated to the "other" sector (in this case, primarily to storage reservoirs for wildlife on the Meander River). Two surface water licences in the "other" category expired in 2015 and accounted for 50 m^3 of surface water allocation (Government of Alberta 2015). Overall, the water allocation in the Lower Hay sub-basin of Alberta accounts for nearly 100% of the total 2015 surface water allocation (1,096,369 m^3) for the sub-basin, and 100% of the total groundwater allocation (2,008 m^3) (Table 6-10).

Table 6-10 Approved Water Allocation in the Lower Hay Sub-basin in 2015

Sector	Surface Water		Groundwater	
	Number of Licences[1]	**Approved Allocation (m^3/year)**	**Number of Licences[1]**	**Approved Allocation (m^3/year)**
Alberta				
Forestry	22	48,500	0	0
Oil and Gas	16	85,000	1	2,008
Other	4	960,112	0	0
AB Total	**42**	**1,093,612**	**1**	**2,008**
Northwest Territories				
Oil and Gas	1	2,757[2]	0	–
NWT Total	**1**	**2,757**	**0**	**–**
Sub-basin Total	**43**	**1,096,369**	**1**	**2,008**

NOTES:
[1] Number of Licences: includes licences, approvals, and authorizations
[2] Value reported is total water use that occurred within the sub-basin, not allocation.

The only usage data available for the Lower Hay sub-basin within Alberta was for the municipal sector: the County of Mackenzie withdrew 1,979 m^3 of groundwater in 2012 for Zama City.

6.4.2 Northwest Territories

In the Lower Hay sub-basin within the Northwest Territories, one active water licence was identified for an oil and gas company in the Cameron Hills area, in the far eastern corner of the sub-basin (Table 6-9, Table 6-10 and Figure 6-1). In January 2015, a total of 2,757 m^3 of water was withdrawn/used from an unnamed lake situated in the sub-basin (Strategic Oil and Gas 2015), though their total allocation was 515,444 m^3, which includes withdrawal sites outside of the Hay River Basin. This water use accounts for less than 1% of the total surface water allocation (1,096,369 m^3) in the Lower Hay sub-basin. In February 2015, activities at in the Cameron Hills site were shut down due to unfavourable economic conditions (SOG 2015); only maintenance activity appears to have occurred since then.

The Town of Hay River withdraws its drinking water from Great Slave Lake, outside of the Hay River Basin, and also provides drinking water to the community of Enterprise.

6.5 SUMMARY

In the Hay River Basin, more than 6.6 million m^3 of surface water and about 300,000 m^3 of groundwater were allocated to various economic sectors in 2015. These figures may be an underestimate because, depending on the jurisdiction, not all water use allocations require a licence. The allocations represent the maximum amount permitted to be used in a year. The full allocation includes the long-term demand, and accounts for emergency uses (e.g., fires), and therefore may not be used in a given year.

Using an average annual surface water discharge estimate of 3.6 billion m^3 (114 m^3/s) for WSC station "Hay River near Hay River" (ID 07OB001 for 1964 to 2012; Table 2-1), the 2015 total surface water allocation represents 0.18% of the basin discharge at this station. When considering the winter low flow period (January to March), this surface water allocation represents approximately 3.85% of the average winter low flow (5.44 m^3/s) at this WSC station (see Section 2.2.1), assuming a constant withdrawal rate (0.21 m^3/s) through this winter period.

For the basin as a whole, allocations of surface water and groundwater were mainly for the oil and gas section (71% each for surface water and groundwater) (Table 6-11). The oil and gas sector had the largest allocation in the Upper Hay and Chinchaga sub-basins and the "other" category had the largest allocation in the Lower Hay sub-basin (which, in this case, was for storage reservoirs for wildlife on the Meander River in Alberta). The agriculture, commercial, and municipal sectors had little or no water allocations in the Chinchaga and Lower Hay sub-basins in 2015 (Table 6-11). By sub-basin, the largest surface water allocation in 2015 was for the Upper Hay sub-basin (83%, mostly in Alberta; see Section 6.2), followed by the Lower Hay (17%, nearly all in Alberta; see Section 6.4), and the Chinchaga sub-basin (less than 1%, roughly split between British Columbia and Alberta; see Section 6.3) (Table 6-11). Total groundwater allocation in the basin is similar, with 94% of the allocation occurring in the Upper Hay, 5% in the Chinchaga, and less than 1% in the Lower Hay (Table 6-11), with nearly all reported allocation occurring in Alberta.

Table 6-11 Total Approved Water Allocation by Sector in the Hay River Basin in 2015

Sector	Upper Hay		Lower Hay		Chinchaga		Hay River Basin	
	Number of Licences	Approved Allocation (m^3/year)	Number of Licences	Approved Allocation (m^3/year)	Number of Licences	Approved Allocation (m^3/year)	Number of Licences	Approved Allocation (m^3/year)
Surface Water								
Agriculture	0	–	0	–	21	1,451	21	1,451
Commercial	1	19,720	0	–	0	–	1	19,720
Forestry	88	231,500	22	48,500	4	6,500	114	286,500
Oil and Gas	81	4,566,748	17	87,757	35	25,000	133	4,679,505
Municipal	2	602,040	0	–	0	–	2	602,040
Other	5	48,850	4	960,112	2	430	11	1,009,392
Total	**177**	**5,468,858**	**43**	**1,096,369**	**62**	**33,381**	**282**	**6,598,608**
Groundwater								
Oil and gas	8	195,522	1	2,008	9	15,969	18	213,499
Commercial	1	3,700	0	–	0	–	1	3,700
Municipal	4	83,870	0	–	0	–	4	83,870
Other	0	–	0	–	1	20	1	20
Total	**13**	**283,092**	**1**	**2,008**	**10**	**15,989**	**24**	**301,089**

7.0 EXISTING AND POTENTIAL DEVELOPMENT ACTIVITIES AND PRESSURES

This section describes existing and potential activities and pressures that can affect aquatic ecosystem health in the Hay River Basin. Land Use Plans for the three jurisdictions are described in Sections 7.1. Direct local pressures, which are activities associated with specific economic sectors, are described in Sections 7.2 through 7.6.3, with a summary in Section 7.8 Indirect global pressures external to, but that influence, the basin are discussed in Section 7.9. These include long range transport of contaminants and climate change. Information in the following sections was collected through a review of grey literature, government and scientific reports, and provincial/territorial data repositories. Some information was obtained from government officials and during interviews (see Foreword).

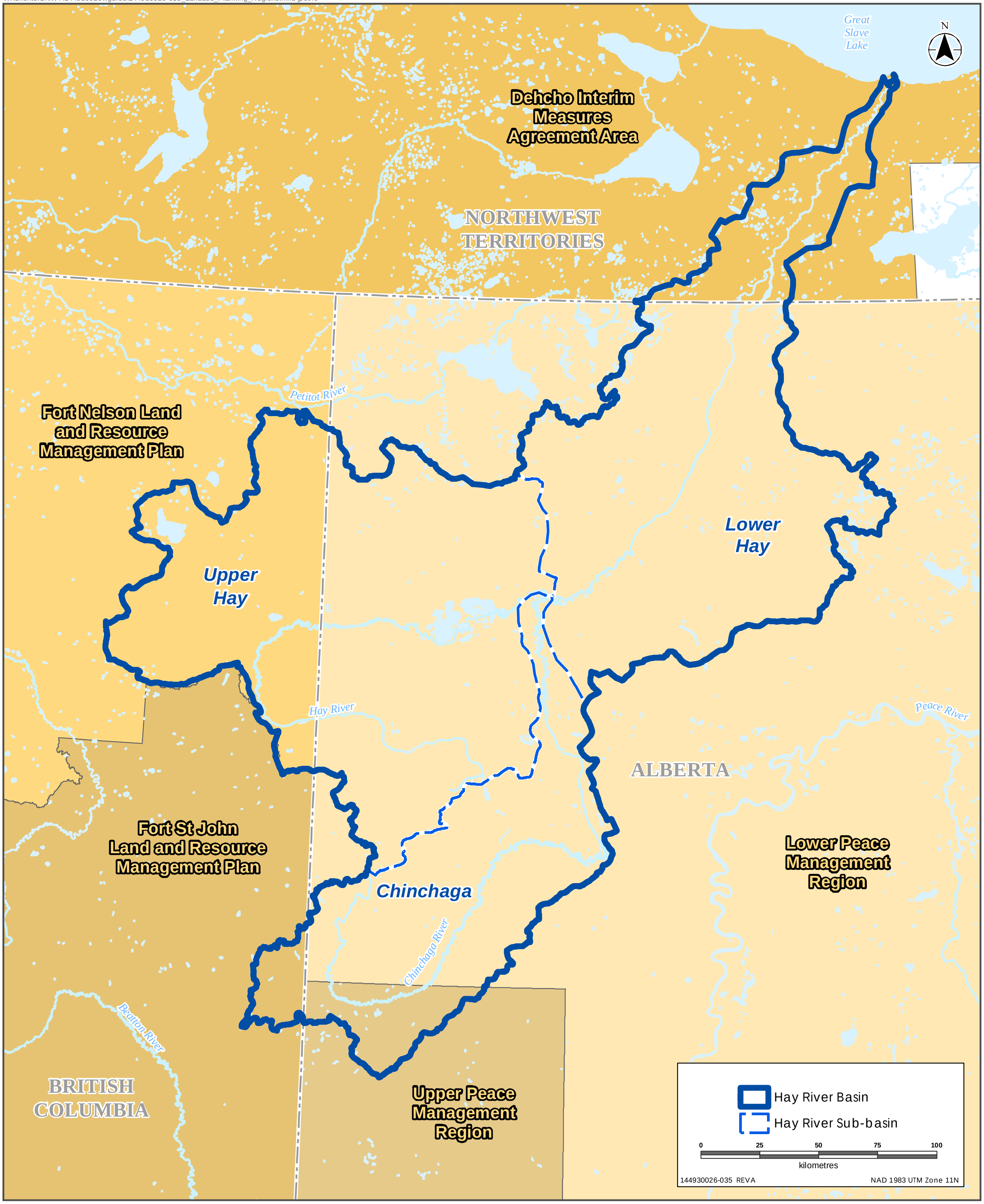
Although the Hay River Basin is sparsely populated, human activity has left a footprint, most obviously through exploitation of natural resources. The oil and gas sector is the primary development pressure in the Hay River Basin, with intensity of activity varying among the three sub-basins. The forestry sector is the second most active development pressure, and occurs mainly in the Upper Hay sub-basin. Agriculture, municipal, and transportation sectors represent minor development pressures in the Hay River Basin. The oil and gas sector, along with forestry, in Alberta and British Columbia, are two major concerns for the Kátł'odeeche First Nation (P. Redvers, pers. comm.).

7.1 LAND USE PLANS

There are five land use planning regions within the Hay River Basin (Table 7-1). Land use plans have been developed in British Columbia and the Northwest Territories, but planning has not begun in Alberta so are not discussed further (Alberta Environment and Parks 2016).

Table 7-1 Land Use Planning Regions in the Hay River Basin

Jurisdiction	Land Use Plan
British Columbia	Fort Nelson Regional Land Use Plan (Upper Hay sub-basin)
	Fort St. John Land and Resource Management Plan (Chinchaga sub-basin)
Alberta	Lower Peace Regional Plan (Upper Hay sub-basin)
	Upper Peace Regional Plan (Chinchaga and Lower Hay sub-basins)
Northwest Territories	Dehcho Interim Measures Agreement Area (Lower Hay sub-basin)



Sources: Base Data - Government of Canada; Thematic Data - Governments of Alberta, British Columbia, and the Northwest Territories.

Disclaimer: This map is for illustrative purposes to support this Stantec project; questions can be directed to the issuing agency.

Hay River Basin and Sub-basins: Land Use Planning Regions

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Figure 7-1

7.1.1 Upper Hay Sub-Basin

The Fort Nelson Regional Land Use Plan covers portions of the Upper Hay sub-basin in British Columbia (Figure 7-1) (Government of British Columbia 2007). This plan provides high-level direction on development activities through use of resource management zones (RMZs). The RMZs provide geographically focused strategic guidance for resource development and land use. The Upper Hay sub-basin in British Columbia overlaps with two RMZs: the Etsho (for enhanced resource development) and the Hay River corridor (for general resource development).

The Etsho RMZ is designated for intense development of resources. It has a long history of oil and gas activities and some timber harvesting. Objectives for this RMZ are to:

1. "*Enhance timber harvesting and a sustainable long-term timber supply.*
2. *Maintain opportunities and access for oil and gas exploration, development and transportation*".

In the Hay River corridor RMZ (major river corridor sub-category), development of resources is expected to be integrated with other on-going activities, such as recreation, and resource values, including wildlife. Objectives for this RMZ are to:

1. "*…encourage management of resource development that supports the intended objectives and acceptable uses of the protected area, including conservation and recreation [for areas adjacent to the Hay River protected area].*
2. *Maintain integrity of island habitat.*
3. *Identify and provide for the protection of traditional use, heritage and cultural sites*".

7.1.2 Chinchaga Sub-Basin

The Chinchaga sub-basin within British Columbia is part of the Fort St. John Land and Resource Management Plan (Figure 7-1) (Government of British Columbia 1997). It overlaps with three RMZs: the Milligan Hills Protected Area, Chinchaga Lake Protected Area, and the Chinchaga. The Milligan Hills Protected Area and Chinchaga Lake Protected Area are approved protected area RMZs, while the Chinchaga RMZ is planned for general resource development.

The Milligan Hills Protected Area RMZ was established for the representation of natural diversity. The 7,931 ha area is located near the British Columbia/Alberta border and contains the headwaters of the Chinchaga River. Land management objectives for in this RMZ are to:

1. *"Provide a full range of recreation opportunities, maintain and enhance ecological integrity in areas subject to resource impacts from recreational use.*

2. *Maintain furbearer habitat for priority species.*
3. *Maintain functioning and healthy ecosystems in the RMZ, restore and rehabilitate negatively affected ecosystems.*
4. *Maintain fish habitat and water quality for priority fish species (e.g., bull trout, grayling and red and blue listed species).*
5. *Protect, over the long-term for ecological representation and natural, culture, heritage, and recreation values*".

The Chinchaga Lake Protected Area RMZ was created to protect "special features". This RMZ covers 1,389 ha and was established to protect First Nations values. There are no specific objectives for this RMZ.

The Chinchaga RMZ is an area where development of resources is expected to be integrated with other on-going activities, such as recreation, and resource values (e.g., wildlife), with no specific objectives for this RMZ.

7.1.3 Lower Hay Sub-Basin

The Dehcho Interim Measures Agreement Area includes the Lower Hay sub-basin within the Northwest Territories (Figure 7-1) and provides high-level direction through the use of Land Use Zones (LUZ) (DLUPC 2006). The plan was approved by Dehcho First Nation in June 2006 but has not been approved by the territorial or federal governments. As such, the document reflects the approved land use by First Nation communities and is used as a reference document in the regulatory process, but has no legal weight in its current state (H. Wiebe, pers. comm.). The Lower Hay sub-basin within the Northwest Territories specifically overlaps with two LUZs of the Dehcho Interim Measures Agreement Area: the Hay River (LUZ #12) and Cameron Hills (LUZ #33).

The Hay River LUZ is considered a conservation zone and is an area that has exceptional cultural and ecological values (DLUPC 2006). The only permitted land use is tourism. Objectives for this LUZ are to:

1. "*Respect community interest in protecting areas for traditional land use and occupancy, and burial sites.*
2. *Protect the scenery for the enjoyment of tourists and local residents*".

The Cameron Hills LUZ is considered a special management zone and is designated for integrated management of conservation and natural resources exploitation. Oil and gas, mining, forestry, and tourism activities are permitted uses in this LUZ, with the objective to:

1. "*Provide opportunities to continue resource development while minimizing the impacts to critical wildlife habitat*" (DLUPC 2006).

7.2 OIL AND GAS

The oil and gas sector is the predominant development pressure in the Hay River Basin. Oil and gas activity, mainly gas, occurs in the three sub-basins and jurisdictions, but primarily in British Columbia and Alberta. Oil and gas activities in the basin appear to have begun in the 1920s in the Upper Hay sub-basin.

Oil and gas production is divided into two primary resource types: crude oil (liquid hydrocarbons) and natural gas (volatile/gaseous hydrocarbons) (Natural Resources Canada 2016). Crude oil is "raw" hydrocarbon buried within rock formations and, upon extraction, is typically refined further into hydrocarbon products (e.g., gasoline, diesel, heating oil). Natural gas is primarily found in sedimentary rock formations and can occur by itself or with crude oil. Natural gas is primarily composed of methane, but can have other constituents (e.g., nitrogen, carbon dioxide, and natural gas liquids like ethane and propane) that are removed with processing (Natural Resources Canada 2016). Refined products from both crude oil and natural gas are used extensively throughout the world.

As outlined by the Alberta Energy Regulator (2016a) and Natural Resources Canada (2016), there are two main types of oil and gas resources: conventional and unconventional, which refer to the type of formation where they are found and the extraction methods used. Conventional hydrocarbon resources are trapped in rock formations that have high permeability and high porosity; the resources can move easily, making them easily extractable. Conventional extraction methods (i.e., drilling a vertical well to access the resource) are used to extract conventional resources. The availability of conventional resources has declined due to their extraction over the last century (Alberta Energy Regulator 2016a).

Unconventional, or "tight", oil and gas resources are trapped in rock formations that have low permeability and low porosity (e.g., shale gas resources, tight oil). These resources are trapped in small, poorly connected rock pores, and do not move easily, making them difficult to extract using conventional methods. Unconventional (or non-conventional) extraction methods are used for extraction as they are more economically viable. An example is hydraulic fracturing (or "fracking"), which consists of drilling a vertical well and then drilling horizontally or diagonally into the rock formation (horizontal or directional drilling) from the vertical well. Multi-stage hydraulic fracturing refers to multiple horizontal drilling from a single common vertical well. Fluid is then pumped into these wells to create pressure and break (or fracture) the rock formation to free the resource.

The following sections discuss the intensity of oil and gas resource extraction activity in each sub-basin by jurisdiction. Seismic exploration, including the extent of cutlines in each sub-basin, has not been included but should be considered for future assessment. Some of the oil and gas well data for British Columbia and/or Alberta were not available in an easily accessible database or format for mapping. This was particularly true for wells that have been hydraulically fractured and for those identified as "confidential" (i.e., well records that are not available or open for public inspection [in Alberta only]; see Section 7.2.1.2 for further explanation). In this report, therefore, information on hydraulically fractured wells was not included for British Columbia; for Alberta, only the number of hydraulically fractured wells, by sub-basin, was available.

7.2.1 Upper Hay Sub-basin

7.2.1.1 British Columbia

The oil and gas sector is the most active industry sector in this sub-basin (Figure 7-2), and its development is a priority identified for the Etsho RMZ in the Fort Nelson Regional Land Use Plan (Government of British Columbia 2007; see Section 7.1.1). There are eight gas (Helmet, Shekilie, Ekwan, Bivouac, Junior, Sierra, Kyko, Kotcho Lake East, Kotcho Lake) and two oil formations (Toga and Hay River) underlying approximately half of the area of the Upper Hay sub-basin in British Columbia (Government of British Columbia 2016b).

The oil and gas sector has been active in this area for several decades, mainly for gas resources. The first well was drilled in 1956 and 92% of the wells have been drilled since 1990 (Government of British Columbia 2016b). Well locations are shown in Figure 7-2. As of December 2015, there were 960 active wells, 900 abandoned wells (reported as abandoned, completed, or cancelled), and 224 wells with potential to be exploited in the future (authorization has been granted, casing built, and/or suspended status) (Government of British Columbia 2016b). The majority of these wells (850 active, 321 abandoned, 131 potential) were non-vertically drilled, which is also called "directional" in the data source.

Although there are data on wells that are or have been hydraulically fractured in British Columbia, the data are not available in an easily accessible format (e.g., GIS shapefiles) and were not included in this report. Natural Resources Canada (2016) reported that as of December 2014, up to 75% of total gas production in British Columbia came from unconventional methods, such as hydraulic fracturing.

Infrastructure associated with the oil and gas sector, including pipelines and roads (Figure 7-3), has also left a visible footprint on the landscape (Government of British Columbia 2016b), with 2,639 km of pipeline and 2,194 km of oil and gas resource roads in the Upper Hay sub-basin of British Columbia.

Management of drilling waste can also affect the basin. Wells may be drilled using water or an oil-based mud system; the latter can introduce contaminants to soil and water. In British Columbia, drilling wastes are disposed of at either a sump location or a waste disposal site. As of December 2015, there were 74 sump locations and 150 waste disposal sites in the Upper Hay sub-basin in British Columbia (Government of British Columbia 2016b) (Figure 7-4). Drilling wastes buried in sump locations must meet criteria to qualify for disposal and are considered "clean waste"; drilling waste that contains contaminants that cannot be disposed of in sumps is sealed and sent to specific waste disposal sites managed by the British Columbia Ministry of the Environment (BC Oil and Gas Commission 2012; A. Khan pers. comm.). The waste disposal sites may also contain industrial waste generated by other industries.

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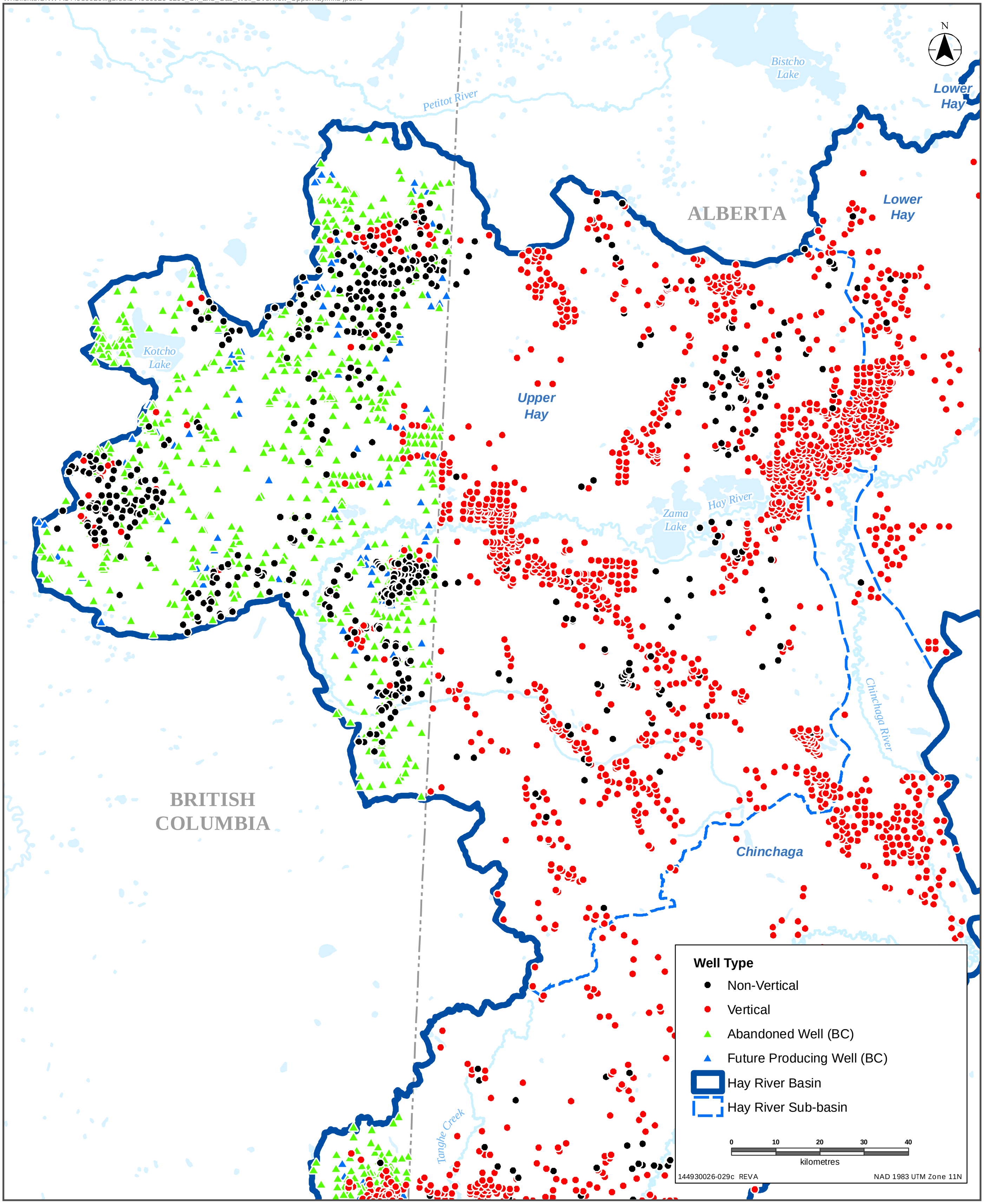

Sources: Base Data - Government of Canada; Thematic Data - Government of Canada, GeoLOGIC (2015), and The Government of British Columbia (2016).

Disclaimer: This map is for illustrative purposes to support this Stantec project; questions can be directed to the issuing agency.

Note: Alberta Well data includes the following substance types: brine, crude bitumen, crude oil, gas, waste, water, and unknown.

Hay River Basin and Sub-basins: Overview of Oil and Gas Wells in Upper Hay Sub-basin

Figure 7-2

Stantec

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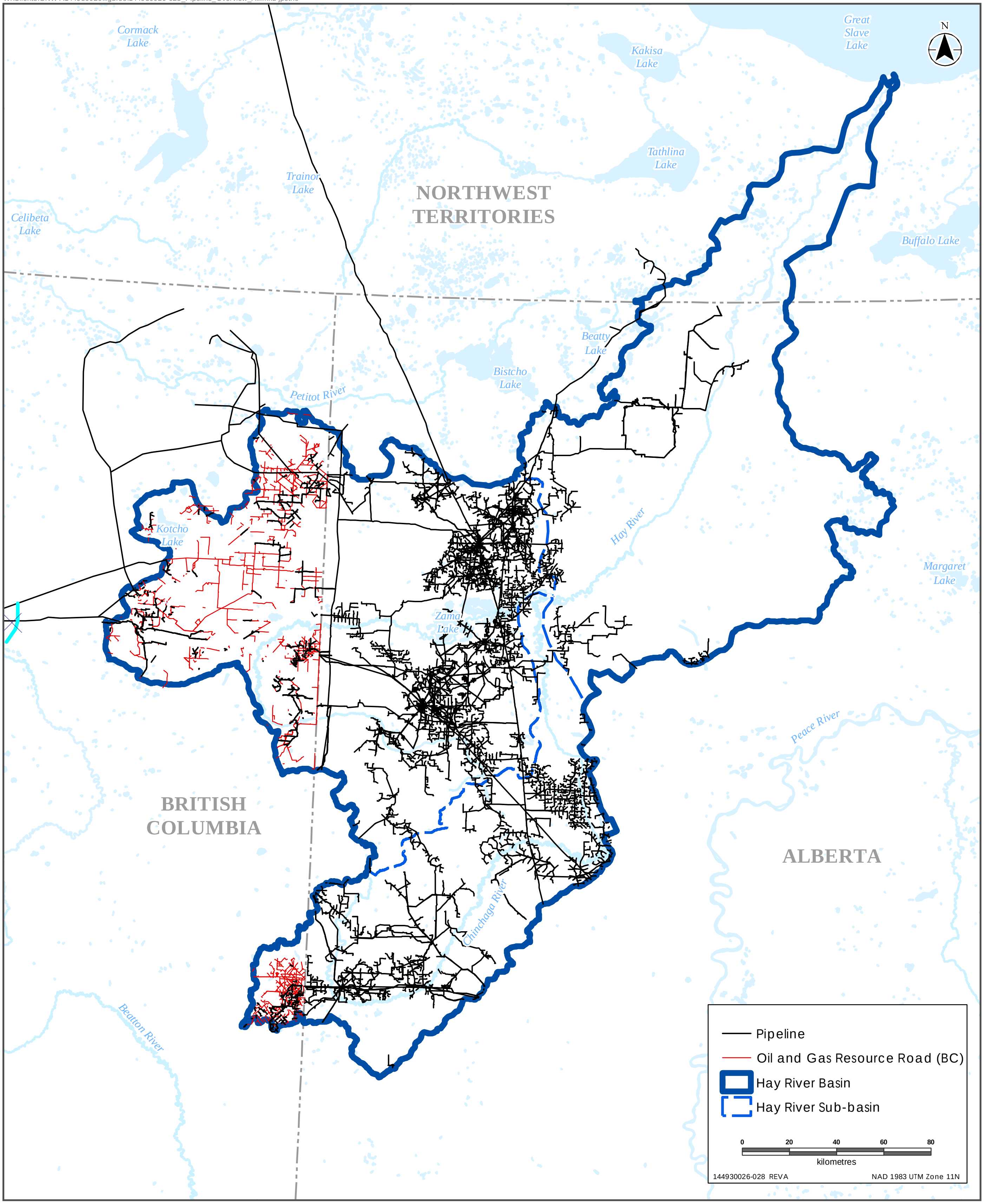


Sources: Base Data - Government of Canada; Thematic Data - Government of Canada, GeoLOGIC (2015), The Government of British Columbia (2016), and NWT Centre for Geomatics, Informatics Shared Service Centre, Government of the Northwest Territories, 2015-2016

Note: Alberta pipeline data includes pipelines with a status of: operational, non operational, not constructed, and unknown. It excludes features with a status of not approved.

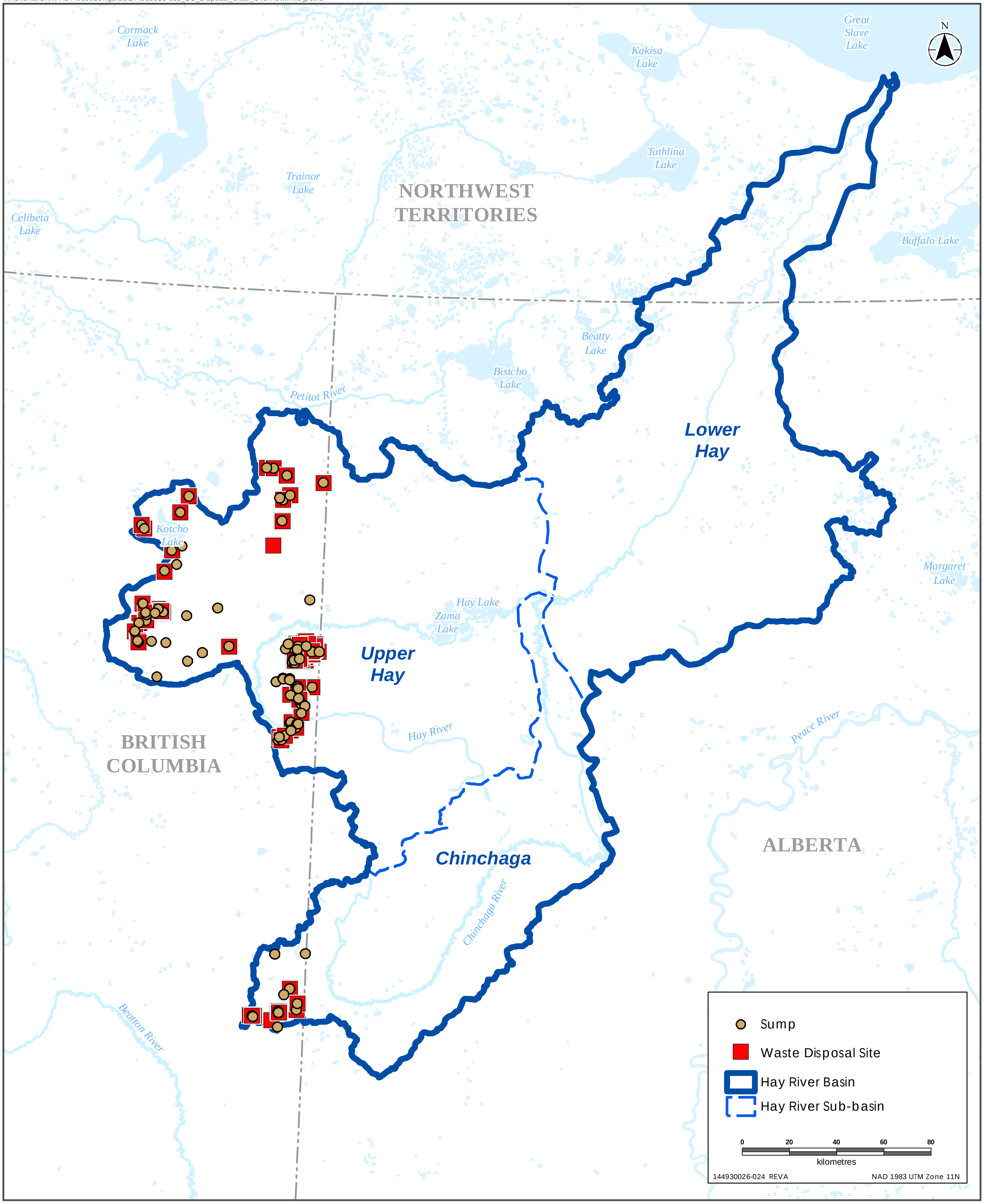
Disclaimer: This map is for illustrative purposes to support this Stantec project; questions can be directed to the issuing agency.

Hay River River Basin and Sub-basins:
Overview of Oil & Gas Pipelines and Resource Roads
in British Columbia and Alberta

Figure 7-3

Stantec

W:\Clients\GNWT\144930026\figures\144930026-025_BC_Disposal_Sites_Overview.mxd jpetho



Sources: Base Data - Government of Canada; Thematic Data - Government of Canada, and The Government of British Columbia (2016).

Disclaimer: This map is for illustrative purposes to support this Stantec project; questions can be directed to the issuing agency.

Hay River Basin and Sub-basins: Overview of Sumps and Waste Disposal Sites in British Columbia

Stantec

Figure 7-4

In British Columbia, oil and gas projects are evaluated through a process managed by the British Columbia Oil and Gas Commission, not through the British Columbia *Environmental Assessment Act* (Government of British Columbia 2016c; A. Gerrard, pers. comm.).

7.2.1.2 Alberta

The oil and gas sector in the Alberta portion of the Upper Hay sub-basin is also very active (Figure 7-2 and Figure 7-3) (Geologic Systems 2015). Three oil and gas fields lie below the Hay-Zama Lakes area, with the Rainbow oil field considered one of the most productive in the country (GNWT and GC 1984). Oil and gas activity in the area has been going on for over four decades (Hatfield 2009). In 1999, the Government of Alberta, conservations groups, First Nations, and the oil and gas industry came into an agreement to ban further oil and gas activity in the Hay-Zama Lakes area once currently identified resources are exhausted and current commitments fulfilled (ATPRC 2007). The time period for this reduction in activities is not known.

In the Alberta portion of Upper Hay sub-basin, 1,346 non-confidential oil and gas wells have been identified (Figure 7-2), though information distinguishing active from abandoned wells was not available from the data source used (Geologic Systems 2015). Of these, 199 wells have been non-vertically drilled (listed as directionally, horizontally, and slant-drilled wells in the data source) (Figure 7-2). Similar to British Columbia, data exist for wells that are or have been hydraulically fractured in Alberta; however, geographic data for these wells were not available in an easily accessible format for inclusion in this report. From the data that are available, the total number of hydraulically fractured wells in the Alberta portion of the Upper Hay sub-basin was reported at 14 wells (S. Guha, pers. comm.). Additionally, in Alberta, "non-confidential" wells include those well records that are available or open for public inspection. This excludes wells currently considered "confidential" based on certain criteria (e.g., exploratory well, regulatory reasons, extenuating circumstances, investment purposes). The Alberta Energy Regulator typically assigns a one-year period to confidential well status but can release the well to non-confidential status at any time through the well's first year; the confidential well list is updated on a daily basis (Alberta Energy Regulator 2016b). Similar to hydraulically fractured wells, however, data exist on confidential wells in Alberta but, given the daily updates and lack of readily accessible geographic data, they were not included in this report.

There is an extensive network of pipelines, many inactive, around the Hay-Zama and Rainbow Lakes areas (Figure 7-3) to support the oil and gas sector (Government of Alberta 2011). Exploration and access roads in the Hay-Zama Lakes area have left the surrounding forests in a fragmented state (Bird Life Canada 2015a). The largest pipeline in the Upper Hay sub-basin within Alberta is the 869 km long Enbridge (NW) Pipeline, which transports crude oil from Norman Wells, Northwest Territories, to Zama City, Alberta (Enbridge 2011). The pipeline was completed in 1985 and has a capacity of 50,000 barrels per day (Enbridge 2011). Zama City appears to be a connection point for several other pipeline networks that transport crude oil and natural gas throughout Canada and the United States (CEPA 2014).

Information on disposal sites for drilling waste was not available for Alberta.

The Government of Alberta has issued 44 approvals for oil and gas activities in the Upper Hay sub-basin (Figure 7-5); this includes Codes of Practice, *Water Act* approvals, and approvals under the Alberta *Environmental Protection and Enhancement Act* (EPEA). Codes of Practice are granted for activities of low intensity that do not require a full *Water Act* approval. A *Water Act* approval is required to conduct activities in a water body and the review process is more rigorous than Codes of Practice. Larger projects (e.g., landfills, gas plants, new pipelines) that affect air, land, or water at a broader scale typically require EPEA approvals.

Five Codes of Practice, three *Water Act* approvals, and six EPEA approvals were issued (Government of Alberta 2015):

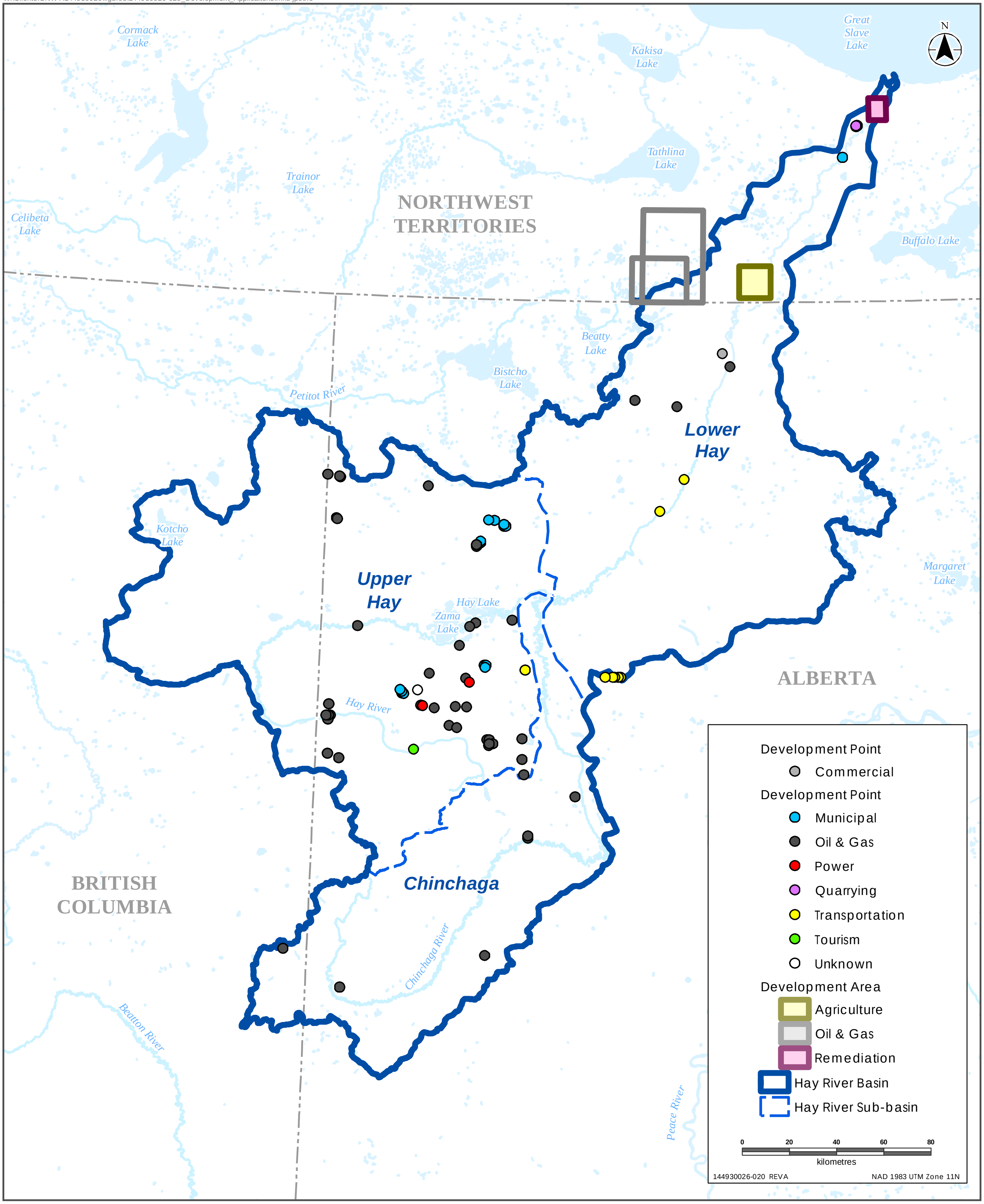
- Codes of Practice were issued to conduct hydrostatic testing on two pipelines, activities related to the Sousa and Rainbow Lake compressor stations, and activities for the Rainbow Lake sour gas processing plant.
- *Water Act* approvals were issued for construction of infrastructure, building of a drilling platform, and remediation of contaminated surface and groundwater (GAB 2015).
- The EPEA approvals were granted for activities related to three sour gas processing plants (Rainbow Lake, West Basset Lake, and Zama 1, 2 and 3), two sweet gas processing plants (East Rainbow and Rainbow), and construction of a new pipeline lateral (Zama Lake and Shekilie River lateral) connecting into British Columbia.

7.2.2 Chinchaga Sub-Basin

7.2.2.1 British Columbia

The most active development pressure in the Chinchaga sub-basin within British Columbia is from the oil and gas sector (mainly gas) from a network of roads and pipelines, wells, and waste disposal sites. Locations of wells in the Chinchaga sub-basin are shown in Figure 7-6 while pipelines and other infrastructure are shown in Figure 7-3. Two gas formations (Chinchaga River and Drake) span approximately half the sub-basin in British Columbia. The first well was drilled in 1921; however, most of the activity is relatively recent, with 80% of the wells drilled after 1990 (Government of British Columbia 2016b). As of December 2015, 258 wells were listed as active non-confidential wells, 152 were listed as abandoned (abandoned, completed or cancelled status), and 40 were listed as having the potential to be exploited in the future (authorization granted, casing built, and/or suspended status).

The majority of wells are vertically drilled, with only 39 active, 38 abandoned, and 20 potential non-vertically drilled wells listed. Although there are data on wells that are or have been hydraulically fractured in British Columbia, these data are not available in an easily accessible format (e.g., GIS shapefiles) and were not included in this report.



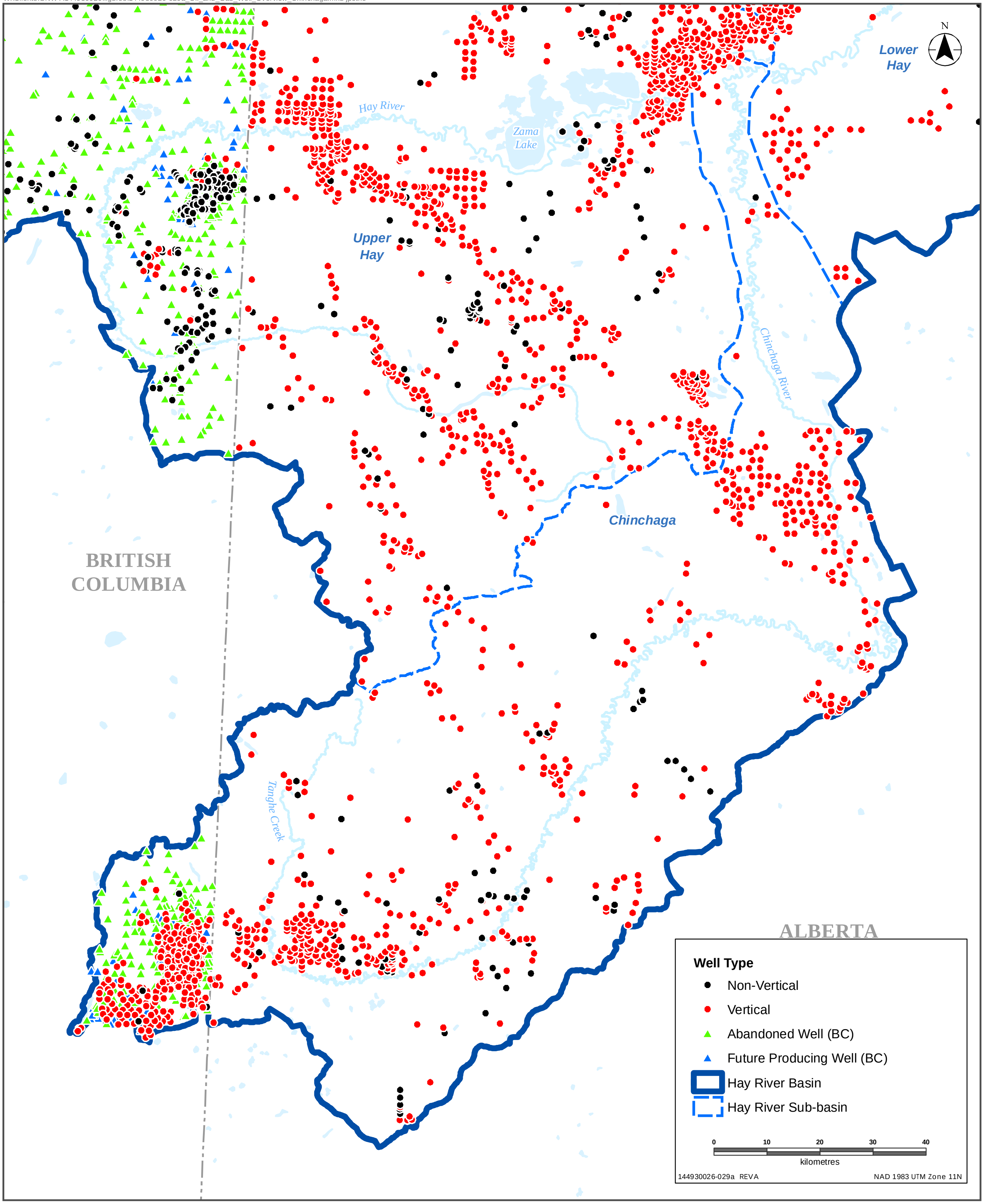
Sources: Base Data - Government of Canada; Thematic Data - Government of Canada, Government of Alberta (2015), British Columbia Oil and Gas Commission (2015), and Mackenzie Valley Land and Water board (2015).

Disclaimer: This map is for illustrative purposes to support this Stantec project; questions can be directed to the issuing agency.

Hay River Basin and Sub-basins:
Overview of Approved Development Applications

Stantec

Figure 7-5



Sources: Base Data - Government of Canada; Thematic Data - Government of Canada, GeoLOGIC (2015), and The Government of British Columbia (2016).

Disclaimer: This map is for illustrative purposes to support this Stantec project; questions can be directed to the issuing agency.

Note: Alberta Well data includes the following substance types: brine, crude bitumen, crude oil, gas, waste, water, and unknown.

Hay River Basin and Sub-basins: Overview of Oil and Gas Wells in Chinchaga Sub-basin

Figure 7-6

As of December 2015, there were 24 sump locations for burial of "clean" drilling waste and 9 waste disposal sites, managed by the British Columbia Ministry of Environment, located in the British Columbia portion of the Chinchaga sub-basin (Figure 7-4) (Government of British Columbia 2016b).

The Ring Border Gas Plant Expansion has been the only project requiring an environmental assessment under the British Columbia *Environmental Assessment Act* in this portion of the Chinchaga sub-basin. In 1997, Canadian Hunter Exploration Ltd. requested approval from the Government of British Columbia to expand its natural gas processing plant, with approval granted in January 1998 (Government of British Columbia 2016c; A. Gerrard, pers. comm.).

7.2.2.2 Alberta

The oil and gas sector (mostly gas) is active in the Alberta portion of the Chinchaga sub-basin, with associated pipeline infrastructure and road access to support the sector (see Figure 7-6 for wells and Figure 7-3 for other infrastructure) (Government of Alberta 2011). In the Alberta portion of the sub-basin, 593 non-confidential wells were identified, of which 83 have been non-vertically drilled; information distinguishing active from abandoned wells was not available from the data source used (Geologic Systems 2015); see Figure 7-6. Geographic data for hydraulically fractured wells, or confidential wells in Alberta were not available in an easily accessible format for inclusion in this report. However, of the hydraulic fracturing data that are available, seven wells were reported as hydraulically fractured in the Alberta portion of the Chinchaga sub-basin (S. Guha, pers. comm.).

In the Chinchaga sub-basin of Alberta, three Codes of Practice and two EPEA approvals (Figure 7-5) have been issued for the oil and gas sector (Government of Alberta 2015):

- Codes of Practice were issued for a pipeline crossing of an unnamed stream and for the Boyer (Haig River) sweet compressor station
- EPEA approvals were granted for the Botha and Hamburg sour gas processing plants

Information on disposal sites for drilling waste in Alberta was not available.

7.2.3 Lower Hay Sub-Basin

7.2.3.1 Alberta

The oil and gas sector (mainly gas) is the main development pressure in the Lower Hay sub-basin within Alberta (Government of Alberta 2011). The pipeline network created to support development in the Upper Hay sub-basin extends into the western portion of the Lower Hay sub-basin, west of Highway 35 (Figure 7-3) (Geologic Systems 2015). A pipeline also borders and crosses the Hay River between Steen River and Indian Cabins in the Lower Hay sub-basin of Alberta (Figure 7-3).

Most of the drilling activity occurs on the western side of the sub-basin, bordering the Upper Hay sub-basin (Figure 7-7), with 409 non-confidential wells identified, 98 of which have been non-vertically drilled. Information distinguishing active from abandoned wells was not available, nor was information on drilling waste disposal sites from the data source used (Geologic Systems 2015). Geographic data on hydraulically fractured or confidential wells were not available in an easily accessible format for inclusion in this report. However, of the data available for hydraulic fracturing wells, 23 wells were reported as hydraulically fractured in the Alberta portion of the Lower Hay sub-basin (S. Guha, pers. comm.).

The Government of Alberta issued three approvals for oil and gas activity in the Lower Hay sub-basin of Alberta: one *Water Act* approval for an unspecified construction activity, and two EPEA approvals for two sour gas processing plants (Marlowe and Steen River) (Figure 7-5) (Government of Alberta 2015).

7.2.3.2 Northwest Territories

Currently there are 45 oil and/or gas wells in the Northwest Territories portion of the Lower Hay sub-basin, 28 of which are abandoned (see Figure 7-8a below, and Figure 7–8b in Appendix D) (OROGO 2016). A permit (MVLWB file MV2014X0020) to remediate seven gas wells drilled between 1922 and 1947, approximately 10 km south of the Town of Hay River, is held by AANDC (Figure 7-5 and Figure 7-8a, as well as Figure 7–8b in Appendix D) (Mackenzie Valley Land and Water Board 2015).

There are numerous gas leases on the northwest slope of the Caribou Mountains in the Cameron Hills area of the Kakisa Basin, just west of the Lower Hay sub-basin in the Northwest Territories (DLUPC 2006). Some leases extend into the Lower Hay sub-basin, in an area that contains the headwaters for tributaries of the Hay River (AANDC 2014). There is potential for gas activity in the Cameron Hills area to affect aquatic resources in the Hay River Basin. Six significant discovery oil and gas licences and seven production leases are located in this part of the Lower Hay sub-basin (Figure 7-8a) (Government of the Northwest Territories 2015b).

In 2002, a land use permit (MVLWB file MV2002B0057) was issued to Paramount Resources Ltd. for access, construction, and operation of a low impact 3-D seismic program. This lease is partially located within the Hay River Basin. The permit was closed in 2007 (Mackenzie Valley Land and Water Board 2015). Strategic Oil and Gas acquired Paramount's Cameron Hills project in 2013 and holds active land use and water use permits to conduct activities relating to oil and gas exploration and development, construction, operation and maintenance. As outlined in Section 6.4.2, activities at in the Cameron Hills site were shut down in February 2015 due to unfavourable economic conditions (Strategic Oil and Gas 2015) and it appears that only maintenance activity has occurred since then.

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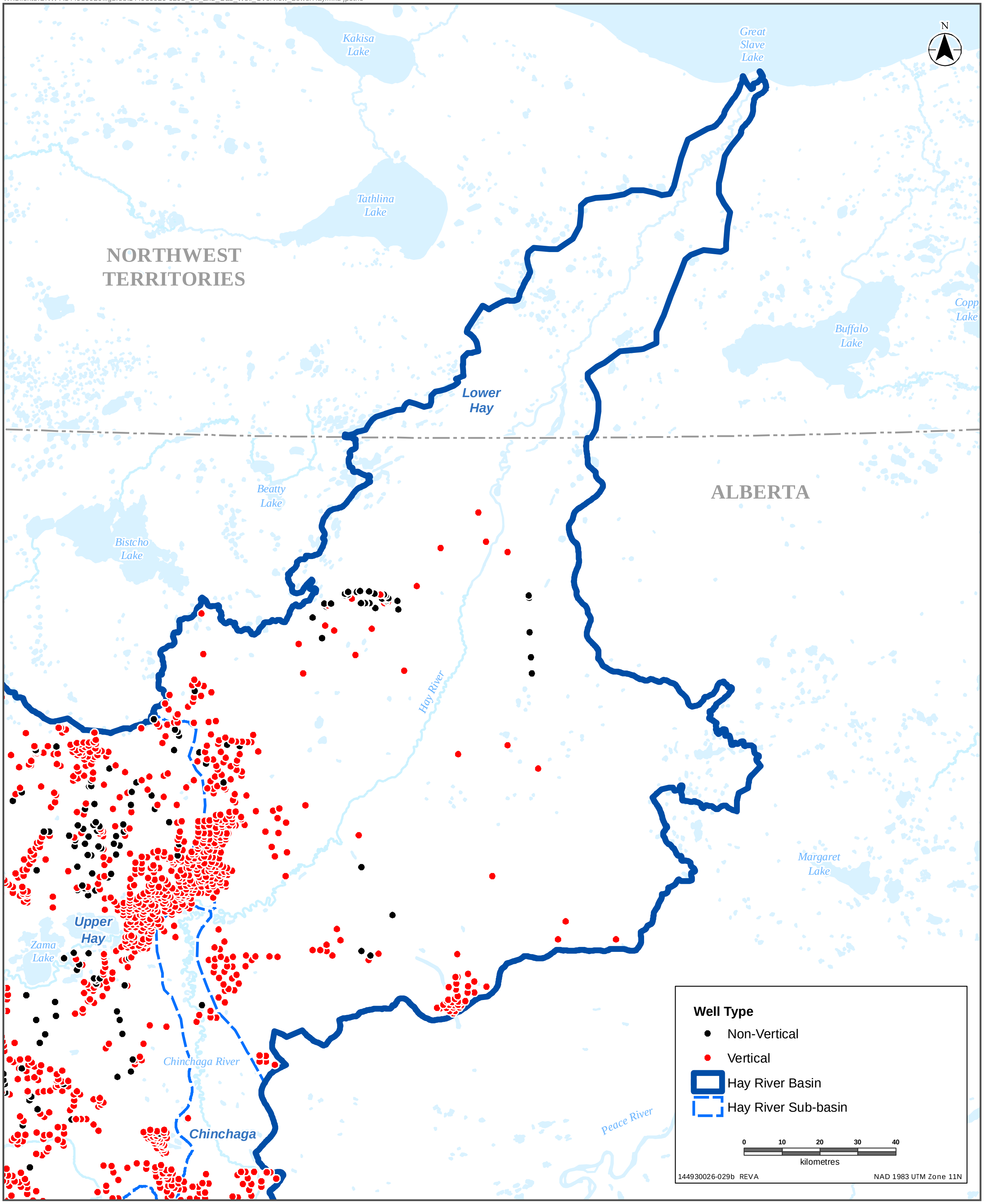


Sources: Base Data - Government of Canada; Thematic Data - Government of Canada, GeoLOGIC (2015), and The Government of British Columbia (2016).

Disclaimer: This map is for illustrative purposes to support this Stantec project; questions can be directed to the issuing agency.

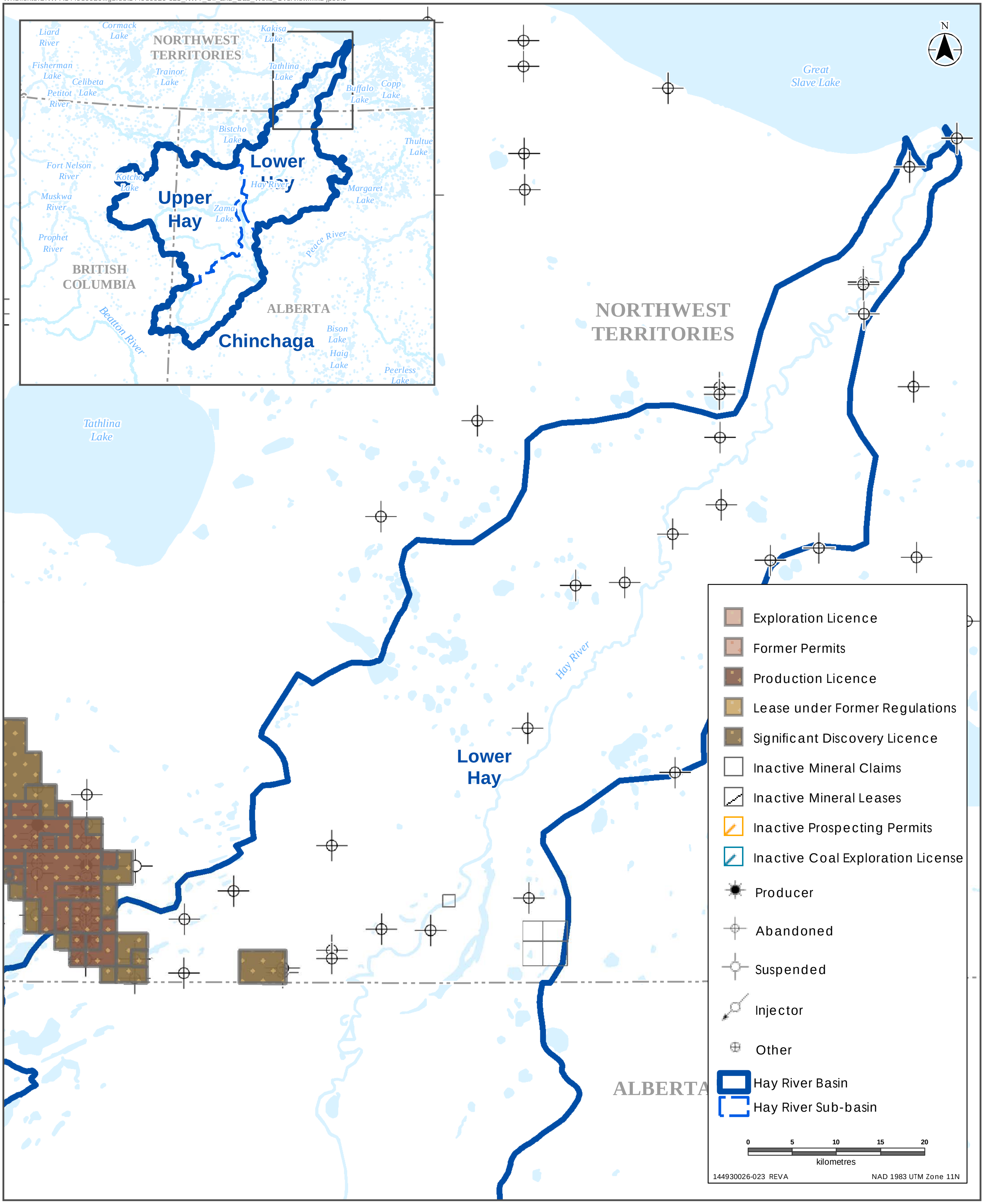
Note: Alberta Well data includes the following substance types: brine, crude bitumen, crude oil, gas, waste, water, and unknown.

Hay River Basin and Sub-basins: Overview of Oil and Gas Wells in Lower Hay Sub-basin of Alberta

Figure 7-7

Stantec

W:\Clients\GNWT\144930026\figures\144930026-023_NWT_Oil_and_Gas_Wells_Overview.mxd jpetho



Sources: Base Data - Government of Canada; Thematic Data - Government of Canada; NWT Centre for Geomatics, Informatics Shared Service Centre, Government of the Northwest Territories, 2015-2016

Disclaimer: This map is for illustrative purposes to support this Stantec project; questions can be directed to the issuing agency.

Hay River Basin and Sub-basins:
Overview of Oil and Gas **Activity** in the Lower Hay Sub-basin of the Northwest Territories

Stantec

Figure 7-8a

7.2.4 Potential Effects from the Oil and Gas Sector

The oil and gas sector (mainly gas) is active in all three sub-basins, but is most active in the Upper Hay and Chinchaga sub-basins (Figure 7-2, Figure 7-6 to Figure 7-8a, and Figure 7–8b in Appendix D). Oil and gas operations could result in potential effects on health of the aquatic ecosystem, related to contaminants in drilling fluids, drilling wastes, and spills; soil erosion during construction; and habitat fragmentation associated with access road and pipeline construction.

Constituents used in the well drilling process, including conventional and unconventional methods, have the potential to reach the aquatic environment (BC Oil and Gas Commission 2012). Drilling fluids may contain bactericides, corrosion inhibitors, defoamers, emulsifiers/de-emulsifiers, foaming agents, lubricants, polymer stabilizers/breakers, shale control inhibitors, and surfactants. These contaminants, along with saltwater injections used during the drilling process, and drilling and oilfield waste disposal sites, could enter groundwater aquifers (GNWT and GC 1984; Cobbert and Wolanski 2011; North/South Consultants et al. 2007). Contaminants could be released if incomplete or improper casing or cementing occurs during well installation, which may allow the migration of oil, gas, salt, or drilling fluids into groundwater or nearby surface waters. Contaminants from drilling waste sumps and disposal sites could also leach into groundwater. Though sumps are considered "clean" waste sites in British Columbia (A. Khan, pers. comm.), high concentrations of salts and metals have been identified at sump locations (Crowe et al. 2008).

Spills from oil and gas activities, including breaches of pipelines in the extensive network shown in Figure 7-3, can also introduce contaminants to the aquatic or terrestrial environment (GNWT and GC 1984, Cobbert and Wolanski 2011; North/South Consultants et al. 2007). A breach from an oil pipeline crossing the Hay River or a tributary would release hydrocarbons into the water and directly affect Hay River water quality (Hatfield 2009). Breaks in gas pipelines are not expected to directly affect water quality given that the gas is largely expected to volatilize.

A pipeline leak detected in June 2013 about 20 km northeast of Zama City resulted in release of 15,400 m^3 of industrial wastewater (process water, consisting of water, oil, and other chemicals, with high salt content) to 42 ha of surrounding wetland and muskeg areas, but no releases to the Zama River. At that time, leakage of 12 barrels of oil, covering about 4 km^2 in area, was also detected. The company, Apache Canada, cleaned up and remediated the site, and was charged by the Alberta Energy Regulator (Apache Canada 2013; CBC News 2015).

Soil erosion and subsequent increased sedimentation in waterbodies may also be associated with oil and gas activities (Severson-Baker 2006; Hatfield 2009). Construction of access roads, seismic cutlines (for oil and gas exploration), and well pads requires removal of vegetation that would normally prevent soil erosion. The exposed soil can erode and introduce sediment to streams. Increased sedimentation in streams can, for example, affect fish by decreasing hatching success, affecting spawning habitat, decreasing feeding rates, and inducing stress and a change in behaviour (Canadian Association of Petroleum Producers 2005).

Fragmentation of the landscape from construction of linear features, such as roads and pipeline right-of-ways and seismic cutlines, reduces the size of habitat patches used by wildlife, may disrupt wildlife movements (Severson-Baker 2006), and can fragment both terrestrial and aquatic ecosystem. For example, stream crossings of access roads, pipelines, or culverts can create physical barriers to fish movement and alter flow during instream work, causing dewatered or shallower areas downstream, resulting in habitat loss or fish mortality (Canadian Association of Petroleum Producers 2005). Many guidelines, codes of practice and best practices are available to minimize effects on the aquatic environment from stream crossings (e.g., BC Ministry of Water, Land, and Air Protection 2004; Canadian Association of Petroleum Producers 2005; Alberta Transportation 2009; Indian and Northern Affairs Canada 2010; BC Ministry of Forests, Lands, and Natural Resource Operations et al. 2012; Alberta Environment and Sustainable Resource Development 2013).

7.3 FORESTRY

The forestry sector is the second most active development pressure in the Hay River Basin and occurs in all three sub-basins. Forestry activities include timber harvesting (typically clear-cutting) and the construction, operation, and maintenance of associated forestry resource roads. The following sections discuss the level of forestry activity in each sub-basin by jurisdiction.

Forestry activities in British Columbia are authorized through a tenure system, whereby the Government of British Columbia transfers rights to private forest companies, communities, and individuals to use forest resources on public (Crown) land (British Columbia Ministry of Forests, Lands and Natural Resources 2012). Timber tenures can be assigned through agreements, licences, or permits that are specific to the type of use and period of time (British Columbia Ministry of Forests, Lands and Natural Resources 2012).

In Alberta, timber harvesting on public (Crown) land is managed under the *Forest Act* through Forest Management Units. The majority of the Hay River Basin in Alberta is located on public land, where logging is managed under this system. Forest Management Agreements are used to allocate harvesting rights to large proponents within the Forest Management Units. Any remaining Forest Management Units are areas that have not been allocated for timber harvesting (AESRD 2011).

In the Northwest Territories, forestry activities are regulated through timber cutting permits and licences issued by the Government of the Northwest Territories, and through land use permitting by the Mackenzie Valley Land and Water Board, or other applicable regional management boards. Residents can also obtain a free permit to harvest fire wood.

7.3.1 Upper Hay Sub-Basin

7.3.1.1 British Columbia

The forestry sector is the second most active development pressure in the Upper Hay sub-basin within British Columbia, mostly related to historical activity (Figure 7-9). As of December 2015, a total of 7,588 ha of land are identified as cutblocks in the Upper Hay sub-basin of British Columbia, with one active timber licence (8 ha), 213 retired timber licences (7,573 ha), and one license with an "unknown" status (7.5 ha) (Figure 7-9) (Government of British Columbia 2016b). The activities allowed under these tenures include construction, use, and maintenance of resource roads required for logging and timber salvage (J. Wynrib, pers. comm.).

Road infrastructure associated with the forestry sector has also left a footprint on the landscape (Figure 7-9). Future activity levels in the forestry sector are not known, though this sector is identified for the Etsho RMZ in the Fort Nelson Regional Land Use Plan (Section 7.1.1; Government of British Columbia 2007).

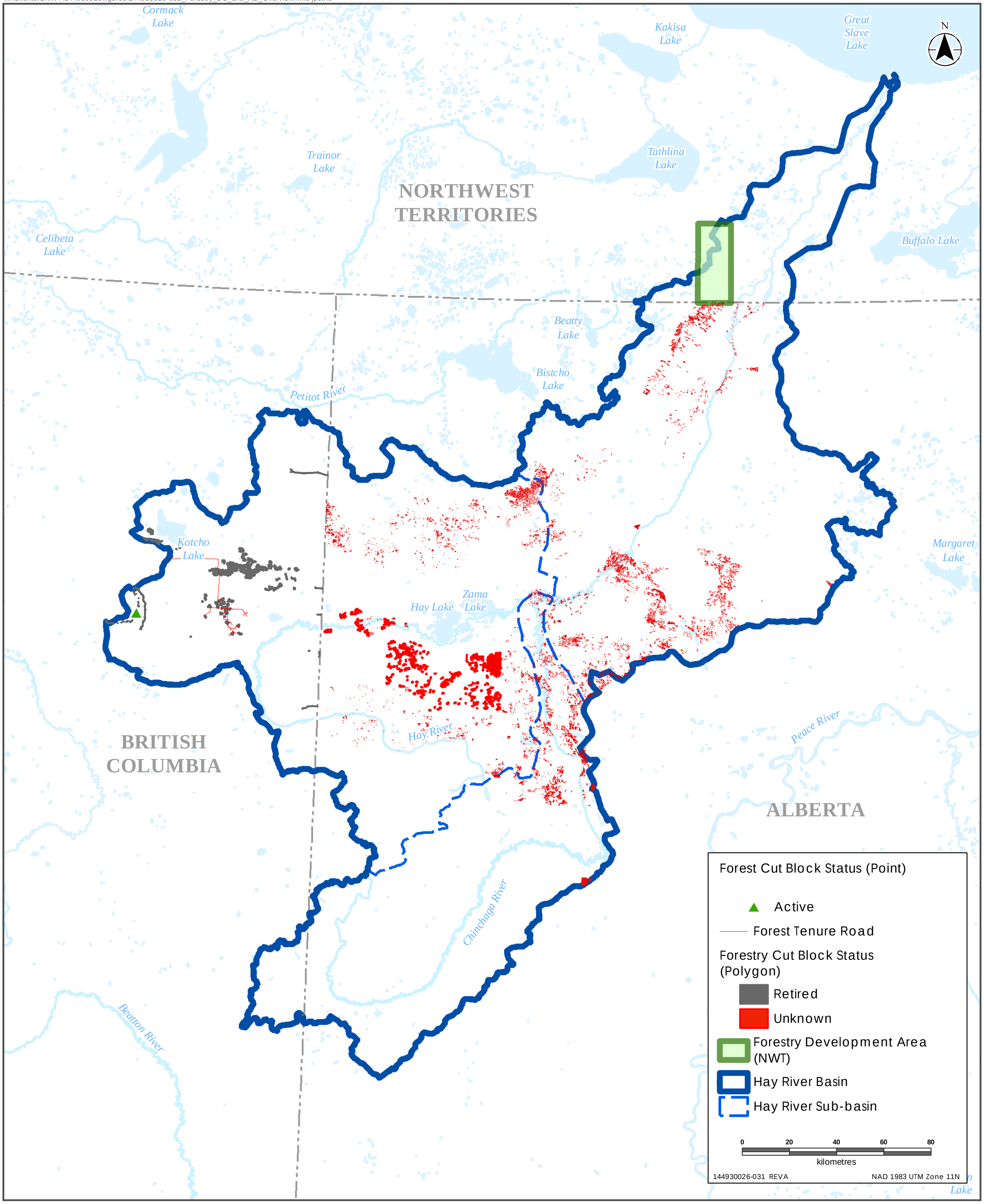
7.3.1.2 Alberta

The Upper Hay sub-basin in Alberta overlaps with two unallocated Forest Management Units (F14 and P8) and two allocated Forest Management Agreements (F26 and P20) (AESRD 2012b). Forestry data for Alberta spans the period 1991 to 2015 (D. Coombs, pers. comm.), and as of 2015, forestry cut blocks in the sub-basin cover an area of 30,690 ha, and are primarily located in the agreement for F26 (Figure 7-9). The proponent exploiting F26 also owns the 88 surface water licences allocated to the forestry sector in this part of the sub-basin (Section 6.2.2, Figure 6-1).

7.3.2 Chinchaga Sub-Basin

7.3.2.1 British Columbia

The level of forestry activity in the Chinchaga sub-basin of British Columbia is low, with only one forestry road identified (Government of British Columbia 2016b). As of December 2015, one retired timber licence (1.1 ha) was identified (Figure 7-9). Similar to the Upper Hay, data depicted in Figure 7-9 show the location of the tenure (J. Wynrib, pers. comm.).



Sources: Base Data - Government of Canada; Thematic Data - Government of Canada, The Government of Alberta, The Government of British Columbia, and Mackenzie Valley Land and Water board (2015).

Disclaimer: This map is for illustrative purposes to support this Stantec project; questions can be directed to the issuing agency.

Hay River Basin and Sub-basins:
Overview of Forestry Activity

Stantec

Figure 7-9

7.3.2.2 Alberta

The 1991 to 2015 cut block data show some timber harvesting in the Chinchaga sub-basin within Alberta, primarily in the northern portion of the sub-basin (Figure 7-9). Within the Chinchaga sub-basin, there are three unallocated Forest Management Units (P8, PO3 and M1) and three allocated Forest Management Agreements (P19, P20 and F26) (AESRD 2012b). As of 2015, forestry cut blocks in the Alberta portion of the sub-basin covered an area of 16,962 ha. In 2003, the Government of Alberta banned logging in 350,000 ha of the P8 Forest Management Unit, adjacent to Chinchaga Wildland Provincial Park, as a result of pressures from conservationists to expand the park (CPAWS 2005). In addition, a large part of the sub-basin near Chinchaga Wildland Provincial Park burned in the 1950s (Alberta Wilderness Association 2016).

7.3.3 Lower Hay Sub-Basin

7.3.3.1 Alberta

The Lower Hay sub-basin within Alberta overlaps with one unallocated Forest Management Unit (F10) and one allocated Forest Management Agreement (F26) (AESRD 2012b). The 1991 to 2015 dataset shows forestry cut blocks in the southern and western portion of the sub-basin, bordering the Chinchaga and Upper Hay sub-basins, and in the northern portion of the sub-basin bordering the Northwest Territories (Figure 7-9). A total of 37,895 ha has been dedicated to forestry cutblocks in the Lower Hay sub-basin of Alberta.

7.3.3.2 Northwest Territories

Some forestry activity occurs in the Northwest Territories portion of the Lower Hay sub-basin. Patterson Sawmill Ltd. (MVLWB file MV2014W0017) holds a land use permit to harvest timber in the Cameron Hills area, west of the Hay River. Most of the area covered under this permit is within the Hay River Basin, but a small portion extends into the adjacent Kakisa River Basin (Figure 7-9) (Mackenzie Valley Land and Water Board 2015). Patterson Sawmill Ltd. has been in operation since the 1970s (DLUPC 2006); however, their current extent of cut block activity was not available for this report.

The future of forestry activities in the Northwest Territories portion of the Hay River Basin is unclear. High timber potential has been identified along the Hay River, just north of the Alberta/Northwest Territories border, and between Enterprise and the Town of Hay River (O'Brien and Mak 2006). However, no land use permits for forestry activities have been submitted in this area.

7.3.4 Potential Effects from the Forestry Sector

The forestry sector is the second most active development pressure in the Hay River Basin, but overall activity levels appear relatively low. A total of 93,136 ha of forest have been assigned to cut blocks, roughly split between the Upper Hay and Lower Hay sub-basins, largely in Alberta. Forestry activity has the potential to adversely affect aquatic ecosystems through changes in stream or river hydrology (e.g., flow quantity, flow patterns, yield), water quality (e.g., elevated temperature or TSS, turbidity, and nutrient levels), and physical habitat (woody debris and other forms of cover). Vegetation clearing can increase sedimentation through erosion of exposed soils, increase the quantity of water entering the aquatic ecosystem (e.g., the water no longer absorbed by vegetation), and increase water temperature due to the lack of shade provided by vegetation (Hatfield 2009; Regional Aquatics Monitoring Program 2016). Access road construction and presence can lead to barriers to fish migration at watercourses crossings.

There are many guidelines, codes of practice and best practices in place in each jurisdiction to minimize effects on the aquatic environment from forestry activities, including construction, operation, and maintenance of associated access roads and stream crossings (e.g., BC Ministry of Water, Land, and Air Protection 2004; Alberta Transportation 2009; Indian and Northern Affairs Canada 2010; BC Ministry of Forests, Lands, and Natural Resource Operations, et al. 2012; Alberta Agriculture and Forestry 2016b).

7.4 MUNICIPAL

The municipal sector represents a relatively low development pressure in the Hay River Basin, with 10 small communities, 8 in Alberta and 2 in the Northwest Territories (Figure 1-10). The Town of Hay River is the largest, with 3,398 residents (Statistics Canada 2015; Section 1.5.1).

7.4.1 Upper Hay Sub-Basin

7.4.1.1 Alberta

Rainbow Lake, Zama City, and Chateh are the only three communities located in the Upper Hay sub-basin within Alberta (Figure 1-10). Chateh and the Town of Rainbow Lake both hold licences to withdraw surface water (see Section 6.1.1). Mackenzie County holds a licence, with no expiry, to withdraw groundwater for Zama City. The Alberta government issued six authorizations to these municipalities under EPEA (Figure 7-5). There are registrations under the Code of Practice for Zama City and the Town of Rainbow Lake for their wastewater systems (wastewater lagoons). The lagoons must be constructed, operated, and reclaimed according to the Code of Practice (Alberta Environment 2003). There are also approvals for the water treatment plants and distribution systems for the Mackenzie Region, for the Rainbow Lake water treatment plant and distribution system, and for Class II industrial landfills at Rainbow Lake and Zama City. The Mackenzie Region approval covers the Fort Vermillion, La Crete, and Zama City water treatment plants and distribution systems (only Zama City is in the Hay River Basin). Further information on the level of wastewater treatment (e.g., primary, secondary, tertiary) at Zama City and Rainbow Lake was not available.

7.4.2 Chinchaga Sub-Basin

No communities were identified in the Chinchaga sub-basin, in British Columbia or Alberta.

7.4.3 Lower Hay Sub-Basin

7.4.3.1 Alberta

The communities of Indian Cabins, Steen River, Slavey Creek, Lutose, and Meander River are located in the Lower Hay sub-basin of Alberta (Figure 1-10).Records for permits to withdraw water or dispose of waste were not identified for these communities. It is assumed that these small communities rely on private water wells, as there are many water wells located in the area (see Section 3.2.2).

7.4.3.2 Northwest Territories

The Town of Hay River and Hamlet of Enterprise are the only municipalities located in the Lower Hay sub-basin within the Northwest Territories (Figure 1-10).

Drinking water for the Town of Hay River comes from the south shore of Great Slave Lake (outside the Hay River Basin boundary). There is a Water Licence (MV2009L3-0005) for disposal of waste, issued by the Mackenzie Valley Land and Water Board (2015) for a tertiary sewage treatment system (wetland) that discharges to Great Slave Lake (FSC 2009). The solid waste disposal facility is located less than 500 m from the west bank of the Hay River; monitoring of the Hay River, required as a condition of the Water Licence, suggests this facility has not affected surface water quality but has affected groundwater quality (AANDC 2014).

The Hamlet of Enterprise relies on water trucked from the Town of Hay River and does not withdraw water for municipal uses, although the existence of private domestic wells was identified (see Section 3.2.2). Solid waste is disposed in a landfill and there is a Water Licence (MV2014L3-0007) to dispose of sewage waste, which is discharged to an exfiltration lagoon every two weeks (Mackenzie Valley Land and Water Board 2015).

7.4.4 Potential Effects from the Municipal Sector

Municipal landfills and wastewater discharges have the potential to affect the health of the aquatic ecosystem. Leaching from landfills can affect water quality by introducing contaminants to surface water or groundwater. Surface runoff from a landfill can also introduce contaminants to waterbodies during rain events. Nutrients, heavy metals, major ions, and volatile organic compounds are usually monitored at landfill sites (Crowe et al. 2008). In Alberta, general monitoring requirements for landfills and wastewater systems are outlined in specific Alberta Environment and Parks Codes of Practice (available www.qp.alberta.ca). Specific details for monitoring requirements can also be found in each facility's approval document and associated plans filed with Alberta Environment and Parks.

Depending on the level of treatment (e.g., primary, secondary, tertiary), wastewater discharges can have varying effects on the aquatic environment. Primary treatment involves settling of solids and removal of scums. Secondary treatment involves primary treatment followed by microbial action to remove biodegradable organic matter and further settle the solids. Tertiary treatment includes both primary and secondary treatment, and further improves effluent quality by removing additional constituents.

Potential effects of landfills and wastewater discharges on the aquatic environment include increases in TSS, nutrient enrichment (eutrophication), and introduction of pathogens (bacteria, viruses), endocrine disruptors, metals, and organic compounds (Crowe et al. 2008; Hatfield 2009). These changes can affect habitat quality, health of aquatic biota, and human health. For example, endocrine disruptors (e.g., estrogenic compounds) have been shown to alter the reproductive systems of fishes and amphibians (Crowe et al. 2008). Municipal effluents are the largest point sources of nitrogen and phosphorus in Canada, and can lead to eutrophication in the receiving waterbodies, including excessive algal growth, reduced DO levels, and fish kills (Crowe et al. 2008); however, permit requirements for these facilities limit the potential for adverse effects.

7.5 AGRICULTURE

The agriculture sector is a minor development pressure in the Hay River Basin, with the most extensive activities reported in Alberta. There was insufficient information to delineate activity levels by sub-basin; however, based on the dominant land cover types shown in Figure 1-9 (Section 1.4), an estimated 0.01% (3.6 km^2) of the total land in the Hay River Basin is used as cropland. Soil and climatic conditions limit the agriculture potential in the basin; soil composition is suggested as the main limiting factor, as soils would require special treatment for agricultural use (GNWT and GC 1984).

7.5.1 British Columbia

No records were found for agricultural activities in British Columbia for the areas within the Upper Hay and Chinchaga sub-basins.

7.5.2 Alberta

The level of agricultural activity in the Alberta portion of the Hay River Basin is low compared to other parts of the province. In 2001, less than 1% of all Alberta farms (approximately 530 farms, covering 206,276 ha) were located within the Hay River Basin; this includes 220 farms for crop growing, 240 farms as pastures for raising livestock, and 70 farms for unspecified purposes (Alberta Environment 2007). In 2001, the livestock population was estimated at four times the human population in the Alberta portion of the Hay River Basin. Livestock included cattle, pigs, sheep and lambs, horses and ponies, bison, and elk (Alberta Environment 2007). The only water licences issued for agriculture in the Hay River Basin were located in the Chinchaga sub-basin (Figure 6-1); however, as noted in Section 6.1, Alberta does not require water licences for raising animals or applying pesticides to crops as part of a farming operation (maximum withdrawal volume of 6,250 m^3/year).

7.5.3 Northwest Territories

In the Northwest Territories (Lower Hay sub-basin), agriculture is a minor development pressure. One land use permit, allowing the farming of hay, was issued to a landowner in 2012 (MVLWB file MV2012X0027) and is still active (Figure 6-1) (Mackenzie Valley Land and Water Board 2015). Choice North Farms, known under the "Polar Eggs" label, is located within the Town of Hay River and sells more than 36 million eggs annually in the Northwest Territories (Serecon 2014).

Agriculture potential in the Hay River valley within the Northwest Territories is greater than in other areas of the basin (Serecon 2014). An area of 19,724 ha has been identified as having soils suitable for agriculture (i.e., "Class 3" soils).

7.5.4 Potential Effects from the Agriculture Sector

Pesticides, fertilizers, and manure (excrement and urine) associated with agricultural operations can introduce herbicides, insecticides, fungicides, nitrate, ammonia, phosphorus, coliform bacteria, endocrine disruptors, and pharmaceuticals (administered to livestock) to the aquatic environment (Crowe et al. 2008). The agricultural sector, along with the municipal sector, is a large contributor of nutrients (primarily nitrogen and phosphorus) to aquatic ecosystems, which can lead to eutrophication. Soil erosion leading to increased sedimentation can also be associated with agriculture (Crowe et al. 2008). North/South Consultants (2007) suggested the low intensity of agriculture in the basin would lead to low levels of pesticides in waterbodies, which is supported by results of pesticide analysis in the Hay River (see Section 4.3.5).

7.6 TRANSPORTATION

There are few major roadways and several resource roads for the oil and gas (Section 7.2) and forestry (Section 7.3) sectors within the Hay River Basin. In the Lower Hay sub-basin, Alberta Highway 35, which becomes Northwest Territories Highways 1 and 2, is the most travelled roadway (Figure 1-10). The Canadian National (CN) rail line generally follows Alberta Highway 35/Northwest Territories Highway 1 on its west side. Small portions of Northwest Territories Highway 5 and Alberta Highway 58 are also situated within the Hay River Basin. There are also a number of small airports and airstrips.

7.6.1 Upper Hay Sub-Basin

7.6.1.1 British Columbia

The Sierra Yoyo Desan resource road is the only all-weather transportation corridor in the Upper Hay sub-basin within British Columbia, with about 27 km in the far west portion of the sub-basin. In 2004, a public-private partnership established with Ledcor led to many road upgrades, with maintenance conducted by Ledcor (Government of British Columbia 2016b, 2016d).

7.6.1.2 Alberta

There are no major transportation corridors in the Upper Hay sub-basin within Alberta. Highway 58, connecting the Town of Rainbow Lake to the Town of High Level, is the most travelled road. Alberta Transportation applied for a Code of Practice to build a permanent bridge for Highway 58 on an unnamed stream (Government of Alberta 2015). There are 19 domestic airstrips in the Upper Hay sub-basin within Alberta, with airports at Zama City, Zama Lake, Rainbow Lake and Chateh (Figure 7-10) (Government of Canada 2014).

7.6.2 Lower Hay Sub-Basin

7.6.2.1 Alberta

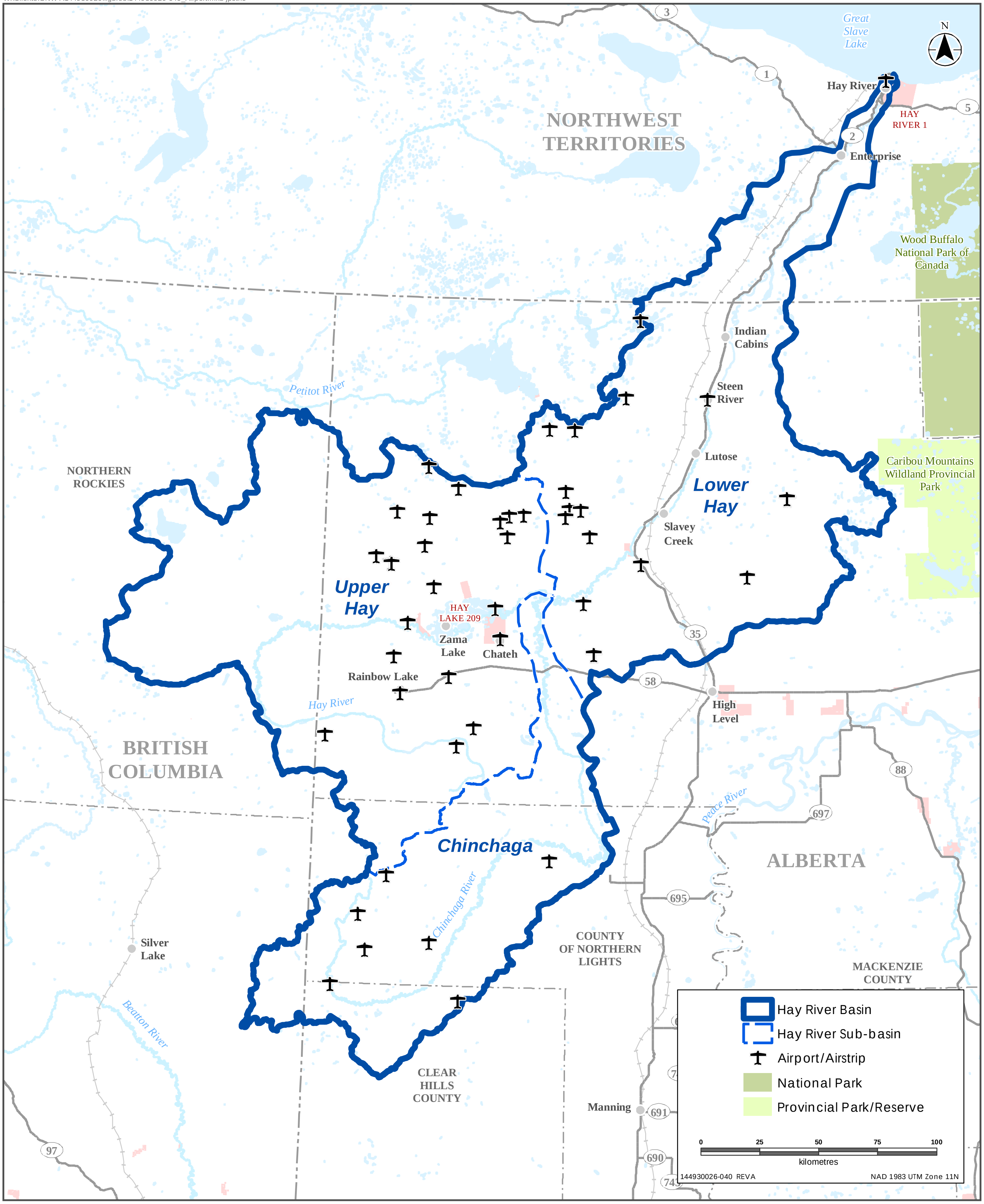
Alberta Highway 35 and the CN rail line are the two major transportation corridors in the Lower Hay sub-basin in Alberta, each about 175 km long (Figure 1-10). They both begin north of High Level and continue into the Northwest Territories, largely following the Hay River. About 10 km of Highway 58 are also located in the Lower Hay sub-basin of Alberta. There are 14 airstrips in the Lower Hay sub-basin in Alberta (Figure 7-10) (Government of Canada 2014). The Alberta Department of Transportation has been issued five *Water Act* approvals for infilling water bodies, and two Codes of Practice for water crossings, one for installation of a permanent bridge and the other for installation of a culvert (Figure 7-5) (Government of Alberta 2015). Details on the extent of the approval activities for infilling of water bodies (e.g., size of infill) was not readily available for this report.

7.6.2.2 Northwest Territories

Northwest Territories Highways 1 and 2 and the CN rail line, are the major transportation corridors in the Lower Hay sub-basin within the Northwest Territories. Highway 1 is the continuation of Alberta Highway 35 north of the Alberta/Northwest Territories border and forks west at Enterprise, with about 85 km of highway located in the Hay River Basin. Highway 2 runs for 50 km between Enterprise and the Town of Hay River. The CN rail line follows the Hay River north from the border to the Town of Hay River, a distance of 110 km (Figure 1-10). About 5 km of Northwest Territories Highway 5, between Highway 2 and Fort Smith, is also located in this area of the basin.

The Hay River/Merlyn Carter airport is the only airport in the sub-basin. It has a low volume of commercial flights because it is served by only a few companies (Northwestern Air Lease, Landa Aviation, Buffalo Airways and First Air).

A Water Licence was issued to Northern Transportation Co. Ltd. In 2010 (MVLWB file MV2000L8-0013) for dredging at the mouth of the Hay River to maintain adequate riverside barge access; the licence is active until 2019 (Figure 7-5) (Mackenzie Valley Land and Water Board 2015).



Sources: Base Data - Government of Canada; Thematic Data - Government of Canada, Stantec

Disclaimer: This map is for illustrative purposes to support this Stantec project; questions can be directed to the issuing agency.

Hay River Basin and Sub-basins: Airports and Airstrips

Stantec

Figure 7-10

7.6.3 Potential Effects from the Transportation Sector

Potential effects of transportation activities on the aquatic environment are related to spills from trucks transporting goods that may contain contaminants, or from truck fuel; the introduction of alien or invasive species transported inadvertently by vehicles and boats; increase in sedimentation from road maintenance, including installation and maintenance of bridges and culverts; barriers to aquatic wildlife from roads and stream crossings (Hatfield 2009); and introduction of chemicals (e.g., glycol used for de-icing airplanes, pesticide use along transportation rights-of-way). The small airports in the Hay River Basin are thought to have a negligible effect on the aquatic environment (GNWT and GC 1984). The effects of habitat fragmentation for the transportation sector (culverts and bridges) would be the same as those described in Section 7.2.4 for pipelines.

7.7 OTHER DEVELOPMENT PRESSURES

7.7.1 Upper Hay Sub-Basin

7.7.1.1 Alberta

Other development pressures include:

- Construction of a boat launch on the Hay River, with a *Water Act* approval issued to Alberta Tourism, Parks and Recreation (Government of Alberta 2015) (Figure 7-5)
- Three small power plants (cogeneration plant and thermal electric generation station near Rainbow Lake and a power plant for a gas processing plant) (Government of Alberta 2015); power produced in the cogeneration and thermal plants is sold to the power pool of Alberta (Figure 7-5) (Atco Power 2016)

7.7.2 Lower Hay Sub-Basin

7.7.2.1 Alberta

Other development pressures include:

- Treatment of hydrocarbon-impacted soils (a Code of Practice issued to the transportation company RTL Robinson Enterprises) (Figure 7-5) (Government of Alberta 2015).

7.7.2.2 Northwest Territories

Other development pressures include:

- Quarrying near the Town of Hay River (three land use permits held by Rowes Construction: MVLWB file MV2014Q0006, MV2012Q0013, MV2013Q0008) (Figure 7-5) (Mackenzie Valley Land and Water Board 2015).

- Two inactive mineral claims (commodity unspecified) just north of the Alberta/Northwest Territories border (see Figure 7-8a) (Government of the Northwest Territories 2015b).
- The Hay River Golf Course, south of the Highway 2 and 5 Junction, and adjacent to the Hay River (the only golf course in this part of the sub-basin; it is unknown if pesticides are used).

There is currently no power sector activity in this sub-basin, as the Town of Hay River and Enterprise are powered from hydroelectricity generated on the Taltson River, located outside the basin (Northwest Territories Power Corporation 2014). However, there is potential for hydroelectric development at the Alexandra and Louise Falls (GNWT and GC 1984), though this has not been advanced to the planning stage (NT Energy 2013).

7.8 SUMMARY OF DIRECT LOCAL DEVELOPMENT PRESSURES

7.8.1 Upper Hay Sub-Basin

Two land use plans cover the Upper Hay sub-basin in British Columbia and Alberta (one each). The oil and gas sector (mainly gas, but also oil in the Zama area) is the main development pressure in this sub-basin in both British Columbia and Alberta, followed by forestry. There is little activity in the transportation, agriculture, and municipal sectors and none in the mining sector.

7.8.2 Chinchaga Sub-Basin

Two land use plans cover the Chinchaga sub-basin in British Columbia and Alberta (one each). The oil and gas sector is the main development pressure in the Chinchaga sub-basin within British Columbia and Alberta. There is little to no activity in other sectors in this sub-basin. There may be agricultural activity in Alberta, given the existence of approved water licences, but locations could not be confirmed.

7.8.3 Lower Hay Sub-Basin

Two land use plans cover the Lower Hay sub-basin in Alberta and the Northwest Territories (one each). In Alberta, the oil and gas sector is the main development pressure in this sub-basin, with minor activity in the agriculture, municipal, forestry, and transportation sectors and none in the mining sector. In the Northwest Territories, development pressure is lower than in other areas of the Hay River Basin, with some activity in the oil and gas, municipal, agriculture, forestry, and transportation sectors and none in the mining sector.

7.9 EFFECTS OF GLOBAL DEVELOPMENT PRESSURES ON THE AQUATIC ECOSYSTEM

Indirect global development pressures are those originating outside the Hay River Basin but that have the potential to influence the health of the aquatic ecosystem. The major pressures are from long-range transport of contaminants and climate change.

7.9.1 Long-Range Transport of Contaminants

Contaminants emitted in one location have the potential to be transported in the atmosphere over thousands of kilometres and be deposited on water, snow, or land far from the emission source (Roiger et al. 2012). Typically, atmospheric pollutants that are emitted in lower latitude areas (i.e., warmer climates) volatilize, are transported via air masses, and can be deposited in higher latitudes (i.e., colder climates), making Canada's northern areas an identified location for such deposition (Environment Canada 2013a).

Canada's Air Pollutant Emission Inventory tracks 17 substances under the *Canadian Environmental Protection Act* 1999. These include total particulate matter, air contaminants (i.e., sulphur oxides, nitrogen oxides, volatile organic compounds, carbon monoxide, and ammonia), metals (e.g., mercury, lead, and cadmium), and persistent organic pollutants (e.g., dioxins and furans, the PAHs benzo[a]pyrene, benzo[b]fluoranthene, benzo[k]fluoranthene, and indeno[1,2,3-cd]pyrene), and the pesticide hexachlorobenzene) (Environment Canada 2015c). These contaminants, largely originating outside the Hay River Basin, can be transported and deposited within the basin and have the potential to affect health of the aquatic ecosystem.

There are also regional sources of atmospheric contaminants, for example from power generation in Alberta. It is estimated that 82% of the electricity generated in Alberta is from coal-fired and natural gas burning plants (Alberta Energy 2016). Sulphur dioxide (leading to acidification of waterbodies) and mercury from power plant emissions could pose a certain risk to aquatic ecosystems in the north (Hatfield 2009).

Water and suspended sediment monitoring at the HR-BORDER site indicates the presence of low concentrations of PCBs, pesticides, and some PAHs that could originate from long-range atmospheric transport (Section 4.3). Existing air quality stations (Environment Canada 2013c; Government of the Northwest Territories 2016b) do not monitor for these parameters.

7.9.2 Climate Change

Climate change has always been part of the natural evolutionary processes of the planet. However, human activities that generate an excess of greenhouses gases (GHGs), such as burning of fossil fuels, has accelerated the process. GHGs occur naturally in the atmosphere and are essential to regulate the planet's temperature. However, excess GHGs accelerate warming by trapping and preventing solar radiation and heat from escaping the planet.

Carbon dioxide (CO_2), the most abundant GHG produced by human activities, accounted for 78% of national emissions in 2013 (Environment Canada 2015d). Other GHGs generated by human activities are methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, sulphur hexafluoride, and nitrogen trifluoride (Environment Canada 2015e).

A 2013 inventory of GHG emission sources for large facilities (minimum reporting threshold of 50 kilotonnes [kt] CO_2 equivalent [eq]), such as gas and cogeneration plants (Table 7-2), indicates there are few facilities in the Hay River Basin that could be sources of GHGs (Environment Canada 2015f). Collectively, large facilities in the basin contributed less than 0.1% of GHG emissions in Canada in 2013 (Table 7-2). On a national level, 726,000 kt of CO_2 eq were generated by large facilities in 2013, an 18% increase since 1990. As GHGs are considered global development pressures, national sources also have the potential to influence health of aquatic ecosystems in the Hay River Basin.

Table 7-2 Greenhouse Gas Emission Sources in the Hay River Basin, in 2013

GHG Source	Location	GHG Emission (kt CO_2 eq)	Percentage of National Emissions
Chinchaga Gas Plant	Chinchaga sub-basin	Not reported	Not reported
Rainbow Lake Cogeneration Power Plant (Unit 4-5)	Upper Hay sub-basin	240.56	0.03%
Rainbow Lake Gas Plant	Upper Hay sub-basin	57.53	0.008%
Zama Gas Plant (Unit 1-3)	Upper Hay sub-basin	53.06	0.007%
Sierra Gas Plant	Upper Hay sub-basin	55.73	0.007%
Sierra Sour Gas Plant	Upper Hay sub-basin	99.78	0.01%
SOURCE: Environment Canada (2015f)			

The excess GHG produced by human activities has resulted in a warming climate trend recognizable since the middle of the 20th century (Environment Canada 2015e). In Canada, annual average temperature increased by 1.6°C between 1948 and 2014 (Environment Canada 2015g). Other changes expected to be associated with climate change include an increase in extreme weather events such as droughts or floods, change in precipitation patterns, and rising sea level (Environment Canada 2015e).

Mean annual temperatures at the Town of Hay River, Northwest Territories (1945 to 2015; Lower Hay sub-basin), and the Town of High Level, Alberta (1971 to 2007; south of the Lower Hay sub-basin and east of Chinchaga sub-basin; Figure 1-10), are plotted in Figure 7-11. The data suggest a slight increasing trend in mean annual temperature of almost 1°C over the last 69 years at Hay River, and almost 2°C over the last 37 years at High Level (Environment Canada 2015c).

There were no obvious trends in total annual precipitation at these two stations over the period of record (Figure 7-12) (Environment Canada 2015b).

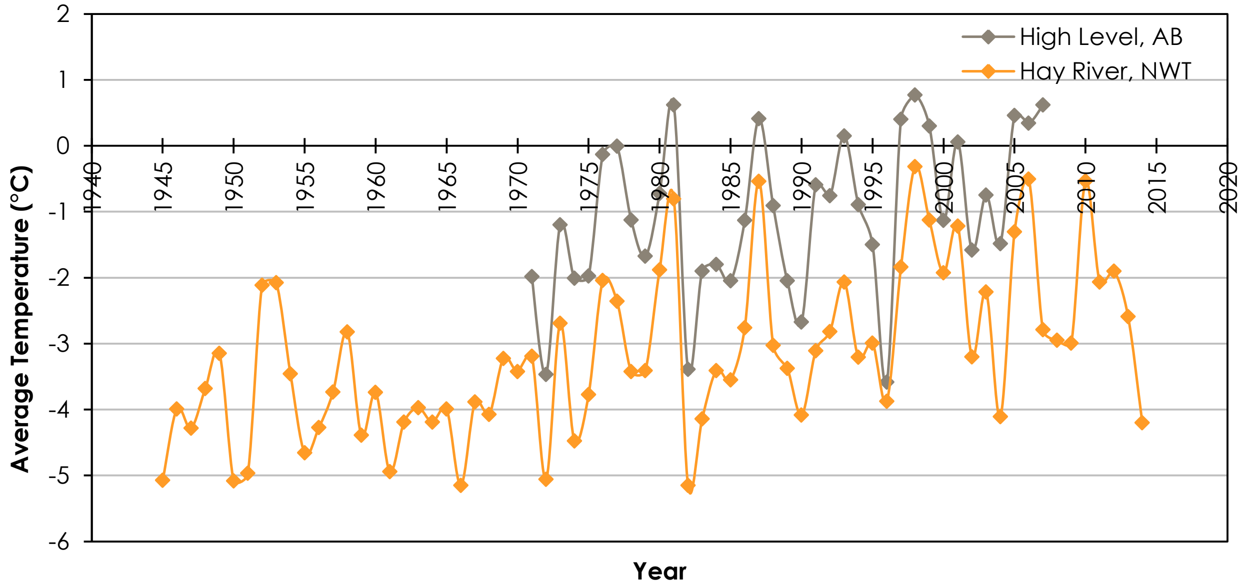
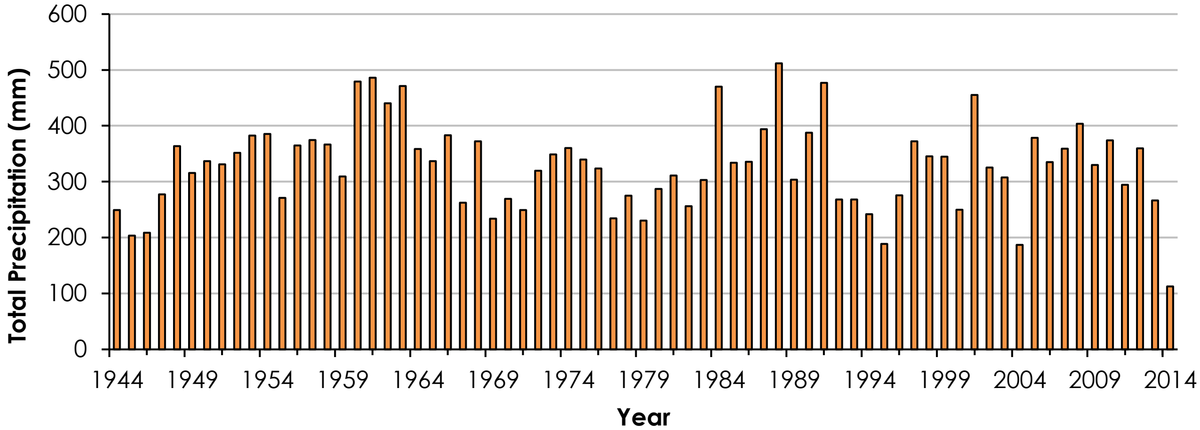


Figure 7-11 Annual Average Temperature (°C) in Hay River, Northwest Territories (1945–2014) and High Level, AB (1970–2007)

a) Hay River (1944 to 2014)



b) High Level (1970 to 2007)

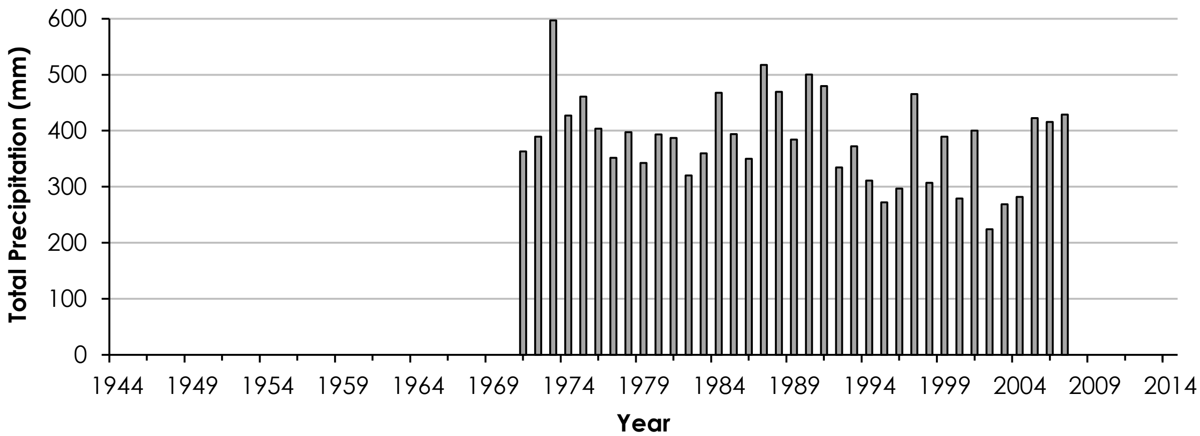


Figure 7-12 Annual Total Precipitation (mm) at Hay River, Northwest Territories (1944 to 2014), and High Level, Alberta (1970 to 2007)

As part of a flood watch program, the Town of Hay River has monitored ice thicknesses at 16 locations around the town from approximately mid-March to mid-April (beginning in 2007) and has recorded the timing of ice break-up (consistently since 2007, occasionally monitored as early as 1904). Ice break-up at the mouth of the river occurs between April 25 and May 14 (Figure 7-13) and average late winter ice thickness ranges from 71.4 to 91.0 cm (Figure 7-14) (Town of Hay River 2015), with no obvious trends in timing of ice break-up since 1904 or ice thickness since 2008. The data record is patchy and one longtime resident of the area commented that ice thickness has decreased and break-up occurs one to two weeks earlier than in the 1970s (G. Low, pers. comm.).

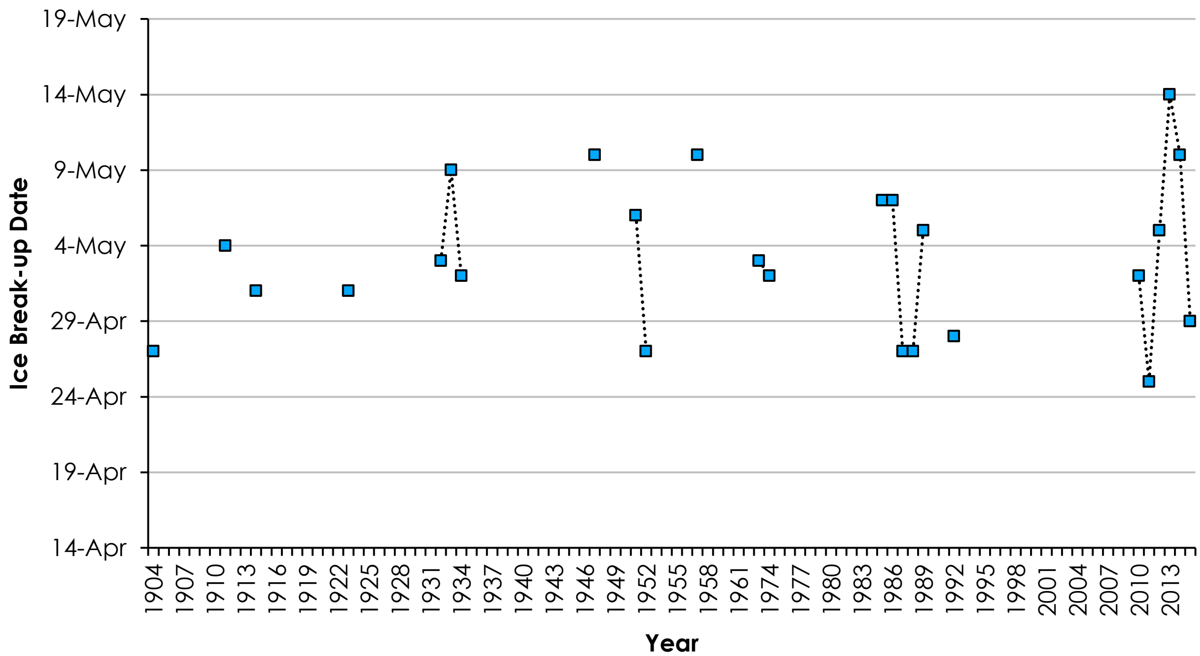
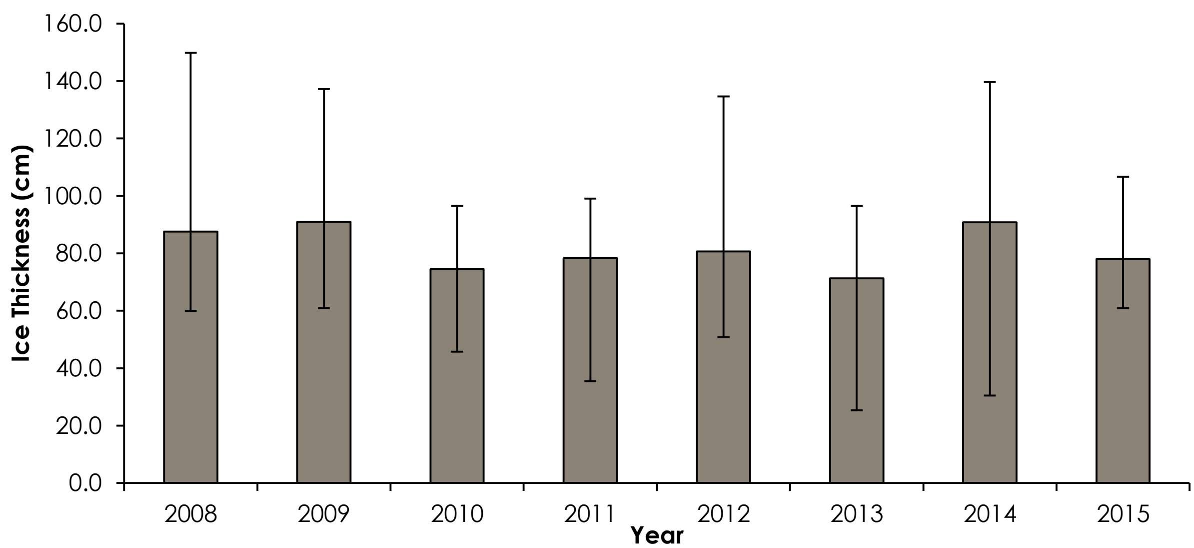


Figure 7-13 Ice Break-up Dates for the Hay River at the Town of Hay River, Northwest Territories, between 1904 and 2015



NOTE: For each year, the bar heights represent the mean ice thickness values over for 16 stations monitored by the Town of Hay River; error bars represent the range in ice thickness values over the 16 stations.

Figure 7-14 Ice Thickness on the Hay River at the Town of Hay River, Northwest Territories, between 2008 and 2015

The effects of climate change on the current and future state of the Hay River Basin have not been defined at this time. The preliminary data presented in Figure 7-11 through Figure 7-14 indicate an increasing trend in average annual temperature in the Lower Hay sub-basin but no obvious trends for total annual precipitation, timing of ice break-up, or ice thickness. Potential effects of climate change on aquatic ecosystems could include any of the following (Wrona et al. 2006; European Environment Agency 2012):

- An increase in water temperature
- Change in stream and river hydrology
- Eutrophication and increase in primary production
- Shift in species distribution, which may introduce diseases or parasites in new areas
- Reduction in ice cover and thickness
- Alteration of water chemistry
- An increase in nutrient, sediment, and carbon loadings from the thawing of permafrost and soil discharges

Thawing of permafrost would mostly affect the Upper Hay and Lower Hay sub-basins, as these sub-basins have areas of sporadic discontinuous permafrost. In the Chinchaga sub-basin, about half of the area contains isolated patches of permafrost (Natural Resources Canada 2000).

8.0 SUMMARY, INFORMATION GAPS, AND RECOMMENDATIONS

This section brings together information about existing aquatic monitoring programs, the current state of aquatic knowledge, and pressures on the aquatic environment (water allocations, water uses, and development pressures) for the Hay River Basin to identify gaps in data and monitoring and make recommendations for future monitoring and data analysis. The preliminary conceptual site model (Section 8.1) provides an overview of how human activities interact with the aquatic environment, as a basis for understanding the pathways of impact and effect from current and future development activities, as discussed in Section 7.2 to 7.9. Section 8.2 provides a summary of the state of aquatic knowledge for the Hay River Basin, identified information gaps, and recommendations.

8.1 CONCEPTUAL SITE MODEL FOR THE HAY RIVER BASIN

A conceptual site model for the basin was developed using information from the review of existing aquatic ecosystem conditions, water uses, and development pressures, (Figure 8-1). This model provides a simplified summary of how the aquatic environment of the Hay River Basin is affected by human activities. There are four general columns shown in Figure 8-1:

- The first column shows the *sources* of human activities by industry sector (oil and gas, forestry, municipal, transportation, and agricultural) and global sources (climate change and long-range transport of contaminants) that have potential *impacts* to the aquatic environment.
- The second lists the specific activities that may contribute either point or non-point source impacts; the *parameters or metrics of concern* that have potential impacts (e.g., sediment load, metals, community diversity) and could be used to monitor or measure potential *effects*; and the paths by which they are transported to the aquatic environment.
- The third shows the transport pathways (groundwater, surface water, suspended sediments in water, air).
- The fourth shows the human and biota receptors and the risks to which they are exposed (e.g., altered health, biomagnification, bioaccumulation, loss of habitat or water uses); links between identified potential effects/risks and receptors (e.g., harvesting pressure) are also suggested.

Many point and non-point source impacts have been identified and assigned to the various sources based on known typical impacts, parameters of concern, and effects from industry, and using professional judgment.

This model is helpful in understanding how additional pressures from development activities could affect health of the Hay River Basin in the future.

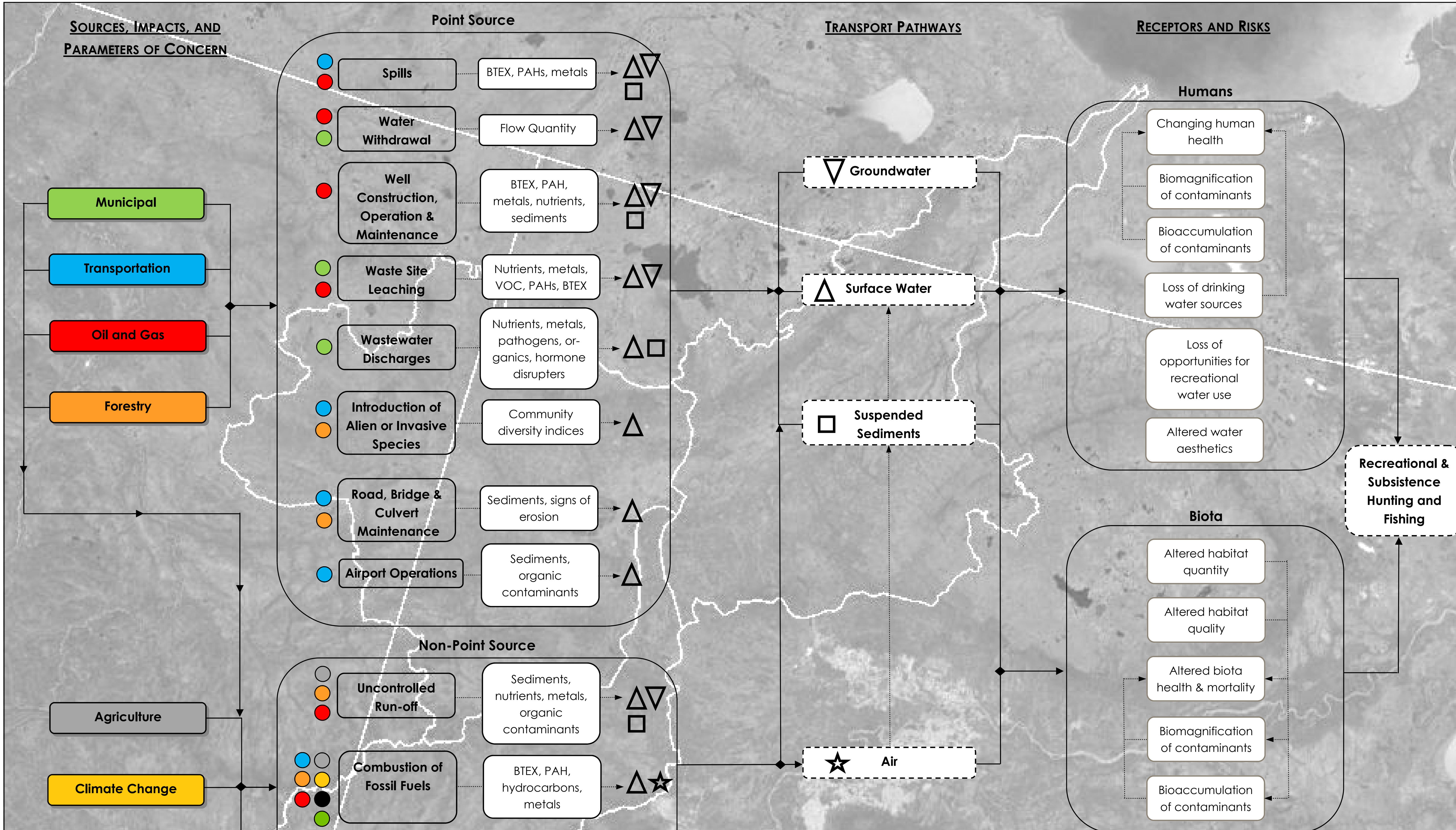


Figure 8-1: Conceptual Site Model on the State of Aquatic Knowledge for the Hay River Basin

Client: Government of the Northwest Territories

8.2 STATE OF AQUATIC KNOWLEDGE

Information compiled for this *State of Aquatic Knowledge* report indicates that the Hay River Basin provides valuable habitat for numerous terrestrial and aquatic wildlife species, and is used by several First Nations for traditional, cultural and subsistence activities. Residents of 10 communities call the Hay River Basin home and industrial activities appear to have been ongoing in the basin since the 1920s. At present, the most substantial development activity is in the oil and gas sector, followed by forestry, with lower levels of activity in the municipal, agriculture, and transportation sectors. The oil and gas sector also had the largest proportion of surface and ground water allocation in the basin, all of which primarily occurred in Alberta, followed by British Columbia and the Northwest Territories.

Existing data on the aquatic environment show little change in surface water flow over the past 40 years for the two continuous hydrologic monitoring stations (in Alberta and the Northwest Territories), and little change in groundwater level for the three relatively continuous monitoring wells (in Alberta). Some temporal trends have been identified for water quality at the single continuous monitoring station (at the Alberta-Northwest Territories border) and there are some naturally-occurring CCME WQG exceedances for metals. At this monitoring station, levels of organic contaminants in water are well-below applicable CCME WQGs. The limited information on aquatic biota communities available for the basin shows species and communities typical of the ecozone, the boreal forest, or of North American aquatic habitats.

However, available data on the existing aquatic environment have either been collected sporadically or opportunistically (e.g., aquatic biota), inconsistently between jurisdictions (e.g., water use/allocation, development activities), or continuously, but are largely concentrated to one or two areas (e.g., water quality, hydrology, hydrogeology). As a result, limited data are available to monitor potential changes in the aquatic environment throughout the basin, whether from local human development activities, long-range transport of contaminants, or climate change.

Table 8-1 provides a summary of the status of each monitoring topic, identifies information gaps and makes recommendations. The recommendations attempt to address these gaps to assist current transboundary water management and monitoring activities, and set a foundation for future actions within the Mackenzie River Basin Transboundary Waters Master Agreement, and the corresponding Bilateral Water Management Agreement.

Table 8-1 Summary of Monitoring Programs, Status of Aquatic Conditions, Information Gaps and Recommendations

Topic	Monitoring Programs, Data Sources	Status	Information Gaps	Recommendations
Environmental Setting (Section 1.0)	Largely historic information, at a national scale to describe overall physical, geologic, climate, soils, and vegetation conditions in the basin. Some information available on traditional use for the basin.	Coverage of ecozone, geologic, soils, and vegetation information relatively good for the basin, albeit at a national scale. Some information is somewhat dated but is not expected to change considerably (e.g., geology, soils, vegetation types). Only two active weather stations in the Basin, with climate normal data only available from one. The basin is used by several First Nation and Metis people.	Spotty weather data available across the basin (several inactive weather stations, no data for Upper Hay and Chinchaga, in AB or BC) This State of Aquatic Knowledge was not meant to provide detailed information on traditional knowledge and use within the basin.	Collect temperature and precipitation data to better characterize climate change effects (likely in cooperation with Environment Canada). Reactivate some of the inactive weather stations in the basin (currently monitored in Town of Hay River and in High Level AB just outside the basin). Consider completing Traditional Knowledge and Use studies to better describe specific types of activities and areas of use in the basin, and obtain an improved understanding of past and present levels of subsistence and traditional use.
Hydrologic Conditions (Section 2.0)	The Water Survey of Canada (WSC) collects continuous water level data, and estimates of flow, at six stations in the basin. The earliest records are from 1963. The WSC produces daily average flow estimates year-round for two stations (Hay River at Hay River and Chinchaga near High Level).	There has been no significant change in total yearly flow over the past 40 years, although flows vary greatly on a seasonal and annual basis, and there is a trend of slightly increased winter baseflow in the Lower Hay sub-basin. Flow typically peaks in May. There has been no significant change in morphology of the Hay River over the past 50 to 60 years, although there are localized examples of erosion and small landslides typical of large rivers.	There are no winter flow measurements by the WSC, under ice conditions, for four of the stations—Sousa Creek near High Level, Hay River near Meander River, Lutose Creek near Steen River, and Steen River near Steen River. This means that flow estimates cannot be produced year-round for these stations.	Change to continuous data collection for stations to improve understanding of hydrologic conditions within sub-basins. This recommendation is consistent with agreements and understandings in the AB-NWT BWMA that "…seek to improve their understanding of and ability to monitor winter flow conditions over time with the goal of improving management over time." (AB-NWT BWMA, Appendix D5[b]) and recommendations to upgrade the stations "Hay River near Meander River" and "Hay River near the AB-NWT Boundary" (AB-NWT BWMA Appendix I3)
			No hydrometric stations in the Upper Hay sub-basin. Insufficient information to identify local water use impacts related to oil and gas sector activities in BC and AB, particularly with the intense oil and gas sector activity in the Hay-Zama Lakes area.	In consultation with the WSC and appropriate provincial jurisdictions, consider: • Conversion of current AB seasonal stations to year-round stations • Adding stations at the AB/BC border in Upper Hay and Chinchaga sub-basins to make links with BC-AB concerns • Adding stations in the Hay-Zama Lakes area. The AB-NWT BWMA outlines two recommendations for this area, including monitoring of lake levels and tributary inflows (AB-NWT BWMA Appendix I3) Gather information on monitoring requirements under licences in AB and BC for water use and local water use impacts.
Hydrogeologic Conditions (Section 3.0)	AB Groundwater Observation Well Network, AB Water Well Information Database, and BC Ground Water Wells and Aquifer Database list registered wells.	Three monitoring wells (two in Upper Hay [Zama area] and one in Lower Hay [Meander River], all in AB) have been monitored for groundwater level and quality since 1989. No obvious temporal trends in groundwater level were identified, though seasonal patterns exist for the two Upper Hay wells. There are 1,254 registered water wells in the basin (1220 in AB and 34 in BC), 74% of which are for the commercial/ industrial sector (mainly oil and gas). About 48% of wells are completed to less than 30 mbgs and 75% are to less than 150 mbgs.	Groundwater quality data was not accessed in time for inclusion in this report	Review available groundwater quality data to develop a baseline and identify potential temporal trends.
			No central registry for well data in NWT	Develop a central database and reporting system for NWT.
			BC records for wells are incomplete because reporting was voluntary before 2015	Check whether reporting will change with implementation of the new British Columbia *Water Sustainability Act*
			No consistent or continuous monitoring of transboundary groundwater conditions in the Hay River Basin.	Monitor groundwater (level and quality) and make it publicly available among jurisdictions

Table 8-1 Summary of Monitoring Programs, Status of Aquatic Conditions, Information Gaps and Recommendations

Topic	Monitoring Programs, Data Sources	Status	Information Gaps	Recommendations
Water Quality (Section 4.0)	Environment Canada and GNWT monitor water quality at HR-BORDER for general parameters, nutrients, metals, and organic contaminants in water and suspended sediment. The long-term dataset began in 1988. There is also a program using PMDs at the Town of Hay River	The AB-NWT BWMA (Appendix E) describes interim triggers for water quality to identify conditions outside the normal (50^{th} percentile) and extreme (90^{th} percentile) range. These have been developed for under ice and open water conditions or on an annual basis. Hay River water has naturally elevated levels of organic carbon, colour and suspended sediment. Many metals meet CCME WQGs for protection of aquatic life. Exceptions are mainly for total iron (60% of samples), aluminum (57%), cadmium (23%), copper (15%), and zinc (4%), typically associated with the particulate fraction. River water is naturally mesotrophic to eutrophic, based on nitrogen and phosphorus levels, respectively. Organic contaminants such as PCBs and pesticides are present in low concentrations (many below detection limits), below WQGs, and likely come from long-range atmospheric transport. PAHs are present at levels below water and sediment guidelines, and are not considered a risk to aquatic biota. Overall, PAH levels are lower in the Hay than the Slave River. The PAHs reflect mainly petrogenic (petroleum) sources and likely come mainly from sources in the basin and, for pyrogenic sources (combustion), possibly from atmospheric transport. Naphthenic acids (associated with petroleum sources) are present. Long term trends were identified for chloride (decrease during open water) and total iron (decreasing on annual basis.)	Only one long-term monitoring site in the Basin (HR-BORDER), which makes it difficult to identify differences that could be attributed to activities in individual sub-basins.	Develop additional monitoring sites at lower ends of Upper Hay and Chinchaga sub-basins, to collect sub-basin data. Co-locate sites with hydrology stations, where possible. Consider adding sites at the AB-BC border in Upper Hay and Chinchaga sub-basins to make links with BC-AB concerns. Expand or upgrade government databases to house data about water and sediment quality collected for individual projects or permit applications within the basin.
			Inorganic and organic monitoring parameters and sampling media are suitable for the types of contaminants that could be related to upstream development activities. Good baseline dataset for evaluating trends over time at HR-BORDER, but no information about sources within individual sub-basins. Ultra-low detection limits of the GNWT program are particularly relevant.	Modify the sampling schedule, recognizing the value of existing baseline data, e.g.: collect PAH, pesticide, and PCB data in water and suspended sediment during the spring freshet and summer every 3 to 5 years at HR-BORDER, rather than every year. Duplicate the inorganic and organic program at new sites at the lower ends of the Upper Hay and Chinchaga sub-basins (spring-through summer, up to three years to establish baseline conditions. At a minimum, use suitable methods at these new locations to measure PAH concentrations, as PAHs are associated with the oil and gas sector, the main development sector.
			Sources of PAHs not yet well defined (natural vs. human activities, relative inputs of petroleum vs. combustion sources).	Explore existing PAH data using various ratios and indices (summarized in Stogiannidis and Laane 2015) to fingerprint and identify sources of hydrocarbons in the Hay River (natural vs. related to human activities).
			No water or sediment guidelines available for naphthenic acids. Currently only two years of monitoring data for naphthenic acids	Promote development of guidelines for napthenic acids. Conduct a minimum of three years of monitoring for naphthenic acids to provide a more robust baseline.
			Occasional issues with cross-contamination during sample collection (field) and analysis (laboratory) of organic contaminants. Stress the importance of clean techniques, particularly when working with ultra-low detection limits.	Review field protocols and checklists to avoid cross-contamination (especially relevant for PMDs, which are very sensitive to outside sources of hydrocarbons). Check all quality assurance/ quality control data when analyzing data trends.
Aquatic Biota (Section 5.0)	There are few reports about aquatic biota in the basin and there is no long-term monitoring of aquatic health of the Hay River	The Hay River Basin provides extensive aquatic habitat values for fish and wildlife; including 26 fish, 81 bird, 4 amphibian, and 12 aquatic mammal species. Many of these species have significant cultural value for local Indigenous people. Numerous wetlands provide habitat for migratory birds and other wildlife. The most extensive is the Hay-Zama Lakes wetland complex (recognized internationally as a Ramsar wetland of importance and nationally as an Important Bird Area). Levels of metals, PAHs, and other contaminants in fish tissue were measured in the late 1980s and early 1990s. Mercury concentrations in walleye and northern pike muscle exceeded the Health Canada advisory level for subsistence or frequent consumers but were below the advisory level for the commercial	Insufficient information about aquatic biota (benthic invertebrates in streams and rivers; plankton in lakes) to assess watershed health or provide a baseline for long term monitoring.	Develop an ongoing benthic invertebrate monitoring program at the site used in 2015 (Hay River near Vale Island, in NWT) and at sites at the lower ends of the Upper Hay and Chinchaga sub-basins to assess aquatic health of individual sub-basins. Use the CABIN protocol followed in 2015. After establishing baseline, monitor every five years or sooner if interim water quality triggers (50^{th} percentile) are exceeded. Consider developing a pilot program with oil and gas sector companies to monitor benthic invertebrates in areas close to their activities. Expand government databases to house data about aquatic biota collected for individual projects or permit applications (e.g., CABIN database or similar for lake data).

Table 8-1 Summary of Monitoring Programs, Status of Aquatic Conditions, Information Gaps and Recommendations

Topic	Monitoring Programs, Data Sources	Status	Information Gaps	Recommendations
		sale of fish. There is very little information about other aspects of aquatic ecosystems (benthic invertebrates, plankton).	Insufficient recent information on fishing pressures (capture and consumption) in the basin	Review fishing licence data to document domestic fishing pressure in the Hay River Basin. Periodically conduct creel surveys to assess fishing pressure, as recommended in 1989 (i.e., every three years; Stewart and Low 2000).
			No recent data on contaminant levels in fish tissue.	Depending on fishing pressure and consumption levels, monitor every 5 to 10 years for contaminants in fish tissue. Monitor for metals (e.g., mercury) and organics (e.g., PAHs) in species of commercial, recreational, and subsistence interest.
Water Use and Allocation (Section 6.0)	Surface water and groundwater allocations are recorded by the BC, AB, and NWT governments, and managed through permit documents and associated permit requirements.	Allocation (2015 data) was highest in the Upper Hay sub-basin (>80% of allocation for the entire basin, mostly in Alberta) and lowest for the Chinchaga sub-basin (less than 1% for the entire basin, roughly split between British Columbia and Alberta). One active withdrawal licence was identified in NWT portion of the basin in 2015. The oil and gas sector accounts for 70% of surface water and 71% of groundwater allocation for the entire basin, with the rest used by agriculture, commercial, forestry, and municipal sectors. Total surface water allocation represents 0.18% of the average annual surface water volume, or 3.85% of the available average winter (January to March) low flow volume (2015 data).	It was challenging to find data on water used (as opposed to allocated) in files from BC and AB; data may not be recorded consistently. Usage is likely less than allocation. Paper/electronic licence documents, including licensee reporting, in AB were not reviewed, and only water use data from the online reporting tool were considered. Not all uses require a permit (e.g., for certain agricultural purposes in AB, for domestic purposes in BC).	Conduct further data review (e.g., non-digital files reporting water use for permits in AB) to identify permit requirements and actual consumption records and, if needed, adjust reporting requirements for permits (e.g., all online reporting). This could be completed when a threshold for water allocation is reached, as described in the Risk-Informed Management approach of the AB-NWT BWMA. Check whether water use reporting will change when the new British Columbia *Water Sustainability Act* is implemented
			Seasonal water use, and sub-basin water use compared to flow, was not evaluated as part of this report.	Conduct a review of water allocations compared to sub-basin flow on a seasonal rather than annual basis using some basic assumptions such as consistent water use throughout the year, or basic sector assumptions (e.g., agricultural use throughout the summer).
Development Activities and Pressures (Section 7.0)	Data on oil and gas and forestry sectors are provided through the permitting process (AB, BC, NWT). Monitoring of contaminants related to local and long-range transport sources is done at HR-Border (water and suspended sediment). The only basin-specific information on GHG emissions is from reporting for major gas plant facilities. The Town of Hay River monitors ice thickness and time of ice break-up.	The oil and gas sector (mostly gas) is the main development pressure in the basin, and is most active in BC (Upper Hay and Chinchaga sub-basins) and AB (Upper Hay, Chinchaga, Lower Hay sub-basins). There are oil reserves and extraction activities in the Hay Zama area (Upper Hay sub-basin).	Data on hydraulically fractured wells in AB and BC were not readily available for inclusion in this report. The scope of this report did not include seismic exploration for the oil and gas industry. Concerns have been expressed about impacts of seismic cutlines on hydrological regimes.	Improve availability/reporting of data on gas extraction. Report by method (e.g., non-vertical, hydraulic fracturing) Consider developing a study to investigate links between the current level of seismic exploration (e.g., cutlines) and potential effects to the aquatic environment (e.g., review of satellite imagery for land cover vs. local hydrology information).
		Forestry is the second most active sector, mainly in the Upper Hay sub-basin (AB and BC), with some forestry in the Chinchaga (AB and BC) and Lower Hay (NWT) sub-basins.	Forestry data are current to 2015 for most jurisdictions though the extent of cut block activity in the NWT was not available.	Continue to monitor forestry activities. Obtain recent cut block data for the NWT.
		There is little activity from transportation, agriculture, municipal, and mining sectors in the basin. Local development pressure in the NWT is low compared to BC and AB.	Available agricultural data for AB are from 2001, and could not be divided by sub-basin. More recent data were not found.	Identify recent sources of agricultural data.
		Long-range transport of contaminants is evident (pesticides and PCBs in water), but levels are low. The PAH profile suggests mainly petrogenic (petroleum) sources (from within the Hay River Basin), with some pyrogenic (combustion) sources (possibly from long-range transport.	No monitoring gaps identified.	Continue monitoring organic contaminants at HR-BORDER in water and sediment (pesticides and PCBs every three to five years; PAHs every year).

Table 8-1 Summary of Monitoring Programs, Status of Aquatic Conditions, Information Gaps and Recommendations

Topic	Monitoring Programs, Data Sources	Status	Information Gaps	Recommendations
		There has been an increase of almost 1°C over the last 69 years at the Town of Hay River, NWT and 2°C over the last 37 years at High Level. AB. Ice thickness at the Town of Hay River shows no trend since monitoring began in 2007. There is no obvious trend for timing of ice break-up (monitored sporadically since 1904, consistently since 2008).	No information found on status of permafrost in the basin Spotty weather data available across the basin (several inactive weather stations, no data for Upper Hay and Chinchaga, in AB or BC)	Collect temperature and precipitation data to better characterize climate change effects (likely in cooperation with Environment Canada). Reactivate some of the inactive weather stations in the basin (currently monitored in Town of Hay River and in High Level AB just outside the basin). Consider monitoring ground temperature for potential permafrost thaw.

NOTES:

AB = Alberta, BC = British Columbia, NWT = Northwest Territories, GNWT = Government of the Northwest Territories, BWMA = Bilateral Water Management Agreement, CCME WQG = Canadian Council of Ministers of Environment Water Quality Guidelines

9.0 CLOSURE

Stantec Consulting Ltd. has prepared this preliminary draft report for the sole benefit of the Government of the Northwest Territories and the Government of Alberta for the purpose of documenting the state of aquatic knowledge for the transboundary Hay River Basin. The report may not be relied upon by any other person or entity, other than for its intended purposes, without the express written consent of Stantec Consulting Ltd., Government of the Northwest Territories, and the Government of Alberta. Any use of this report by a third party, or any reliance on decisions made based upon it, are the responsibility of such third parties.

The information provided in this report was compiled from existing documents and data provided by Government of the Northwest Territories, the Government of Alberta, and the Government of British Columbia, and by data compiled by Stantec Consulting Ltd. This report represents the best professional judgment of our personnel available at the time of its preparation. Stantec Consulting Ltd. reserves the right to modify the contents of this report, in whole or in part, to reflect any new information that becomes available. If any conditions become apparent that differ significantly from our understanding of conditions as presented in this report, we request that we be notified immediately to reassess the conclusions provided herein.

Respectfully submitted,

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APPENDIX A
SUPPORTING DATA FOR WATER AND SUSPENDED SEDIMENT CHEMISTRY

APPENDIX A1

REVIEW OF METHODS AND STATISTICS USED TO IDENTIFY STATUS AND TRENDS IN THE HAY RIVER BASIN

A.1 REVIEW OF METHODS AND STATISTICS USED TO IDENTIFY STATUS AND TRENDS

To date, the status and trends of water chemistry in the Hay River Basin have been examined three times in three different studies, including:

- Hatfield Consultants (Hatfield). 2009. Current state of surface water quality and aquatic ecosystem health in Alberta--Northwest Territories transboundary waters. Report prepared for Alberta Environment.
- Environ EC (Canada) Inc. (Environ). 2012. Status and trends of hydrology, water quality, and suspended sediment quality of the Hay River. Yellowknife, NT. Report prepared for Aboriginal Affairs and Northern Development Canada.
- HDR Corporation (HDR). 2015. Site specific water quality objectives for the Hay and Slave transboundary rivers: technical report. Report prepared for Department of Environment and Natural Resources, Government of the Northwest Territories.

These reports have primarily examined the status and trends in general water chemistry, nutrients, and metals, as well as suspended sediments (Environ 2012 only). The studies used similar datasets, though the periods of record slightly differed given the different years the analyses were conducted. The statistical methods used did vary between the studies given the slight differences in answering each study's key questions. Each of the statistical methods used have similarities however, and are proven trend analyses of water chemistry. There are assumptions and limitations to each statistical method however, and the key questions asked by each consultant helped drive the selection of the method used, as well as the structure of the data.

The methods used to identify trends in suspended sediment chemistry also differed. Hatfield (2009) summarized the sediment chemistry and identified guideline exceedances. Environ (2012) summarized suspended sediment chemistry and analyzed the data for the presence of trends. HDR (2015) did not analyze suspended sediment chemistry.

A comparison of the methods used in each of the three studies is outlined in the following sections, and are summarized in Table A1.

Table A1: Comparison of Methods Employed in Three Studies to Analyze Water and Suspended Sediment Chemistry in the Hay River Basin

Analyses	Hatfield (2009)	Environ (2012)	HDR (2015)
Key Questions or Objectives	1. Identify available water and suspended sediment data 2. Identify current water quality at transboundary sites relative to upstream and to guidelines 3. Describe effects of known effluent discharges on on water quality 4. Assess changes in water quality over time, with primary concern for aquatic organisms without accounting for flow variability	1. Assess the presence of trends over the 1963-2010 monitoring period 2. Test for differences in the trends between flow seasons 3. Assess the presence of trends from 2000-2010 4. Assess differences in trends between flow seasons from 2000-2010	1. Identify periods where water quality is not changing to develop water quality objectives; these would indicate when observed values are outside of natural variability and actions are needed to address the changes 2. Produce statistically sound estimates for water quality objectives.
Software	WQStat Plus v2.1 (NIC 2003). Microsoft Excel	Microsoft Access	SPSS, NCSS, ProUCL
Summary Statistics	Inorganics, Metals, Organics, Alberta and CCME Guidelines, number of samples, Minimum, Maximum, Median, Number of water quality guideline exceedances (for water) and sediment quality guidelines exceedances (for suspended sediment)	Fraction dissolved/total metal, Minimum, Maximum, Median, Mean, Standard Deviation, Min and Max non-detect value, Min and Max detected value, Human health screening value and frequency exceeded. Frequency ecological screening values exceeded	Mean, Median, Standard Deviation, Minimum, Maximum, Percentile, Skewness, Kurtosis, Standard Error of Mean, Number below method detection limit, Number of samples, Number of different units, Normality, Lognormality
Data Preparation - addressing the assumptions and limitations of sampling, and statistical methods.	• Water quality parameters with > 6 years of data from 1980-2008 with trends assessed using quarterly or seasonal data • Graphical analysis, plotting time series in the Slave River but not the Hay River	• Parameters were divided into 40 target and 188 non-target, with trend analyses done for target parameters • Dissolved vs total ratio correlation • Data analyzed as a whole, as 2000-2010 subset and as flow/season subset. • Graphical analysis of all parameters' trend analysis	• Addressed unit discrepancies, distribution of parameters, parameter names, sample size, censoring, log transformed, outliers, skewness and kurtosis statistics from the Shapiro-Wilk tests for normality, replicate samples, adjusting for seasonality. • Graphical analysis of trends, distributions. Analyses based on

Table A1: Comparison of Methods Employed in Three Studies to Analyze Water and Suspended Sediment Chemistry in the Hay River Basin

Analyses	Hatfield (2009)	Environ (2012)	HDR (2015)
			classification of multiple groups, based on sample size and the percentage of samples below DL
Addressing Non-Detects	Set to half the detection limit, no more than 50% non-detectable values, Subsets were created to eliminate the effect of different detection limits	Used the full detection limit, parameters had to have 70% total detects in a minimum of five samples.	• < 20% non-detects, 20% to 40% non-detects, > 40% non-detects • Used Maximum Likelihood Estimates (MLE) Regression for non-detects that accounts for non-detects in the model
Locations	HR/Border	HR/Border Hay River West Channel (HR/WC)	HR Border
Years Analyzed	Water Chemistry: 1988 – 2008 Suspended Sediment: 1995 – 2001/2002	Water Chemistry: HR/Border: 1963 – 2010, 2000 – 2010 HR/WC: 1988 – 2010 Suspended Sediment: 1995 - 2005	Water Chemistry: 1969 – 2014 Suspended Sediment: not analyzed
Number of Parameters	Water Chemistry: 86 Suspended Sediment: 19	Water Chemistry: 40 target parameters 188 non-target parameters Suspended Sediment: 11	Water Chemistry: 70 Suspended Sediment: not analyzed
Statistical Tests for Trends	Summary/descriptive statistics to identify exceedance of water quality guidelines	Linear Regression, ANCOVA for flow/seasonal trends	MLE Regression for non-detects, piece-wise polynomial regression
Assumptions of Statistical Tests	Not applicable	Normality, linearity, variables measured without error, variance in error the same across all variables	Lognormality, linearity in MLE Regression, variables measured without error, variance in error the same across all variables
Other tests	Not applicable	Correlation of water quality parameters and total/dissolved ratios.	ANOVA to test for differences between seasonal subgroups

Key Questions Driving Methods

The Hatfield (2009), Environ (2012), and HDR (2015) studies focused on slightly different key questions, which were reflected in the methods and statistical approaches chosen to identify trends in water quality. Each study focused on identifying water chemistry or suspended sediment parameters that exceeded guidelines, but beyond that, the goals of the data analyses differed:

- Hatfield (2009) focused their analysis with prime concern for aquatic organisms and identifying the exceedance of guidelines set by Alberta and Canadian Council of Ministers of the Environment (CCME).
- Environ (2012) focused their methods on identifying statistically significant trends during two time periods, different flow regimes, and the relationships between water chemistry parameters. The methods used to analyze suspended sediment data focused on identifying exceedances of human health and ecological screening levels, statistically significant trends, different flow regimes and total organic carbon (TOC).
- HDR (2015) focused on identifying periods where water chemistry was not changing to define the range of natural variability and develop water quality objectives that would distinguish data outside natural levels. HDR (2015) did not analyze suspended sediment.

Data Preparation and Cleaning

Hatfield (2009) used Microsoft Excel to organize water chemistry data from the HR-BORDER site collected between 1988 and 2008. Summary statistics were provided for 86 inorganic, metals, and organic parameters by number of samples collected, minimums, maximums, medians, and number of guideline exceedances. Alberta and CCME guidelines for water quality (freshwater aquatic life) and sediment (interim freshwater sediment quality guidelines and probable effect levels) for suspended sediment comparisons were used. The presence of water or sediment chemistry data for many lakes within the Hay River Basin was indicated, but no trend analysis was provided, likely due to the scarcity of samples at individual sampling locations.

Environ (2012) used Microsoft Access for database creation but did not indicate the software used in trend analyses and comparison of water quality. For water chemistry, data for 40 routinely measured parameters, from 1963 to 2010, and 188 parameters, which were mainly organic contaminants analyzed in 2004 and 2005, were summarized. Eleven suspended sediment parameters fit their criteria for trend analysis for data collected from 1995 to 2005. The summary statistics for both water and suspended sediment included sample size, minimum, maximum, median, mean, standard deviation, minimum and maximum non-detect values, minimum and maximum detect values, and frequency of exceedance of human health and ecological screening values. To prepare the water chemistry data for trend analysis, non-detect values were set to the detection limit, and parameters were analyzed only if there was greater than 70% detectable measurements and a minimum of five data points. Two time periods were identified for trend analysis: the whole dataset (1988 to 2010) and the more recent data (2000 to

2010). Data were grouped to reflect flow conditions, based on base flow, freshet, and recession of the hydrograph; trends were evaluated for the two time periods for each flow regime.

HDR (2015) used SPSS, NCSS, and ProUCL software for the trend analyses of 70 water chemistry samples collected from 1969 to 2014. The dataset was standardized by addressing discrepancies in units and parameter names. Distribution of each parameter was tested for normality, skewness, kurtosis, presence of outliers, seasonality. Data were transformed using the natural logarithm to satisfy assumptions of the statistical trend tests. Data were classified based on sample size and the percentage of samples below the detection limit (three categories: less than 20% non-detects, 20% to 40% non-detects, and greater than 40% non-detects). Summary statistics for each water chemistry parameter reported were mean, median, standard deviation, minimum, maximum, skewness, kurtosis, standard error of mean, number below Maximum Detection Level (MDL), number of different units, normality, and lognormality.

Statistical Tests and Models for Analysis of Trends

Hatfield (2009) did not employ statistical tests to analyze trends in water or suspended sediment chemistry in the Hay River, but both Environ (2012) and HDR (2015) used regression models.

Environ (2012) used Analysis of Covariance (ANCOVA) to test the significance of seasonal and flow trends, and linear regression on water chemistry parameters that had enough samples for seasonal, or flow analysis. They also used correlation to test the relationship among water chemistry and suspended sediment parameters, though they did not specify whether they used Spearman's, Pearson's, or Kendall's correlation.

HDR (2015) used multiple Maximum Likelihood Estimates (MLE) non-detects regression to analyze for the presence of linear trends over time and piece-wise polynomial regression to identify breaks, or changes in trends in the time periods tested. They also used Analysis of Variance (ANOVA) and the Kruskal-Wallis test to quantify the difference between seasonal subgroups to identify significant variation between ice-free and ice-covered periods and between seasons.

Addressing Assumptions and Limitations of Statistical Tests

Regression analysis relies on several assumptions for the results to be robust and interpretation made easy. The Environ (2012) report did not state that they analyzed the distributions of the water chemistry or suspended sediment samples to determine if they were normal, though they did a graphical analysis of data plots. Without a normal distribution it is possible for non-normally distributed parameters to distort relationships and significance tests. Often water chemistry parameters have a lognormal rather than normal distribution, meaning they are normal when taking their natural logarithm. However, log transforming the data often makes no difference in the significance of regression models when testing for trends in water quality over time. Assumptions of linear relationships must be made when using regression and correlation; the only question when considering this was which correlation was used by Environ (2012) when testing relationships between parameters. They did not specify which type of correlation analysis was used, so it is difficult to interpret the true degree of the correlations reported. Spearman's correlation accounts for non-linear relationships better than Pearson's correlation, so knowing which test was used helps for better interpretation. Knowing which parameters are related to a higher number of other parameters will help minimize time spent collecting highly correlated parameters.

Regression analysis also assumes that parameters are measured without error. There is always a degree of measurement error, but including more samples reduces that error. Environ (2012) addressed this commonly encountered problem through the data preparation techniques outlined above and by defining limits for how many non-detects to use in the analysis. Also, use of ANCOVA and regression reduces the influence of sampling error by employing two methods for analysis of trends. ANCOVA is not as robust as regression in quantifying trends but it helps identify areas of further analysis using regression and was appropriately applied in the study.

HDR (2015) addressed the assumption of normality in water chemistry data by analyzing the distributions and the degree of skewness and kurtosis, then log-transforming the data. The assumption of no sampling error was addressed by using data preparation techniques outlined above and defining limits for how many non-detects were used in the analysis. ANOVA and Kruskal-Wallis tests will essentially identify differences between multiple groups: ANOVA is parametric and tests the difference in means; Kruskal-Wallis is non-parametric and tests the difference among population ranks equivalent to the median and does not rely on normally distributed data. This allowed multiple tests of the data in different transformations to add to the robustness of the result, since there was no difference between the results of each of the types of tests.

Conclusions

Considering that the three studies set out to answer variations of the same question regarding exceedance of water quality guidelines and the presence of trends, it is possible that differences in methods could result in different conclusions. The Hatfield (2009), Environ (2012), and HDR (2015) studies analyzed many of the same parameters but over different time periods, which could explain differences in trend analysis and summary statistics. HDR (2015) employed the most extensive data preparation and cleaning, which could make a more conservative estimate of trends. The treatment of non-detects was different in the regression analyses and HDR (2015) used Maximum Likelihood Estimates (MLE) -non detects regression which accounts for non-detects in the model. Environ (2012) assigned all non-detects at the full detection level, which accounts for these values in a different way but both methods allow for a limited effect of non-detects in trend analysis. These two different methods may result in different results for trend analyses. Regression techniques were slightly different between Environ (2012) and HDR (2015) which could account for differences in results. Since Environ (2012) did not address assumptions of normality in their regression models, and did not report which type of correlation was used, it raises questions about the robustness of their results.

For suspended sediments, Hatfield (2009) and Environ (2012) set out to summarize chemistry data and determine when there were exceedances of guidelines for sediment quality for the protection of aquatic life. In addition Environ (2012) analyzed the trends for 11 sediment parameters over a ten year period. There were two differences in the analyses that could determine differences in results. The first was the use of different guidelines for determining exceedance values. Hatfield (2009) used the CCME interim sediment quality guidelines (ISQGs) and probable effects levels (PELs) while Environ (2012) used only the ISQGs. The use of different temporal scales in the analysis would have produced different results in summary statistics. Environ (2012) had limited samples in their trend analysis and results must be interpreted with caution. Similar to water chemistry, since Environ (2012) did not address assumptions of normality and did not report which type of correlation was used the robustness of their results are in question.

APPENDIX A2

INTERIM SURFACE WATER QUALITY TRIGGERS FOR THE HR-BORDER SITE

Table A2: Interim Site-Specifc Surface Water Quality Triggers for the Hay River, near the Alberta/Northwest Territories border, as identified in the Alberta-Northwest Territories Bilateral Water Management Agreement (2015)

	Hay River near the Alberta/NWT Border					
Parameter	**Seasonal**				**Annual**	
	Open Water		**Under Ice**			
	50th	**90th**	**50th**	**90th**	**50th**	**90th**
Alkalinity (mg/L)	93	127	191	272	*	*
Dissolved Oxygen (mg/L)	8.8	11.22	5.75	10.1	*	*
pH (pH units)	7.81	8.12	7.46	7.79	*	*
Specific Conductance (µS/cm)	322	401	584	793	*	*
Total Dissolved Solids (mg/L)	249	302	414	549	*	*
Total Suspended Solids (mg/L)	41	218	6	12	*	*
Turbidity (NTU)	33.1	149	12.5	20.5	*	*
Calcium – dissolved (mg/L)	40	49	73.7	99.5	*	*
Chloride – dissolved (mg/L)	2.84	5.21	7.42	12.27	*	*
Magnesium – dissolved (mg/L)	11.3	14.4	21.4	29.3	*	*
Sodium – dissolved (mg/L)	12.5	15.9	21.5	32.7	*	*
Potassium – dissolved (mg/L)	1.9	2.67	2.42	3.12	*	*
Sulphate - dissolved (mg/L)	61	88.4	105	141.4	*	*
Ammonia - dissolved (mg/L)	0.018	0.054	0.07	0.217	*	*
Nitrogen – dissolved (mg/L)	0.617	1.009	0.924	1.498	*	*
Nitrate + Nitrite (mg/L)	--	--	--	--	0.09	0.587
Organic Carbon – dissolved (mg/L)	25.6	32.7	28.2	37.2	*	*
Organic Carbon – particulate (mg/L)	2.1	4.77	0.68	1.57	*	*
Phosphorus – dissolved (mg/)	0.025	0.05	0.027	0.049	*	*
Phosphorus – total (mg/L)	0.107	0.256	0.054	0.113	*	*
Aluminum – dissolved (µg/L)	--	--	--	--	[22.00]	[47.69]
Aluminum – total (µg/L)	436	2086	89	211	*	*
Antimony – dissolved (µg/L)	--	--	--	--	[0.16]	[0.20]
Antimony – total (µg/L)	--	--	--	--	0.108	0.168
Arsenic – dissolved (µg/L)	--	--	--	--	[0.765]	[1.153]
Arsenic – total (µg/L)	--	--	--	--	[1.49]	[3.27]
Barium – dissolved (µg/L)	--	--	--	--	[41.40]	[58.84]

Table A2: Interim Site-Specifc Surface Water Quality Triggers for the Hay River, near the Alberta/Northwest Territories border, as identified in the Alberta-Northwest Territories Bilateral Water Management Agreement (2015)

Parameter	Hay River near the Alberta/NWT Border					
	Seasonal				Annual	
	Open Water		Under Ice			
	50th	90th	50th	90th	50th	90th
Barium – total (µg/L)	60	102	80	110		
Beryllium – dissolved (µg/L)	--	--	--	--	[0.01]	[0.02]
Beryllium – total (µg/L)	0.05	0.176	0.05	0.05		
Bismuth – dissolved (µg/L)	--	--	--	--	[0.003]	[0.005]
Bismuth – total (µg/L)	--	--	--	--	[0.01]	[0.03]
Boron – dissolved (µg/L)	--	--	--	--	[30.00]	[49.49]
Boron – total (µg/L)	--	--	--	--	31.95	47.25
Cadmium – dissolved (µg/L)	--	--	--	--	[0.03]	[0.06]
Cadmium – total (µg/L)	0.12	0.5	0.2	0.52	*	*
Chromium – dissolved (µg/L)	--	--	--	--	[0.14]	[0.21]
Chromium – total (µg/L)	0.79	3.37	0.344	0.66	*	*
Cobalt – dissolved (µg/L)	--	--	--	--	[0.21]	[0.50]
Cobalt – total (µg/L)	0.86	2.75	0.5	1.3	*	*
Copper – dissolved (µg/L)	--	--	--	--	[2.04]	[3.35]
Copper – total (µg/L)	3	7.01	2.1	3.1	*	*
Iron – dissolved (µg/L)	--	--	--	--	[484.00]	[926.20]
Iron – total (µg/L)	1790	6434	2080	3112	*	*
Lead – dissolved (µg/L)	--	--	--	--	[0.15]	[0.25]
Lead – total (µg/L)	0.9	3.4	0.5	1.3	*	*
Lithium – dissolved (µg/L)	--	--	--	--	[13.30]	[22.12]
Lithium – total (µg/L)	13.9	23.98	24.15	56.11	*	*
Manganese – dissolved (µg/L)	--	--	--	--	[16.45]	[252.60]
Manganese – total (µg/L)	78	169	192	666	*	*
Mercury – dissolved (µg/L)	--	--	--	--	--	--
Mercury – total (µg/L)	--	--	--	--	--	--
Molybdenum – dissolved (µg/L)	--	--	--	--	[0.76]	[1.00]
Molybdenum – total (µg/L)	0.76	1.22	0.62	1.05	*	*

Table A2: Interim Site-Specifc Surface Water Quality Triggers for the Hay River, near the Alberta/Northwest Territories border, as identified in the Alberta-Northwest Territories Bilateral Water Management Agreement (2015)

Parameter	Hay River near the Alberta/NWT Border					
	Seasonal				Annual	
	Open Water		Under Ice			
	50th	90th	50th	90th	50th	90th
Nickel – dissolved (µg/L)	--	--	--	--	[3.17]	[3.80]
Nickel – total (µg/L)	4.19	9.19	3.5	5.36	*	*
Selenium – dissolved (µg/L)	--	--	--	--	[0.21]	[0.37]
Selenium – total (µg/L)	--	--	--	--	0.24	0.39
Silver – dissolved (µg/L)	--	--	--	--	[0.004]	[0.008]
Silver – total (µg/L)	--	--	--	--	0.013	0.066
Strontium – dissolved (µg/L)	--	--	--	--	[138.00]	[264.60]
Strontium – total (µg/L)	126	156	224	305	*	*
Thallium – dissolved (µg/L)	--	--	--	--	[0.008]	[0.014]
Thallium – total (µg/L)	--	--	--	--	0.017	0.066
Uranium - dissolved (µg/L)	--	--	--	--	[0.54]	[1.47]
Uranium - total (µg/L)	--	--	--	--	0.645	1.494
Vanadium – dissolved (µg/L)	--	--	--	--	[0.42]	[0.54]
Vanadium – total (µg/L)	1.6	6.32	0.5	0.86	*	*
Zinc – dissolved (µg/L)	--	--	--	--	[1.28]	[12.03]
Zinc – total (µg/L)	6.3	22.5	4.9	17	*	*

Notes:

1. 50th: Trigger 1 (50th percentile; median); 90th: Trigger 2 (90th percentile)
2. "--" Less than 30 observations. Trigger values will be calculated and tested during the Learning Plan when sufficient data (n≥30) is available.
3. "*"In accordance with section E3, only the most detailed trigger values are included in this table. All subclass trigger values are included in the Technical Appendix entitled: Site Specific Water Quality Objectives at the Hay and Slave Transboundary Rivers: Technical Report (HDR Decision Economics, February 2015) and are available for testing during the Learning Plan.
4. Spring: May and June, Summer: July and August, Fall: September and October, Winter: November to April
5. Open Water: Spring, Summer and Fall; Ice Covered: Winter
6. Values in square brackets are preliminary calculations based on n=26. They will be recalculated when n=30.

APPENDIX A3

WATER AND SUSPENDED SEDIMENT STATUS AND TRENDS AT THE HR-BORDER

Table A3-1: Water Chemistry Summary Statistics and Temporal Trends

Parameter	Concentration (µg/L)			Temporal Trends[1]	
	Minimum	Maximum	Median	Environ (2012)	HDR (2015)
Alkalinity, Total (as Caco3)	14700	305000	115500	↓	↔
Total Aluminum[5]	11	7,950	25	–	↔[2]
Dissolved Aluminum	6.5	91.7	27	–	↔[2]
Total Arsenic	0.19	5.9	1.42	↔	↔
Dissolved Arsenic	0.1	1.6	0.5	↑	↔
Total Boron	9.1	66.2	31.5	–	↔
Dissolved Boron	17.1	60.9	29	–	↔
Total C11-C60 Hydrocarbons	50	50	50	–	–
Dissolved C11-C60 Hydrocarbons	50	50	50	–	–
Total Cadmium[6]	0.014	2.56	0.157	↓	↔
Dissolved Cadmium	0.015	0.186	0.028	↓	↓[2]
Carbon Dissolved Organic	2858	72533	26200	↔	↔
Carbon Organic	3417	73157	28730	↔	↔
Total Conductivity	100	820	355	↔	↔
Total Chloride	1600	9590	3700	↔	–
Dissolved Chloride	1360	24400	4245	↔	↔
Total Chromium[7]	0.01	12.2	0.544	↔	↔
Dissolved Chromium	0.09	0.342	0.152	–	↔[2]
Total Cobalt	0.067	8.9	0.7	↔	↔
Dissolved Cobalt	0.12	2.2	0.24	–	–
Total Copper[6]	0.55	24.7	2.5o	↔	↔
Dissolved Copper	1.3	5.6	2.5	–	↔[2]
Total Dissolved Soilds	42000	2700000	247000	–	↔
Total Hardness	51554	421400	166038	i	↔
Total Iron	200	21,800	2,015	↔	↓
Dissolved Iron	237	3,170	500	–	↓[2]
Total Lead[6]	0.088	11.3	0.7	↔	↔
Dissolved Lead	0.026	0.915	0.151	–	↓[2]
Total Magnesium	6760	31600	12400	↓	–
Dissolved Magnesium	3000	13133	32600	↓	↔
Total Manganese	6.5	1340	91	↓	↔
Dissolved Manganese	3.2	682	22	–	–
Total Molybdenum	0.05	1.9	0.73	–	↔
Dissolved Molybdenum	0.54	1.29	0.77	–	↔[2]
Total Nickel[6]	0.74	27.3	3.91	↔	↔
Dissolved Nickel	2.27	7.78	3.19	–	↓[2]
Total Nitrogen Nitrate (as N)	10	580	128	–	–
Dissolved Nitrogen Nitrate-Nitrite	8	2460	101	↑	↔
Total Nitrogen, Nitrite	10	1180	10	–	–
Total pH	6.9	8.8	7.9	↑	↑
Total Phosphorus	10	728	79	↑	↔

Table A3-1: Water Chemistry Summary Statistics and Temporal Trends

Parameter	Concentration (µg/L)			Temporal Trends[1]	
	Minimum	Maximum	Median	Environ (2012)	HDR (2015)
Total Potassium	700	7500	2050	↓	–
Dissolved Potassium	330	4790	2025	–	↔
Total Selenium	0.06	0.51	0.24	–	↔
Dissolved Selenium	0.05	0.6	0.2	–	↔[2]
Total Silver	0.001	0.2	0.044	–	↔
Dissolved Silver	0.001	0.047	0.004	–	↔[2]
Total Strontium	50	346	137	↔	↔
Dissolved Strontium	65	323	138	–	–
Dissolved Sulfate (as SO4)	11800	151000	72200	↓	↔
Total Thallium	0.003	0.209	0.019	–	↔
Dissolved Thallium	0.006	0.021	0.008	–	↑[2]
Turbidity	0.2	595	17	↔	↔
Total Uranium	0.24	2.1	0.59	–	↔
Dissolved Uranium	0.25	2	0.5	–	–
Total Vanadium	0.1	23	0.95	↑	↑
Dissolved Vanadium	0.15	0.69	0.45	–	–
Total Zinc	0.5	93.3	5.8	↔	↔
Dissolved Zinc	0.3	14.4	1.3	–	↔[2]

NOTES:

1. Temporal trends identified for entire data record by Environ (2012) and HDR (2015); ↑ = increasing, ↓ = decreasing, ↔ = no trend
2. Trends identified based on a dataset with less than 30 data points (HDR 2015)

SOURCE: Environ 2012, HDR 2015

Table A3-2: Suspended Sediment Summary Statistics and Temporal Trends

Parameter	Units	Concentration			Temporal Trends[4]
		Minimum	Maximum	Median	
Arsenic	mg/kg	12.5	19.6	16	↔
C11-C60 Hydrocarbons	mg/kg	30	760	300	–
Calcium	mg/kg	9450	10900	9960	–
Carbon, Organic	%	2	10	3.1	↔
Carbon, Inorganic	%	<0.1	0.43	0.31	–
Cadmium[6]	mg/kg	0.66	1	0.9	–
Chromium[7]	mg/kg	26.8	118	71	↔
Cobalt	mg/kg	11	18	14	↔
Copper[6]	mg/kg	17	43	25.9	↔
Iron	mg/kg	32900	48400	39100	↔
Lead[6]	mg/kg	10	17.7	15.4	↔
Magnesium	mg/kg	8410	10300	8875	–
Manganese	mg/kg	409	3190	758	↔
Mercury	mg/kg	0.064	0.092	0.08	↔
Naphthalene	mg/kg	0.01	0.086	0.083	–
Nickel	mg/kg	30	53	42	↔
Nitrogen, Inorganic	%	0.31	0.31	–	–
Nitrogen, Organic	%	0.17	0.85	0.25	–
Phosphorus,	mg/kg	875	1,730	1,170	–
Potassium	mg/kg	8770	14200	11530	–
Pyrene	mg/kg	0.01	0.1	0.094	–
Sodium	mg/kg	500	579	524	–
Strontium	mg/kg	11	104	85	–
Thallium	mg/kg	0.55	0.85	0.7	–
Tin	mg/kg	0.3	0.6	0.3	–
Uranium	mg/kg	2.2	3	2.6	–
Vanadium	mg/kg	130	183	156	–
Zinc	mg/kg	110	158	142	↔

NOTES:

1. CCME SQG = Canadian Council of Ministers of the Environment (CCME) sediment quality guidelines
2. nND / n = number of non-detect data points over number of data points
3. # > CCME SQG = number of data points greater than the CCME SQG ISQG and PEL guidelines
4. Temporal trends identified for entire data record by Environ (2012); ↑ = increasing, ↓ = decreasing,

SOURCE: Environ 2012

APPENDIX B
QUALITY ASSURANCE/QUALITY CONTROL FOR ORGANIC CONTAMINANTS IN WATER

Appendix B QUALITY ASSURANCE/QUALITY CONTROL FOR ORGANIC CONTAMINANTS IN WATER

B.1 INTRODUCTION

For sampling quality assurance/quality control (QA/QC) purposes, field duplicate/triplicate, field blank, and travel blank samples were collected throughout the surface water, centrifugate water, polyethylene membrane device (PMD), and suspended sediment field programs, and analyzed for organic contaminants. Field duplicates are collected to check for field precision, field blanks are collected to check for potential cross-contamination during sample collection, and travel blanks are collected to measure volatile compounds or determine if contamination might enter a water sample during transportation.

An example of QA/QC objectives in Canada are the quality assurance guidelines in the British Columbia Field Sampling Manual (BC MOE 2013). The BC Field Sampling Manual specifies that a relative percent difference (RPD) for duplicates or a relative standard deviation (RSD) for triplicates greater than 20% indicates a possible sample contamination, or a lack of sample representativeness. An RPD or RSD greater than 50% indicates a definite sample integrity problem; however, it is not unusual to find high variability for the field duplicates, especially if the water is turbid (total suspended solids greater than 25 mg/L). The acceptable criterion for blank samples is: contamination preferably should not be significantly greater in concentration nor occurrence than laboratory method blank contamination. Detectable field or travel blank values should be checked to determine the source of contamination, and to determine the impact of this contamination upon the sample data (BC MOE 2003)[1].

The laboratory (AXYS Analytical; accredited by the Canadian Association for Laboratory Accreditation) QA/QC program also included analysis of certified reference material, matrix spikes and laboratory blanks to determine accuracy and precision of instrumentation and methods.

B.2 METHODS

The RPD between duplicate samples was calculated according to the equation below, and compared to the 20% and 50% data quality objectives:

$$RPD = \frac{(X1 - X2)}{(\frac{X1 + X2}{2})} \, x \, 100$$

[1] British Columbia Ministry of Environment. 2013. British Columbia Field Sampling Manual for Continuous Monitoring plus the Collection of Air, Air-Emission, Water, Wastewater, Soil, Sediment, and Biological Samples. Available at: http://www2.gov.bc.ca/assets/gov/environment/research-monitoring-and-reporting/monitoring/emre/field_sample_man2013.pdf

The RSD between triplicate samples was calculated according to the equation below, and compared to the 20% and 50% data quality objectives:

$$RSD = \frac{(S * 100)}{\bar{X}}$$

where S = standard deviation and $\bar{X}$ = mean of the data.

B.3 POLYCYCLIC AROMATIC HYDROCARBONS

B.3.1 PAHs in the Surface Water

At the HR-BORDER site, PAHs were analyzed in 32 surface water samples collected in May to September from 1994 to 2008, then annually in May from 2009 to 2014.

B.3.2 PAHs in the Centrifugate Water

From 2013 to 2015 centrifugate samples were collected monthly during the summer from the HR-BORDER and SR-SMITH sites and analyzed for up to 75 parent and alkylated PAHs, using ultra-low detection limits. The following QA/QC samples were included in the program:

- Duplicate and triplicate samples
- Four field blank samples collected at HR-BORDER and five at SR-SMITH
- Ten laboratory blanks

The sums of the PAH concentrations (i.e., total PAH) in the duplicate and triplicate samples, rather than individual compounds, were assessed for precision by calculating the RPD and RSD. The RPD between duplicate samples collected in July 2013 was 40% (Total PAHs: Dup 1 = 0.0758 µg/L, Dup 2 = 0.114 µg/L). The RSDs of triplicate samples were all less than 10% and five times their detection limit, with the exception of samples collected in August 2013 (22% RSD).

The sums of the PAH concentrations in the field blank samples ranged from 0.021 µg/L to 0.099 µg/L, with the exception of one field blank sample collected in August 2014 (0.224 µg/L) (Table B-1). This field blank sample was most likely contaminated; however, the SR-SMITH sample collected on the same date (see Section 4.3.3.2) did not appear to have been contaminated (PAH concentrations were within the range of other SR-SMITH samples); therefore, the field data were not excluded.

The sums of PAH concentrations in laboratory blank samples ranged from 0.0083 µg/L to 0.063 µg/L (Table B-1). The field blank PAH concentrations were typically higher than the laboratory blank concentrations, indicating small amounts of PAHs are likely introduced in the field.

Based on the review of the QA/QC data, this PAH dataset is considered reproducible and representative of the water chemistry at the HR-BORDER and SR-SMITH sites.

Table B-1 Quality assurance/quality control samples for the centrifugate water sampling program for polycyclic aromatic hydrocarbons at HR-BORDER and SR-SMITH

Sampling Date	QA/QC samples (µg/L)			
	Field Blank		Lab Blank	
	Total PAH[1]	Total DL[1]	Total PAH[1]	Total DL[1]
Jul, 2013	0.099	0.013	—	—
Jul, 2013	0.07	0.02	0.055	0.011
Aug, 2013	0.065	0.011	0.051	0.009
Aug, 2013	—	—	0.044	0.017
Jun, 2014	0.054	0.008	0.05	0.01
Jul, 2014	0.036	0.008	0.063	0.018
Aug, 2014	0.021	0.003	0.026	0.004
Aug, 2014	0.224	0.003	0.01	0.002
Jun, 2015	0.029	0.003	0.017	0.003
Jul, 2015	—	—	0.008	0.003
Aug, 2015	0.03	0.011	0.014	0.009

NOTES:

QA/QC = quality assurance/quality control

— = no data

Total DL = total detection limit

1. Where a concentration was reported as less than the DL the full DL was used to calculate total PAH (sum of all PAH compounds). The sum of the DLs (total DL) is included to provide context to the reported values.

B.3.3 PAHs in the Suspended Sediment

Between July 2013 and August 2015, suspended sediment samples were analyzed for PAHs in six samples collected at HR-BORDER and eight samples collected at SR-SMITH. The following QA/QC samples were included in the program:

- One duplicate sample
- Two bowl blanks
- A laboratory blank sample each month a field sample was analyzed, except July 2014

One duplicate was collected at SR-SMITH in August 2014. The sums of PAHs in the duplicate samples were 2,864 µg/kg dw and 2,528 µg/kg dw, with an RPD of 24%. Of the 75 compounds analyzed, 12 duplicates had an RPD greater 20% and were more than 5 times the detection limit. The maximum RPD, at 36%, was calculated for retene.

The sums of the PAH concentrations in the laboratory blank samples (analyzed using reference sediment) ranged from 5.3 µg/kg to 17.3 µg/kg, and were generally close to their total DLs (up to 3 times higher; Table B-2). Total PAHs (see Section 4.3.3.3) were notably higher in the field samples compared to the laboratory blanks, which suggest the suspended sediment samples were likely not contaminated in the lab.

Bowl blank samples obtained from the centrifuge sampler were also analyzed to check for potential contamination from cleaning between samples or contamination from the machine itself. Several PAHs were detected in bowl blank samples (e.g., total PAH in the July 2015 bowl blank sample was 31 times higher than total DL). This suggests some PAHs may be introduced into the sample after the machine has been cleaned. However, the bowl blank concentrations were notably lower than the suspended sediment field samples (see Section 4.3.3.3); thus the contribution from cleaning and/or the machine appears to be relatively minor.

Table B-2 Quality assurance/quality control samples for the suspended sediment sampling program for polycyclic aromatic hydrocarbons at HR-BORDER and SR-SMITH

	QA/QC samples			
	Lab Blank (µg/kg)		Bowl Blank (µg/L)	
Sampling Date	Total PAH[1]	Total DL[1]	Total PAH[1]	Total DL[1]
Jul, 2013	15.6	6.5	—	—
Aug, 2013	10.2	3.8	0.36	0.014
Jun, 2014	13.8	4.4	—	—
Aug, 2014	7.5	5.1	—	—
Jun, 2015	5.3	3	—	—
Jul, 2015	6.4	5.8	0.126	0.004
Aug, 2015	17.3	11.6	—	—

NOTES:

QA/QC = quality assurance/quality control

— = no data

Total DL = total detection limit

1. Where a concentration was reported as less than the DL, the full DL was used to calculate total PAH (sum of all PAH compounds). The sum of the DLs (total DL) is included to provide context to the reported values.

Overall, there is good agreement between the duplicate samples and the blank samples; therefore, the dataset was considered reproducible and representative.

B.4 POLYETHYLENE MEMBRANE DEVICE WATER CHEMISTRY

The PMDs passively sample for dissolved hydrocarbons for approximately 30 days. For the Hay River PMD sampling program, HAY-01 was sampled once in 2012, twice in 2013, and three times in 2014, while HAY-02 was sampled only once in 2013. For the Slave River PMD sampling program, SMITH-01 was sampled once in 2012, five times in 2013, and three times in 2014. The following QA/QC samples were included in the PMD sampling program:

- Two duplicate samples (one at HAY-01 and one at SMITH-01)
- Field blanks
- Travel Blanks

One field duplicate sample was collected at HAY-01 during the July to September 2014 (40 day) exposure period. Results from the duplicate samples were similar, with RPDs of 22% for total PAHs, 12% for total parent PAHs, and 28% for total alkylated PAHs. A second field duplicate sample was collected at SMITH-01 in June to July 2014 (28 days). Again, results for the two duplicates were similar, with RPDs of 1.6% for total parent PAHs, and 3.8% for total PAHs and total alkylated PAHs.

A field blank sample was collected at HAY-01 in September 2014 (Table B-3). The field blank had measureable total PAHs (0.0083 µg/L). The total PAH and total alkylated PAH concentrations in the field blank were similar to the field PMD samples (see Section 4.3.3.4); however, there was a higher percentage of parent PAHs (91%) in the field blank compared to the field samples (16% to 75%; Table 4-11).

Table B-3 Quality assurance/quality control field blank sample for the Polyethylene Membrane Device sampling program at HAY-01

Sampling Site	Sampling Dates	Duration (days)	Total PAH	Parent PAH	Alkylated PAH	% Parent
			(µg/L)			
HAY-01	Sep, 2014	NA	0.0083	0.0076	0.00077	91%
NOTES: NA= not applicable						

Nine travel blank samples were analyzed as part of the Hay and Slave rivers PMD program (Table B-4). There were measurable concentrations of PAHs in the travel blanks samples, with total PAHs ranging from 0.00022 µg/L (July 2013) to 0.0122 µg/L (September 2014).

Table B-4 Quality assurance/quality control travel blank samples for the Polyethylene Membrane Device sampling program at SMITH-01

Sampling Dates	Total PAH	Parent PAH	Alkylated PAH	% Parent
	(µg/L)			
Aug. 2012	0.0100	0.0020	0.0080	20%
Aug. 2012	0.0079	0.0012	0.0067	15%
Sep. 2012	0.0080	0.0009	0.0071	11%
Oct. 2012	0.0024	0.0006	0.0018	25%
Jun. 2013	0.0004	0	0.00036	0%
Jul. 2013	0.0002	0	0.00022	0%
Jul. 2014	0.0052	0.0052	0	100%
Aug. 2014	0.0087	0.0087	0	100%
Sep. 2014	0.0122	0.0118	0.000006	97%

- Total PAH concentrations in travel blanks were similar to field PMD samples in September 2012 and September 2014 (78% of the field sample concentration was recorded in the travel blank; see Table 4-11).
- In August and September 2014, there were higher amounts of parent PAHs in travel blank samples (0.0087 µg/L and 0.0118 µg/L, respectively) than field samples (0.0070 µg/L and 0.0116 µg/L, respectively) (see Table 4-11).
- In September 2012 and June 2013, alkylated PAHs in travel blank samples were higher than parent PAHs; however, in 2014, the total concentration of parent PAHs in the travel blank samples were considerably higher, due to higher concentrations of naphthalene (0.0052 µg/L to 0.0114 µg/L).

B.5 NAPHTHENIC ACIDS

B.5.1 Naphthenic Acids in the Centrifugate Water

Centrifugate water samples collected in June to August 2014 at the HR-BORDER and SR-SMITH stations were analyzed for naphthenic acids. There were no field duplicate/triplicate samples collection, but the following QA/QC samples were included in the program:

- Two field blank samples
- Five laboratory blank samples

The sum of the total naphthenic acid concentrations in the field banks samples were 0.39 µg/L (total DL = 0.29 µg/L) and 0.62 µg/L (total DL = 0.3 µg/L) (Table B-5). Field blank concentrations were higher than their detection limits in 18 of the 60 compounds analysed in August 2014 and 10 of the 60 compounds analysed in August 2015, and were less than 10 times their detection limit except on two occasions in 2014 (for $C_{18}H_{24}O_2$ and $C_{20}H_{30}O_2$).

Table B-5 Quality assurance/quality control samples for the centrifugate water sampling program for naphthenic acids at HR-BORDER and SR-SMITH

	QA/QC samples (µg/L)			
	Field Blank		Lab Blank	
Sampling Date	Total NAs[1]	Total DLs[1]	Total NAs[1]	Total DLs[1]
Jun, 2014	—	—	0.33	0.30
Jul, 2014	—	—	0.49	0.31
Aug, 2014	0.62	0.30	0.67	0.31
Jul, 2015	—	—	4.39	1.61
Aug, 2015	0.39	0.29	0.32	0.30

NOTES:
QA/QC = quality assurance/quality control
— = no data
Total NA = total naphthenic acids
Total DL = total detection limit
1. Where a concentration was reported as less than the DL, the full DL was used to calculate total PAH (sum of all PAH compounds). The sum of the DLs (total DL) is included to provide context to the reported values.

The sum of the total naphthenic acid concentrations in the laboratory blank samples ranged from 0.32 µg/L to 0.67 µg/L, excluding one blank in July 2015 which was 4.39 µg/L. The detection limits were also elevated for this sample, which could suggest laboratory interference occurred.

B.5.2 Naphthenic Acids in the Suspended Sediment

Suspended sediment samples were collected at the same time as the centrifugate samples (June to August 2014) at the HR-BORDER and SR-SMITH sites and analyzed for naphthenic acids. Two laboratory blank samples were analyzed for QA/QC purposes (Table B-6). Naphthenic acids were occasionally detected in the blanks, ranging from 1.1 to 5.6 times the detection limits in June and 1.6 to 20 times the detection limits in July. Laboratory detection limits were higher in July than June.

Table B-6 Quality assurance/quality control samples for the suspended sediment sampling program for naphthenic acids at HR-BORDER and SR-SMITH

Sampling Date	Lab Blank (µg/g)	
	Total NAs[1]	Total DLs[1]
Jun, 2014	0.073	0.056
Jul, 2014	0.319	0.158

NOTES:

Total NA = total naphthenic acids

Total DL = total detection limit

1. Where a concentration was reported as less than the DL, the full DL was used to calculate total PAH (sum of all PAH compounds). The sum of the DLs (total DL) is included to provide context to the reported values.

B.6 PESTICIDES

B.6.1 Pesticides in the Surface Water

Samples were collected at the HR-BORDER site for pesticide analysis during May to September from 1994 to 2008, then annually in May from 2009 to 2014, and in July and August 2015.

B.6.2 Pesticides in the Centrifugate Water

Centrifugate water samples were collected at the HR-BORDER station in July and August 2013 and at the HR-BORDER and SR-SMITH stations in June 2014 and June, July and August 2015 and analyzed for pesticides. From 2014 onwards, laboratory blanks were analyzed each month that a field sample was analyzed. All pesticides in the field and laboratory samples were reported as non-detectable.

Multi-residue (MRES) pesticides were also analysed in the HR-BORDER centrifugate water samples collected from June to August 2014 and June 2015, and in the SR-SMITH samples collected from June to August 2014 and 2015.

A laboratory blank sample was analysed for MRES pesticides in each month a field sample was analysed.

- Most compounds were below the detection limit, with the exception of six compounds in June 2014 (dicamba, MCPP, dichlorprop, triclopyr, 2,4,5-TP [Silvex], and 2,4,5-T), which were less than ten times their detection limit.
- Hexachlorobenzene and aldrin were just above their detection limit in August 2014.

Two field blank samples were also collected – one at HR/Border in July 2014 and one at SR-SMITH in June 2015. Concentrations were below the detection limits, except for hexachlorobenzene in July 2014, which was 1.5 times the detection limit at 0.000016 µg/L.

Based on a review of the laboratory and field blanks, the dataset was considered reproducible and representative.

B.6.3 Pesticides in the Suspended Sediment

Suspended sediment samples were collected at the HR-BORDER site between 1995 and 2013 and analyzed for pesticides. During the sampling program, three field duplicates were collected. Laboratory detection limits were lower in 2011 to 2013 than in previous years. All concentrations in the field duplicates were recorded as non-detects.

A suspended sediment sample was also collected at the HR-BORDER and SR-SMITH sites in June 2014 and at the SR-SMITH site in August 2015. No detectable concentrations were recorded in the laboratory blank samples.

The MRES pesticides were analyzed in the HR-BORDER and SR-SMITH suspended sediment samples in June, July and August 2014. A laboratory blank sample was analyzed for MRES pesticides each time a field sample was analyzed. Most compounds were below or just above detection limits, except for MCPA in June 2014 (2.37 µg/kg dw) (Table B- 7). This suggests laboratory contamination may have occurred for this sample, as similarly high concentrations of MCPA were measured in the field sample collected at HR-BORDER and SR-SMITH in June 2014 compared to other months (see Section 4.3.5.3).

Table B-7 Multi-residue pesticides reported as greater than their detection limit in suspended sediment laboratory blank samples

Sampling Date	2,4,5-T		Dicamba		MCPA		MCPP	
	Conc.	DL	Conc.	DL	Conc.	DL	Conc.	DL
Jun. 2014	0.091	0.049	0.07	0.017	2.37	0.017	—	—
Jul. 2014	0.017	0.017	—	—	—	—	0.034	0.017
Aug. 2014	—	—	—	—	0.118	0.013	0.039	0.013

NOTES:
All values are reported in µg/kg
Conc. = reported concentration
DL = detection limit
— = not detected

B.7 POLYCHLORINATED BIPHENYLS

B.7.1 PCBs in the Surface Water

Between 1994 and 2007, nine samples collected at the HR-BORDER site were analyzed for PCBs.

B.7.2 PCBs in the Centrifugate Water

In 2015, one HR-BORDER sample collected in June, and three SR-SMITH samples collected in June, July and August were analyzed for a large suite of PCB congeners at ultra-low detection limits (note: concentrations are reported in picograms instead of micrograms [1 pg = 0.000001 µg]). A laboratory blank each month and one triplicate set collected at SR-SMITH were analyzed for QA/QC purposes.

The RSD between the triplicates collected in July 2015 at SR-SMITH ranged from 8% to 57% for the detectable PCB compounds (Table B-8). Detection limits varied between the triplicates but individual concentrations were each greater than five times their detection limit.

Table B-8 Relative standard deviation of triplicate samples collected at SR-SMITH in July 2015 for PCB analysis

PCB Compound	Concentration (pg/L)						RSD %
	Replicate 1		Replicate 2		Replicate 3		
	Concentration	DL	Concentration	DL	Concentration	DL	
3,3'-DiCB	52.1	1.14	45.2	2.75	51.7	2.22	8
Aroclor 1242	72.3	3.09	103	7.56	125	6.12	26
Aroclor 1254	—	—	23.8	4.15	56.3	4.15	57
TOTAL PCBs	119	—	170	—	224	—	31

NOTES:
DL = detection limit
— = not detected/no detection limit
RSD = relative standard deviation

The following compounds were detected in the blank samples at concentrations greater than ten times the detection limit: 3'-DiCB in all three months and Aroclor 1242 in June and August (Table B-9). There was no detection limit set for total PCBs; however, detectable concentrations ranged from 107 pg/L to 205 pg/L in the blank samples. The laboratory blank samples indicate some cross-contamination, as detectable levels of some PCBs were similar to the field samples (see Section 4.3.6.2).

Table B-9 Polychlorinated Biphenyls reported as greater than their detection limit in centrifugate water laboratory blank samples

Sampling Date	Concentration (pg/L)									
	3,3'-DiCB		Aroclor 1242		Aroclor 1254		Aroclor 1260		TOTAL PCBs	
	Conc.	DL	Conc.	DL	Conc.	DL	Conc.	DL	Conc.	DL
Jun. 2015	55.2	0.931	74.8	2.48	—	—	—	—	205	—
Jul. 2015	52.8	4.66	56.9	12.6	19.8	8.4	—	—	107	—
Aug. 2015	37.3	2.31	84.2	6.33	7.32	4	4.06	2.5	158	—

NOTES:
Conc. = reported concentration
DL = detection limit
— = not detected/no detection limit

B.7.3 PCBs in the Suspended Sediment

Similarly to centrifugate samples, one sample collected at HR-BORDER in June 2015 and three samples collected at SR-SMITH in June, July and August 2015 were analyzed for PCBs at ultra-low detection limits (pg/g). A laboratory blank was also analyzed each month for QA/QC purposes.

The following compounds were detected in the blank samples at concentrations greater than ten times the detection limit: 3,3'-DiCB, Aroclor 1242, and Aroclor 1260 (Table B-10). There was no detection limit set for total PCBs; however, detectable concentrations ranged from 7.43 pg/g to 16.8 pg/g in the blank samples. The laboratory blank samples indicate some cross-contamination; however, detectable levels of most PCBs were considerably lower in the blank samples compared to the field samples (see Section 4.3.6.3).

Table B-10 Polychlorinated Biphenyls reported as greater than their detection limit in suspended sediment laboratory blank samples

Sampling Date	3,3'-DiCB		Aroclor 1242		Aroclor 1260		TOTAL PCBs	
	Conc.	DL	Conc.	DL	Conc.	DL	Conc.	DL
Jun, 2015	5.21	0.0801	8.71	0.214	0.395	0.36	16.8	—
Jul, 2015	—	—	3.55	0.975	—	—	7.43	—
Aug, 2015	3.41	0.0883	8.72	0.239	0.745	0.318	15.6	—

NOTES:
All values are reported in pg/g
Conc. = reported concentration
DL = detection limit
— = not detected/no detection limit

APPENDIX C
SPECIES LISTS

Table C1: Amphibian Species Likely to Occur in the Hay River Basin

Common Name	Scientific Name	Alberta		Northwes Territories		British Columbia	National	
		General Status	*Wildlife Act*	General Status	*Wildlife Act*	List Status	SARA	COSEWIC
Western toad	*Anaxyrus boreas*	Sensitive	N/A	May Be At Risk	N/A	Blue	Special Concern	Special Concern
Canadian toad	*Anaxyrus hemiophrys*	May Be At Risk	Data Deficient	Sensitive	N/A	N/A	N/A	Not at Risk
Wood frog	*Lithobates sylvaticus*	Secure	N/A	Secure	N/A	Yellow	N/A	N/A
Boreal chorus frog	*Pseudacris maculata*	Secure	N/A	Secure	N/A	Yellow	N/A	N/A
	Total nomber of species	**4**						
	Species of management concern	**2**						

Table C2: Aquatic Mammals Species Likely to Occur in the Hay River Basin

Common Name	Scientific Name	Alberta		Northwest Territories	British Columbia	National	
		General Status	*Wildlife Act*	General Status	List Status	SARA	COSEWIC
Moose	*Alces alces*	Secure	N/A	Secure	Yellow	N/A	N/A
American beaver	*Catstor canadensis*	Secure	N/A	Secure	Yellow	N/A	N/A
Northern American river otter	*Lontra canadensis*	Secure	N/A	Secure	Yellow	N/A	N/A
Meadow jumping mouse	*Zapus hudsonicus*	Secure	N/A	Undetermined	Yellow	N/A	N/A
Meadow vole	*Microtis pennsylvanicus*	Secure	N/A	Secure	Yellow	N/A	N/A
Short-tailed weasel	*Mustela erminea*	Secure	N/A	N/A	N/A	N/A	N/A
American mink	*Mustela vison*	Secure	N/A	Secure	Yellow	N/A	N/A
Muskrat	*Ondatra zibethicus*	Secure	N/A	Secure	Yellow	N/A	N/A
Arctic shrew	*Sorex arcticus*	Secure	N/A	Secure	Yellow	N/A	N/A
Masked shrew	*Sorex cinereus*	Secure	N/A	N/A	Yellow	N/A	N/A
Common water shrew	*Sorex palustris*	Secure	N/A	Secure	Blue	N/A	N/A
Northern bog lemming	*Synaptomys borealis*	Secure	N/A	Secure	Yellow	N/A	N/A
	Total nomber of species	**12**					
	Species of management concern	**1**					

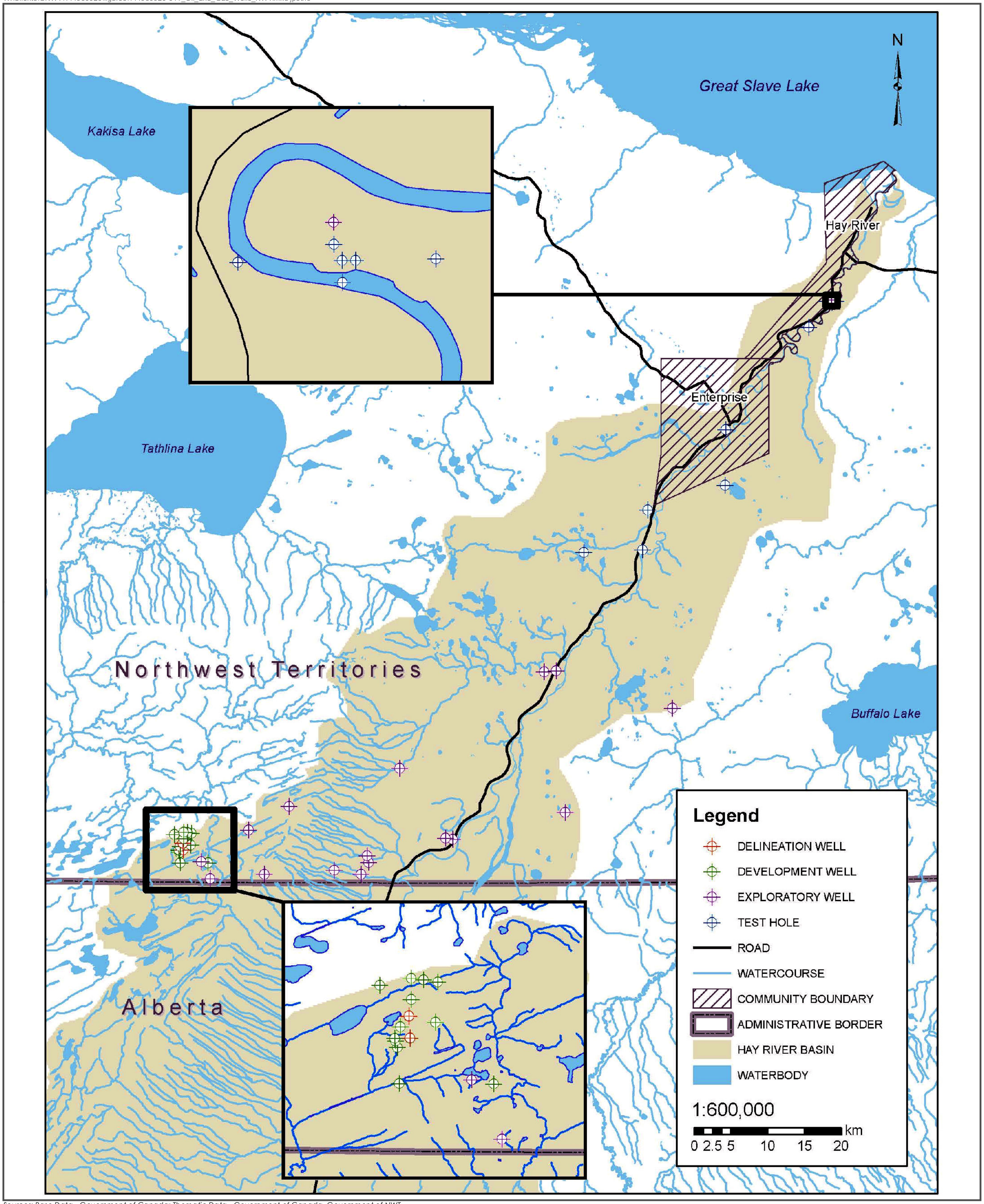
Table C3: Aquatic Avian Species Likely to Occur in the Hay River Basin

Common Name	Scientific Name	Alberta		Northwest Territories	British Columbia	National	
		General Status	*Wildlife Act*	General Status	List Status	SARA	COSEWIC
American avocet	*Recurvirostra americana*	Secure	NA	Undetermined	Blue	NA	NA
hudsonian godwit	*Limosa fedoa*	Secure	NA	Sensitive	Red	NA	NA
American bittern	*Botaurus lentiginosus*	Sensitive	NA	Sensitive	Blue	NA	NA
American coot	*Fulica americana*	Secure	NA	Secure	Yellow	NA	Not at Risk
American wigeon	*Anas americana*	Secure	NA	Secure	Yellow	NA	NA
arctic tern	*Sterna paradisaea*	Secure	NA	Secure	Yellow	NA	NA
bald eagle	*Haliaeetus leucocephalus*	Sensitive	NA	Secure	Yellow	NA	Not at Risk
baird's sandpiper	*Calidris bairdii*	Secure	NA	Secure	Unknown	NA	NA
black-bellied plover	*Pluvialis squatarola*	Secure	NA	Sensitive	Yellow	NA	NA
buff-breasted sandpiper	*Calidris subruficollis*	Secure	NA	Sensitive	Unknown	NA	Special Concern
belted kingfisher	*Megaceryle alcyon*	Secure	NA	Secure	Yellow	NA	NA
black tern	*Chlidonias niger*	Sensitive	NA	Sensitive	Yellow	NA	Not at Risk
Bonaparte's gull	*Chroicocephalus philadelphia*	Secure	NA	Secure	Yellow	NA	NA
bufflehead	*Bucephala albeola*	Secure	NA	Secure	Yellow	NA	NA
blue-winged teal	*Anas discors*	Secure	NA	Secure	Yellow	NA	NA
California gull	*Larus californicus*	Secure	NA	Secure	Blue	NA	NA
Canada goose	*Branta canadensis*	Secure	NA	Secure	Yellow	NA	NA
canvasback	*Aythya valisineria*	Secure	NA	Secure	Yellow	NA	NA
common goldeneye	*Bucephala clangula*	Secure	NA	Secure	Yellow	NA	NA
common loon	*Gavia immer*	Secure	NA	Secure	Yellow	NA	Not at Risk
common merganser	*Mergus merganser*	Secure	NA	Secure	Yellow	NA	NA
common tern	*Sterna hirundo*	Secure	NA	Secure	Unknown	NA	Not at Risk
dunlin	*Calidris alpina*	Secure	NA	Sensitive	Yellow	NA	NA
eared grebe	*Podiceps nigricollis*	Secure	NA	Vagrant	Blue	NA	NA
gadwall	*Anas strepera*	Secure	NA	Undetermined	Yellow	NA	NA
great blue heron	*Ardea herodias*	Sensitive	NA	Vagrant	No Status	NA	NA
greater scaup	*Aythya marila*	Secure	NA	Secure	Yellow	NA	NA
greater yellowlegs	*Tringa melanoleuca*	Secure	NA	Undetermined	Yellow	NA	NA
greater white-fronted goose	*Anser albifrons*	Secure	NA	Secure	Yellow	NA	NA
American green-winged teal	*Anas crecca*	Sensitive	NA	Secure	Yellow	NA	NA
herring gull	*Larus argentatus*	Secure	NA	Secure	Yellow	NA	NA
horned grebe	*Podiceps auritus*	Sensitive	NA	Sensitive	Yellow	NA	Special Concern
killdeer	*Limosa haemastica*	Secure	NA	Secure	Yellow	NA	NA
long-billed dowitcher	*Limnodromus scolopaceus*	Secure	NA	Sensitive	Yellow	NA	NA
least sandpiper	*Calidris minutilla*	Secure	NA	Sensitive	Yellow	NA	NA
lesser scaup	*Aythya affinis*	Sensitive	NA	Sensitive	Yellow	NA	NA
lesser yellowlegs	*Tringa flavipes*	Secure	NA	Sensitive	Yellow	NA	NA
mallard	*Anas platyrhynchos*	Secure	NA	Secure	Yellow	NA	NA
marsh wren	*Cistothorus palustris*	Secure	NA	Undetermined	Yellow	NA	NA
mew gull	*Larus canus*	Secure	NA	Secure	Yellow	NA	NA
Nelson's sparrow	*Ammodramus nelsoni*	Secure	NA	Undetermined	Red	NA	Not at Risk
northern pintail	*Anas acuta*	Sensitive	NA	Sensitive	Yellow	NA	NA
northern waterthrush	*Parkesia noveboracensis*	Secure	NA	Secure	Yellow	NA	NA

Table C3: Aquatic Avian Species Likely to Occur in the Hay River Basin

Common Name	Scientific Name	Alberta		Northwest Territories	British Columbia	National	
		General Status	*Wildlife Act*	General Status	List Status	SARA	COSEWIC
northern shoveler	*Anas clypeata*	Secure	NA	Secure	Yellow	NA	NA
osprey	*Pandion haliaetus*	Sensitive	NA	Secure	Yellow	NA	NA
pacific loon	*Gavia pacifica*	Secure	NA	Secure	Yellow	NA	NA
pied-billed grebe	*Podilymbus podiceps*	Sensitive	NA	Sensitive	Yellow	NA	NA
pectoral sandpiper	*Calidris melanotos*	Secure	NA	Secure	Unknown	NA	NA
ring-billed gull	*Larus delawarensis*	Secure	NA	Secure	Yellow	NA	NA
red-breasted merganser	*Mergus serrator*	Secure	NA	Secure	Yellow	NA	NA
redhead	*Aythya americana*	Secure	NA	Secure	Yellow	NA	NA
red-winged blackbird	*Agelaius phoeniceus*	Secure	NA	Secure	Yellow	NA	NA
red knot	*Calidris canutus rufa*	May Be At Risk	NA	At Risk	Red	Endangered	Endangered
ring-necked duck	*Aythya collaris*	Secure	NA	Secure	Yellow	NA	NA
red-necked grebe	*Podiceps grisegena*	Secure	NA	Secure	Yellow	NA	Not at Risk
red-necked phalarope	*Phalaropus lobatus*	Secure	NA	Sensitive	Blue	NA	Special Concern
Ross's goose	*Chen rossii*	Secure	NA	Secure	Accidental	NA	NA
red-throated loon	*Gavia stellata*	Secure	NA	Secure	Yellow	NA	NA
rusty blackbird	*Euphagus carolinus*	Sensitive	NA	Sensitive	Blue	Special Concern	Special Concern
ruddy duck	*Oxyura jamaicensis*	Secure	NA	Secure	Yellow	NA	NA
ruddy turnstone	*Arenaria interpres*	Secure	NA	Sensitive	Yellow	NA	NA
sandhill crane	*Grus canadensis*	Sensitive	NA	Secure	Yellow	NA	Not at Risk
Sabine's gull	*Xema sabini*	Secure	NA	Secure	No Status	NA	NA
sanderling	*Calidris alba*	Secure	NA	Sensitive	Yellow	NA	NA
short-billed dowitcher	*Limnodromus griseus*	Undetermined	NA	Undetermined	Blue	NA	NA
semipalmated plover	*Charadrius semipalmatus*	Sensitive	NA	Secure	Yellow	NA	NA
semipalmated sandpiper	*Calidris pusilla*	Secure	NA	Sensitive	Unknown	NA	NA
snow goose	*Chen caerulescens*	Secure	NA	Secure	Yellow	NA	NA
sora	*Porzana carolina*	Sensitive	NA	Secure	Yellow	NA	NA
solitary sandpiper	*Tringa solitaria*	Secure	NA	Undetermined	Yellow	NA	NA
spotted sandpiper	*Actitis macularius*	Secure	NA	Secure	Yellow	NA	NA
stilt sandpiper	*Calidris himantopus*	Secure	NA	Secure	Unknown	NA	NA
surf scoter	*Melanitta perspicillata*	Secure	NA	Sensitive	Blue	NA	NA
swamp sparrow	*Melospiza georgiana*	Secure	NA	Secure	Yellow	NA	NA
trumpeter swan	*Cygnus buccinator*	At Risk	Threatened	Sensitive	Yellow	NA	Not at Risk
whimbrel	*Numenius phaeopus*	Secure	NA	Sensitive	Unknown	NA	NA
Wilson's phalarope	*Phalaropus tricolor*	Secure	NA	Undetermined	Yellow	NA	NA
Wilson's snipe	*Gallinago delicata*	Secure	NA	Secure	Yellow	NA	NA
white-rumped sandpiper	*Calidris fuscicollis*	Secure	NA	Secure	Accidental	NA	NA
white-winged scoter	*Melanitta fusca*	Sensitive	Special Concern	Sensitive	Yellow	NA	NA
yellow rail	*Coturnicops noveboracensis*	Undetermined	NA	May Be At Risk	Red	Special Concern	Special Concern
	Total nomber of species	**81**					
	Species of management concern	**35**					

APPENDIX D
ADDITIONAL SUPPORTING INFORMATION



Sources: Base Data - Government of Canada; Thematic Data - Government of Canada, Government of NWT.

Disclaimer: This map is for illustrative purposes to support this Stantec project; questions can be directed to the issuing agency.

Figure Disclaimer: The above figure was provided by the GNWT and used at the request of the GNWT.
It has been re-sized to fit and may not be to scale. It is a representation only

Hay River Basin and Sub-basins:
Overview of Oil and Gas Wells in the Northwest Territories

Stantec

Figure 7-8b