HANGINGSTONE RIVER BASIN STUDY

PRESENTED TO

Regional Municipality of Wood Buffalo

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CONSULTING ENGINEERS & SCIENTISTS · www.eba.ca

Tetra Tech EBA Inc.
14940 - 123 Avenue
Edmonton, AB T5V 1B4 CANADA
Tel 780.451.2121 Fax 780.454.5688

EXECUTIVE SUMMARY

Tetra Tech EBA Inc. was retained by the Regional Municipality of Wood Buffalo (RMWB) to undertake a desktop analysis of the Hangingstone River Basin to provide the basis for a detailed flood protection plan, including mitigation measures, for the city of Fort McMurray. The study included a description and assessment of the entire basin, with a focus on understanding the basin hydrology.

The Hangingstone River originates in a set of low hills about 60 km south of Fort McMurray and flows northward to Clearwater and Athabasca Rivers at Fort McMurray. The basin has a total area of 1,105 km^2, comprised of the main basin which drains 966 km^2 to the Water Survey of Canada (WSC) stream gauge on the Hangingstone River at Fort McMurray, and Saline Creek which drains a basin area of 137 km^2 and joins the Hangingstone below the WSC gauge. The lower reach of the Hangingstone River is within a provincially-designated flood hazard area that is susceptible to backwater flooding associated with ice jam conditions on the Athabasca River. In June 2013, a record flood occurred which raised awareness of the additional flood risk associated with open water conditions.

Data sources to characterize the basin include WSC streamflow stations, Environment Canada climate stations, and various monitoring sites established for the Regional Aquatics Monitoring Program (RAMP). Additional georeferenced digital data obtained to describe the basin include mapping of natural regions, vegetation, environmentally significant areas, geology, water wells, historic resources, existing and future urban development boundaries, and oil and gas lease areas. Under existing conditions, wetlands occupy over 90% of the total basin area, while urban development and non-urban disturbances respectively account for less than 2% and 5% of the basin. From a hydrological perspective, the basin is in a predominately natural state.

The June 2013 flood at Fort McMurray was preceded by three days of very heavy rain in the east-central portion of the basin, flood closures of Highway 63 upstream from Fort McMurray, issuance of a provincial flood watch warning for Fort McMurray, and equipment failure at the WSC Hangingstone River gauge. Initial overtopping of the channel banks occurred in the middle of the night near Heritage Park just downstream from Highway 63, with water then flowing down the local road network and inundating additional properties including but not limited to Keyano College. Flood response activities, which included emergency bank stabilization work near Ptarmigan Court and at the upper end of Grayling Terrace, continued for five days following the flood peak on June 11. The peak flow at the WSC gauge was subsequently estimated to be about 200 m^3/s and to have a return period slightly higher than the statistical 100-year flow.

Water surface profiles for Hangingstone River 2-year through 500-year flood events were developed for both (1) open water conditions and (2) composite open water and ice jam conditions. For the regulatory 100-year flood, the profiles intersect just below Highway 63, near Heritage Park where the 2013 overtopping occurred. Because this location is subject to a double flood risk from open water as well as ice jam conditions, it should be considered as priority site for completion of flood mitigation works (berms) to address the open water risk. Upstream, along Grayling Terrace where overtopping in 2013 was imminent but did not occur, channel conveyance improvements have already been constructed to contain 200-year flood levels and so further open water mitigation is not required to meet the RMWB's criteria for a 100-year level of protection.

For the lower reach of the Hangingstone River downstream from Highway 63, a system of berms and floodwalls is being designed, under other contracts, to reduce the occurrence of ice jam backwater flooding. The present study supported those designs with recommendations for buffer setbacks along the Hangingstone, a review of flood mitigation practices and lessons learned in other jurisdictions, and a compilation of flood mitigation engineering manuals and guidelines used in the United States. The flood mitigation measures under design for the Clearwater and lower Hangingstone Rivers at Fort McMurray do not meet minimum flood mitigation requirements from other jurisdictions for freeboard, factors of safety, and discouraging new development in known hazard areas.

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LIMITATIONS OF REPORT

This report and its contents are intended for the sole use of the Regional Municipality of Wood Buffalo (RMWB) and their agents. Tetra Tech EBA Inc. (Tetra Tech EBA) does not accept any responsibility for the accuracy of any of the data, the analysis, or the recommendations contained or referenced in the report when the report is used or relied upon by any Party other than RMWB, or for any Project other than the proposed development at the subject site. Any such unauthorized use of this report is at the sole risk of the user. Use of this report is subject to the terms and conditions stated in Tetra Tech EBA's Services Agreement. Tetra Tech EBA's General Conditions are provided in Appendix A of this report.

1.0 INTRODUCTION

1.1 General

Tetra Tech EBA Inc. (Tetra Tech) was retained by the Regional Municipality of Wood Buffalo (RMWB) to conduct a desktop study of the Hangingstone River Basin, to provide the basis for a detailed flooding protection plan including mitigation measures for the Fort McMurray urban service area within the RMWB. In addition, this study assesses the long-term health and integrity of the basin in context of the full watershed. Figure 1 presents a location plan showing the extent of the basin boundary relative to Fort McMurray and other area features.

The Fort McMurray lower townsite was originally established along the south bank of the Clearwater River between its confluences with the Hangingstone River and the Athabasca River. The community has a long history of floods associated with ice jamming on the Athabasca River which has backed water up into both the Clearwater and lower Hangingstone channels. Flood risk studies and mapping has been prepared in prior studies by the Alberta Government to describe this ice jam flood hazard and to delineate the associated flood risk boundaries. Figure 2 presents a 2012 (pre-flood) orthophoto of the lower Hangingstone River in the vicinity of its confluence with the Clearwater, showing the Alberta Environment and Sustainable Resource Development (AESRD)-defined flood hazard lines for ice jam events.

In June 2013, an open water flood occurred on the Hangingstone River which caused significant damage within Fort McMurray and raised awareness of this flood hazard. Later that same month, major floods in southern Alberta resulted in record economic damages which stimulated provincial funding of programs to improve preparedness for future flood events, including but not limited to identification and implementation of mitigation measures for the areas that were hard-hit in 2013.

1.2 Scope of Services and Checkpoint Meetings

The initial objectives for the Hangingstone River Basin Study were as follows:

1. To provide flood protection up to the 100-year flood hazard at Fort McMurray for open water floods from the Hangingstone River. Consideration should also be given to the ice-breakup related flooding from the Athabasca River, whichever is more critical.

2. To embark on a comprehensive study of the river basin in terms of describing, assessing, and managing the river basin with the main focus on flood protection. The basin description elements include, but are not limited to, physiography, climate and hydrology, ecology and natural ecosystems, human influences, and hydrogeology.

3. To provide a conceptual design of the structural elements for flood protection on the potentially affected areas within the city or upstream from the city area.

A basin study kickoff meeting with Tetra Tech and RMWB representatives was held in Fort McMurray on January 14, 2015, to review the study objectives and approach. A key outcome of this meeting was identification of the need to coordinate the basin study with other flood response and mitigation activities in progress by others. In particular, Hangingstone River 2013 flood response activities related to bridge repairs, channel cleaning, and bank armouring had already been designed, reviewed, permitted, and tendered for construction in advance of the basin study. Also, a separate contract was being issued, to be completed concurrent with the basin study, for the detailed design of berms to protect against ice jam flooding along the lower Hangingstone River. Coordination of work efforts was accomplished through a re-allocation of basin study resources to provide on-call technical services requested by the RMWB to support the ongoing and proposed detailed designs.

A study mid-point meeting was held in Fort McMurray on March 12, 2015 with Tetra Tech, Associated Engineering, and RMWB representatives to discuss the detailed design for berms required to provide flood protection along the lower Hangingstone River, including but not limited to the area of Longboat Landing as shown on Figure 2. Tetra Tech's contributions to this meeting included recommendations for buffer setbacks to preserve riparian ecological functions where feasible, and identification of reaches with significant bank erosion during the 2013 flood where larger setbacks or channel armouring would be recommended as a component of the berm designs.

1.3 Study Approach and Information Sources

The desktop study relied in part on the acquisition and interpretation of information from sources identified below, and processed in a Geographic Information System (GIS) framework when possible.

- 1:50,000 scale and 1:250,000 scale georeferenced topographic mapping, digital elevation data, and corresponding vector data were obtained from the Geogratis website maintained by Natural Resources Canada.
- GIS database layers from various sources with archaeology, fisheries, wildlife, vegetation, and other natural and anthropogenic features.
- Fort McMurray orthophotos, LiDAR data, and elevation models, for both pre- and post-flood conditions in the lower Hangingstone Basin were obtained from the RMWB GIS Department, together with georeferenced files describing the existing urban storm drain infrastructure, urban development boundaries, and other relevant information.
- Fort McMurray flood hazard assessments, georeferenced flood hazard boundaries, and Hangingstone River 2013 flood advisories and high water mark data were obtained from AESRD.
- Historic climate data for the Fort McMurray vicinity were obtained from Environment Canada's Climate data website and supplemented with information from the provincial weather network station viewer maintained by Alberta Agriculture's AgroClimatic Information Service. Additional information for the Hangingstone Basin vicinity was obtained for climate stations operated for the oil sands' Regional Aquatics Monitoring Program (RAMP).
- Historic streamflow data for the Hangingstone River at Fort McMurray, Water Survey of Canada (WSC) station 07CD004, were obtained from the WSC website. Station rating curves, discharge measurement notes, station history, and preliminary flow and water level data for 2013 were obtained through written request to WSC.
- Fort McMurray 2013 flood fight information including timelines of emergency response activities and local water level records, were obtained from the RMWB Engineering Department together with engineering drawings for subsequently-completed channel restoration, bank stabilization, and bridge repairs.
- Post-2013 flood hazard assessments by others for the Athabasca, Clearwater, and Hangingstone Rivers were also obtained from the RMWB Engineering Department. These assessments included a calibrated HEC-RAS model of the lower Hangingstone River which had been developed to estimate the 2013 flood peak discharge.

The study was performed with an engineering emphasis reflecting the collective expertise of Tetra Tech senior water resources engineers with international water management and flood mitigation experience, primarily in Canada and the US. Ecological, social, and hydrogeological elements of the basin description were performed with input from specialists in terrestrial resources, aquatic resources, archaeology and hydrogeology, to provide an informed perspective from each of these disciplines.

The General Conditions attached as Appendix A are considered a part of this report.

2.0 BASIN DESCRIPTION

2.1 Physiography, Climate and Hydrology

The Hangingstone River originates in a set of low hills and flows northward into the Clearwater River in the community of Fort McMurray, approximately 65 km from its origin. The river basin boundary shown on Figure 1 has a total area of 1,105 km^2. From the perspective of flood management for Fort McMurray, the basin has three main components. First, WSC stream gauge 07CD004, Hangingstone River at Fort McMurray, located just downstream from Highway 63, has a basin area of approximately 966 km^2. Second, Saline Creek is a major tributary which joins the Hangingstone one kilometre downstream of the WSC gauge as shown on Figure 2, and has a basin area of approximately 137 km^2 above Tolen Drive near its mouth. Finally, there is a small basin area of about 2.0 km^2 which drains to the lower portion of the river below the WSC gauge and Saline Creek.

The basin areas given above were derived by adjustments to the georeferenced basin boundary obtained for the WSC Hangingstone gauge from Agriculture and Agri-Food Canada's Waters Project. The primary adjustments were: (1) delineation of the Saline Creek sub-basin based on 1:50,000 scale topographic mapping coupled with digital elevation data for the Fort McMurray Urban Area, and (2) adjustment of watershed areas to reflect the developed service areas for the Fort McMurray storm drainage system. In particular, the stormwater systems for the Abasand Heights and Beacon Hill neighbourhoods have altered the pre-development basin boundaries and have slightly increased the area that drains to the Hangingstone River upstream from the WSC gauge.

National Topographic System 1:250,000 scale mapping presented on Figure 1 shows the basin physiography as derived from information which was current in 1977. Since that time, additional roadway, pipeline, seismic line, and transmission line disturbances have affected vegetation cover although the overall imperviousness (hard-surface) level of the basin is little changed except in the Fort McMurray urban area. The river and tributaries drain in a predominantly northward direction and contain expansive areas of wetlands and boreal forest.

The elevation change from the headwaters to the mouth within the basin is about 500 m with the highest areas along the east border (Stony Mountain Wildland Provincial Park). The main channel of the river has an average bed slope of about 0.8% with the steepest sections within the lower third of the basin. Saline Creek is a tributary of the Hangingstone with its confluence close to the mouth of the Clearwater River. There are few large waterbodies in the basin and those in existence are located near the headwaters and watershed boundary. As a result, there is little open water detention storage within the basin once tributary flows enter the main stem of the river.

Table 1 lists the WSC hydrometric stations and the Environment Canada climate stations that are located in the Hangingstone Basin vicinity. The table also includes a water quality sampling site and climate stations in the basin vicinity that are operated for the Regional Aquatic Monitoring Program (RAMP) for the oil sands region, and were operational during the 2013 flood event. The locations of the water quality monitoring site, and active climate and streamflow stations are shown on Figure 1. Table 2 presents a summary of climate normal information obtained from the Environment Canada website for the Fort McMurray Airport climate station, supplemented with Alberta Environment computed lake evaporation values for Fort McMurray. Climate information for Fort McMurray is expected to be reasonably representative of conditions for the entire Hangingstone Basin.

Annual precipitation at the Fort McMurray Airport is approximately 420 mm, of which 75% typically falls as rain and 25% falls as snow. Snow cover typically persists from around November 1 through April 20, based on information presented in the Hydrological Atlas of Canada (Fisheries and Oceans Canada, 1978). Monthly precipitation is seasonally highest in the summer months of June (73 mm) and July (81 mm). Fort McMurray's highest one-day precipitation amount of 94.5 mm was recorded on August 26, 1976. Precipitation frequency duration information for Fort McMurray was evaluated during the course of the study and used to evaluate the severity of rainfall amounts which preceded the 2013 flood event.

The WSC stream gauge on the Hangingstone River at Fort McMurray has been operated since 1965, with seasonal May through October flows reported from 1965 through 1969 and full-year operation from 1970 through 1986. Since 1987, the gauge has been operated on a seasonal basis from March through October. During the period of full-year operation, the annual streamflow has ranged from 1.63 to 8.16 m^3/s, with a mean of 3.98 m^3/s. For the WSC-published basin area of 962 km^2 (without urban area adjustments), these flows translate to annual runoff depths that range from 53 to 267 mm, with a mean of 130 mm. This mean runoff is equivalent to about 30% of the (non-coincident) climate normal annual precipitation.

Seasonally, about 94% of the total annual runoff occurs during the open water months of April through October. The highest average monthly runoff of 25 mm occurs in May when flows are expected to be dominated by snowmelt conditions. The next highest monthly runoff amounts are 21 and 20 mm for July and June, respectively, which are the months with the highest average precipitation.

Assessment of the Hangingstone River peak flow frequency characteristics and the severity of the 2013 flood is presented in Section 3.0 of this report.

2.2 Ecology, Ecosystems, Water Quality, and Aquatics

2.2.1 Natural Regions

The Hangingstone River Basin is located within two subregions of the Boreal Forest Natural Region of Alberta (Natural Regions Committee 2006). As shown on Figure 3, the northern portion of the basin occupies the Central Mixedwood Natural Subregion, and the southern portion occupies the Lower Boreal Highlands Subregion.

Central Mixedwood Natural Subregion

The Central Mixedwood Natural Subregion in the north portion of the Hangingstone River Basin is the largest subregion in Alberta. Vast expanses of upland forests and wetlands on level to gently undulation plains are characteristic of the Central Mixedwood Natural Subregion. Short, warm summers, and long, cold winters result in a mosaic of aspen (*Populus tremuloides.*), mixedwood and white spruce (*Picea glauca*) forests on uplands, with extensive areas of mainly treed fens in the central areas, and jack pine (*Pinus banksiana*) stands on coarser materials to the east. The subregion contains Gray Luvisols on medium to fine-textured upland sites, with organics and Brunisols on sands in low-lying areas. Elevations range from 200 m to 1,050 m in the Central Mixedwood Natural Subregion (Natural Regions Committee 2006). The Hangingstone River Basin is located in a part of the subregion that has a high concentration of wetlands in the form of fens and bogs.

Lower Boreal Highlands Natural Subregion

The Lower Boreal Highlands Natural Subregion in the south portion of the Hangingstone Basin is the third largest subregion in Alberta. The subregion consists of diverse mixedwood forests located on moist lower slopes of northern hill systems and extensive wetlands at slope bases and on adjacent lowlands. The forests consist of aspen, white and black spruce (*Picea mariana*), white birch (*Betula papyrifera*), lodgepole pine (*Pinus contorta*), and jack pine, with treed, shrubby, and graminoid fens occurring in depressions, seepage zones, and level areas. The subregion contains Gray Luvisols on medium textured glacial till deposits, with organic and Gleysolic soils in wetlands. Elevations range from 400 m to 1,000 m in the Lower Boreal Highlands Natural Subregion (Natural Regions Committee 2006).

2.2.2 Land Use

The Hangingstone River Basin is located within the forested, unsettled Green Area of Alberta (AESRD 2012). The basin remains largely undeveloped, with the exception of the Urban Service Area of Fort McMurray and some linear highway, pipeline and power transmission infrastructure through the central regional. Other land uses include forestry blocks, and oil and gas exploration activities including seismic lines, and well pads. The majority of the land within the Hangingstone River Basin is Crown Land (not privately owned).

Gregoire Lake Provincial Park, Maqua Lake Provincial Recreation Area, and Hangingstone Provincial Recreation Area are located within, or partially within, the Hangingstone River Basin (AltaLIS 2015; Figure 3). The Stony Mountain Wildland Provincial Park, which is known for a high density of patterned and non-patterned fens in connection with small waterbodies, is also located in close proximity to the southeast portion of the Hangingstone River Basin (AltaLIS 2015; Figure 3).

There are no First Nations Reserves located within the Hangingstone River Basin; however, there are four Reserves located to the east of the river basin boundary, Clearwater No. 175, Gregoire Lake No. 176, Gregoire Lake No. 176A,and Gregoire Lake No. 176B (Figure 3).

Gregoire Lake was originally known as Willow Lake until 1940 when the name was changed to Gregoire Lake. In 1992, that name was rescinded, and the Canadian Geographical Names Query tool[1] reports that the current name is again Willow Lake.

Environmentally Significant Areas (ESA) in Alberta are quarter sections of land that have been ranked as having relatively high environmental significance compared to other quarter sections of land, based on characteristics considered important for the long-term maintenance of biological diversity, physical landscape features or other natural processes (Fiera Biological Consulting Ltd. 2014). The intention of ranking lands according to relative environmental significance was to be informative for land-use and watershed planning (Fiera Biological Consulting Ltd. 2014). There are 842 ESAs within the Hangingstone River Basin, occupying approximately 71% of the total area within the basin (Fiera Biological Consulting Ltd. 2014; Figure 3).

2.2.3 Wetlands

The Hangingstone River Basin is located in an area with a high density of wetlands, as shown on Figure 4. The majority of these are in the form of bogs, fens, and swamps.

It is estimated that two thirds of the wetlands in the White Area (settled portion) of Alberta have been lost; however, wetland losses in the Green Area are not known or widely understood (AESRD 2013). Wetlands in the Green Area, including those within the Hangingstone River Basin, contribute to a wide range of ecosystem functions including, but not limited to: flood and drought mitigation, natural filtration, groundwater recharge, and habitat provisions supporting biodiversity. Bogs and fens may require hundreds to thousands of years to form naturally and can be very sensitive to anthropogenic disturbances.

Many wetlands within the Hangingstone River Basin are connected networks associated with the Hangingstone River and its tributaries. Industrial practices, such as oil and gas exploration, forestry, and road construction, have created some disturbances within these wetlands, often due to hydrological impacts when road construction or other forms of disturbance intercepts or disrupts the movement of surface water or groundwater. The 'new' *Alberta Wetland Policy* (AESRD 2013) aims to protect all wetlands in the Province, including bogs, fens, and swamps, and not just those found within the White Area of Alberta.

According to the Alberta Merged Wetland Inventory (AESRD 2014a), approximately 16,000 ha of bog, 68,000 ha of fen, 650 ha of marsh, 475 ha of open water, and 21,000 ha of swamp are present within the Hangingstone River Basin, totalling more than 106,000 ha of wetlands occupying approximately 96% of the total river basin. These zones are shown on Figure 4. Earlier wetland mapping developed for National Topographic System mapping

[1] http://www4.rncan.gc.ca/search-place-names/search?lang=en

(Figure 1, CanVec 2013) had identified a much smaller area of only 27,700 ha (25%) of wetlands within the basin, mostly north and west of Highway 63.

2.2.4 Vegetation

According to CanVec mapping (2013), the majority (62.5%) of the Hangingstone River Basin is occupied by broadleaf dense (deciduous) and coniferous dense vegetation cover types (Figure 5). Small portions of the basin are occupied by coniferous open, herb, mixedwood dense, or shrub tall vegetation cover types. It should be noted that the wetlands identified on Figure 5 are reported using CanVec mapping, and are not consistent with the newer updated wetland mapping using the Alberta Merged Wetland Inventory (AESRD 2014a).

Upland portions of the basin include aspen, balsam poplar (*Populus balsamifera*) or white spruce-dominated stands, in addition to mixedwood (aspen-white spruce) stands. Jack pine stands are present on well-drained, coarse-textured substrates. Little to no Lodgepole pine is present in the area, however hybrid pine have the potential to be present. Understory species that are commonly present include prickly rose (*Rosa acicularis*), Canada buffaloberry (*Shepherdia canadensis*), red-osier dogwood (*Cornus stolonifera*), green alder (*Alnus viridis*), bunchberry (*Cornus canadensis*), wild sarsaparilla (*Aralia nudicaulis*), bluejoint (*Calamagrostis canadensis*), and various feather mosses. Lowland (wetlands) portions of the basin include tamarack (*Larix laricina*), black spruce (*Picea mariana*), various willows (*Salix* spp.), bog birch *Betula glandulosa*), bog cranberry (*Vaccinium vitis-idaea*), various sedges (*Carex* spp.), feather and peat mosses, and in some cases lichens.

Vegetation Elements of Conservation Concern

Generally, vegetation elements of conservation concern are vegetation resources of a rare or sensitive nature that may be of value for their contribution to biodiversity at a local, regional, provincial, federal, or international scale. According to various sources identified below, vegetation elements of conservation concern are considered to be:

- Species listed as Special Concern, Threatened or Endangered under Schedule 1 of the federal *Species at Risk Act* (SARA) (Government of Canada 2002);
- Species assessed as Special Concern, Threatened or Endangered according to the Committee on the Status of Endangered Wildlife in Canada ([COSEWIC] 2014);
- Species assessed as Special Concern, Threatened or Endangered according to the Alberta Endangered Species Conservation Committee (ESCC) (AESRD 2014b);
- Vascular plant species and ecological communities listed on the Alberta Conservation Information Management System (ACIMS) *List of Tracked and Watched Elements – May 2014* (Alberta Tourism Parks and Recreation [ATPR] 2014a); and
- Species listed as Threatened or Endangered under Schedule 6 of the *Wildlife Regulation* of the Alberta *Wildlife Act* (AWA) (Province of Alberta 2000).

Vegetation elements of conservation concern listed under the Alberta AWA are protected from disturbance where they occur on Crown Lands in Alberta.

According to the ACIMS *List of Tracked and Watched Species – May 2014*, 105 Tracked and Watched elements have the potential to be found within the Central Mixedwood and Lower Boreal Highlands Natural Subregions; however, based on habitat preferences, some of these species have a higher potential than others to occur within the Hangingstone River Basin (ATPR 2014a; Table 3). According to the *ACIMS Element Occurrence Data* database, a total of 217 historical vegetation element occurrences have been recorded within the Hangingstone River Basin, comprising 25 rare plant species and one rare ecological community (ATPR 2014b; Figure 5).

2.2.5 Wildlife

The Hangingstone River basin provides a diverse habitat for boreal forest species. The abundant wetland areas support numerous wetland bird species such as Bufflehead (*Bucephala albeola*), Canada Goose (*Branta canadensis*), Greater Yellowlegs (*Tringa melanoleuca*) and Red-winged Blackbird (*Agelaius phoeniceus*). Wetlands also provide habitat for mammals such as Beaver (*Castor Canadensis*), Moose (*Alces alces*), and in some cases Caribou (*Rangifer tarandus*). Caribou range is shown on Figure 6. Riparian areas and watercourse valleys along major streams such as the Hangingstone River provide excellent wildlife habitat due their diverse vegetation communities and their ability to act as natural travel corridors. Birds such as Bald Eagle (*Haliaeetus leucocephalus*), Pileated Woodpecker (*Hylatomus pileatus*) and Yellow-rumped Warbler (*Setophaga coronata*) may be found throughout stream side habitats. American Black Bear (*Ursus americanus*) and American Mink (*Neovison vison*), are two mammals that may be commonly found in riparian and streamside habitats throughout the basin.

Large areas of mixedwood upland forest in the Hangingstone River Basin provide adequate habitat for numerous boreal songbird species such as Black-throated Green Warbler (*Setophaga virens*), Least Flycatcher (*Empidonax minimus*), Swainson's Thrush (*Catharus ustulatus*) and Tennessee Warbler (*Oreothlypis peregrina*). Anthropogenic disturbed areas are located throughout the Hangingstone River basin as a result of industrial disturbances. These developments have permanently removed wildlife habitat in some areas (e.g., Fort McMurray), but has also, in some cases, produced more diverse habitat through linear development projects such as pipelines and transmission line corridors. Species that have benefitted from linear development disturbance areas, largely due to increased food sources and access, include White-tailed Deer (*Odocoileus virginianus*), Sharp-tailed Grouse (*Tympanuchus phasianellus*) and Gray Wolf (*Canis lupus*).

Wildlife Species of Management Concern

Tetra Tech compiled a list of wildlife species of management concern (SOMC), presented in Table 4, based on species ranges and habitat, known or having the potential to occur within the Hangingstone River basin. The list was compiled by querying the Fisheries and Wildlife Management Information System (FWMIS; Government of Alberta 2015) and species ranges (Federation of Alberta Naturalists 2007; Ridgely et al. 2007; International Union for Conservation of Nature 2014). The list includes species that breed in the area or are migrants. Species of management concern are any that meet one or more of the following criteria:

- Have provincial and/or federal restricted activity dates or setback distances (Government of Alberta 2011; Environment Canada 2011; P. Gregoire 2013);
- Ranked as 'Sensitive', 'May Be At Risk', or 'At Risk', by the General Status of Alberta Wild Species (GSAWS; AESRD 2010);
- Assessed as by the 'Threatened', 'Endangered', or 'Special Concern' by the Endangered Species Conservation Committee (ESCC; AESRD 2014b);
- Listed as 'Threatened' or 'Endangered' under the Alberta *Wildlife Act* (AWA; Province of Alberta 2000);
- Assessed as 'Special Concern', 'Threatened', or 'Endangered' by the Committee on the Status of Endangered Species in Canada (COSEWIC; Government of Canada 2015); and
- Listed as 'Special Concern', 'Threatened', or 'Endangered, or under the *Species at Risk Act* (SARA; Government of Canada 2002).

A total of 48 wildlife species of management concern are known or have the potential to occur within the Hangingstone River basin (Table 4). These species and their nests and dens are generally protected by their applicable governing bodies; however, development and disturbances to habitat within species' ranges can have indirect negative effects on some wildlife species.

Caribou ranges are present in the Hangingstone River Basin and encompass approximately 75% of the overall basin (Figure 6). The Caribou found within the basin are part of the East Side Athabasca River Woodland Caribou population and more specifically, part of the Algar and Egg-Pony subpopulations (herds) (AESRD 2013a) and noted on Figure 6. A Key Wildlife Biodiversity Zone (KWBZ) is also found with the Hangingstone River basin. A portion of lower the Hangingstone River valley immediately upstream of Fort McMurray has been designated a KWBZ by AESRD (Figure 6). According to AESRD (2015); "The Key Wildlife Biodiversity Zone is a combination of key wildlife habitat from both uplands and major watercourse valleys. The Key Wildlife and Biodiversity Zone is intended to prevent loss and fragmentation of habitat; prevent short and long-term all-weather public vehicle access; prevent sensory disturbance during periods of thermal or nutritional stress on wildlife; and prevent the development of barriers to wildlife corridors (e.g. stream crossings)." No other key wildlife zones or sensitivity ranges as designated by AESRD are found within the Hangingstone River basin.

2.2.6 Water Quality

Studies of water quality in the Hangingstone River Basin have been centred on the Hangingstone River itself. The first main study was performed as part of the Alberta Oil Sands Environmental Research Program (AOSERP), in which samples from near Fort McMurray were analyzed from 1976 to 1983 (Corkum 1985). Water quality has also been tested periodically under the Regional Aquatics Monitoring Program (RAMP), from one location upstream of Fort McMurray (sampled from 2004 to 2008, and in 2013) and one location near the mouth of the river (sampled only in 2013) (RAMP 2013). These sampling locations are noted on Figure 1.

Based on data collected during both monitoring programs, the Hangingstone River is a productive system with slightly alkaline waters. Total aluminum, total phenols, and total iron were above published guidelines (CCME 2007; AESRD 2014) at both upstream and downstream monitoring locations based on 2013 RAMP data. Additionally, sulphide, total phenols, and total phosphorous exceeded guideline levels in 2013 at the upstream location. The 2013 RAMP data also indicated that nutrients, select metals, and all tested ions were present at increased concentrations as compared to data collected between 2004 and 2008.

2.2.7 Aquatic Habitat and Fish Species

Resource extraction projects and anthropogenic development throughout northeastern Alberta has resulted in the collection of a relatively large body of aquatics and fisheries data on the Hangingstone River and its tributaries. Comprehensive studies in the watershed during the 1970s through to the 1980s and then in the early 2000s were focused on the Hangingstone River, and were in relation to oil sands exploration within the mineable areas of the basin (Tripp and Tsui 1980; RAMP 2013).

The Hangingstone River Basin supports a number of fish species, including sportfish and coarse fish species. An AOSERP study investigating fisheries and habitat quality within the AOSERP study area (Tripp and Tsui 1980) was the main fish sampling program documenting the occurrences of fish species in the 1980s and encountered the fish listed in Table 5. Occurrences of fish species in the Hangingstone River recorded in the provincial FWMIS dataset (AESRD 2015) are also provided in Table 5, with the conservation status listed for those fish that have been designated provincially as a species of special concern. None of the fish species known to occur in the watershed are listed federally as species of Special Concern, Threatened or Endangered under Schedule 1 of the federal SARA, or assessed similarly according to COSEWIC. Arctic Grayling (*Thymallus arcticus*) and Northern Redbelly

Dace (*Phoxinus eos*) are classified as Sensitive, and Spoonhead Sculpin (*Cottus ricei*) is classified as May be at Risk, according to the Alberta Species at Risk 2010 database (AESRD 2010).

The Hangingstone River was believed to support an abundant Arctic Grayling population and Griffiths (1973) identified the river as a hatchery stream. However, catch rates during the Tripp and Tsui (1980) study suggested that grayling were relatively scarce as compared to other tributary streams of the Athabasca River. Given that Alberta Highway 63 intersects the river and that a campground is present adjacent to the river providing easy access, there is the possibility that over-exploitation of Arctic Grayling in tandem with other anthropogenic development in the region may have led to substantial declines in population numbers, as was evident throughout other parts of the province in the 1950s to 1970s when approximately 50% of subpopulations declined by over 90% (ASRD 2005).

According to Tripp and Tsui (1980), the Hangingstone River has headwaters and upper reaches located in muskeg, with a moderate gradient and moderate to fast flow rates, a high incidence of riffles and substrates comprising primarily of cobble, boulders and gravels. Main channel stream widths range between 6 to 13 m and riparian vegetation consists mostly of alder, aspen and spruce, while riparian vegetation closer to the headwaters are more water-tolerant species (willow, birch, spruce, grasses and sedges). Slimy Sculpin (*Cottus cognatus*) were historically the most abundant fish species in the upper reaches of the river (AOSERP 1980), though Brook Stickleback (*Culaea inconstans*) and Pearl Dace (*Margariscus margarita*) were captured frequently during more recent sampling efforts within the upper parts of the watershed (AESRD 2015), and there were documented catches of Arctic Grayling in Hangingstone River.

The middle reaches of the Hangingstone River (approximately 30 to 60 km upstream of the confluence with the Clearwater River; and downstream of Highway 63) are slower-flowing as the river valley broadens and becomes more meandering, with the substrate changing to a more sandy texture, and beaver influence on the river becomes common. The width of the river averages between 14 and 26 m in the middle reaches, with riparian vegetation consisting mainly of alder, aspen and spruce. The middle reaches of the river are dominated by Trout-Perch (*Percopsis omiscomaycus*) (Golder 2002), though Lake Chub (*Couesius plumbeus*), Finescale Dace (*Phoxinus neogaeus*) and other minnow species also show a high incidence throughout the middle reaches of the river and its tributaries based on recent FWMIS data for the basin (AESRD 2015). The middle reaches of the river are also known to support Arctic Grayling.

The gradient steepens again in the lower section of the Hangingstone River, as it cuts through a steep, narrow valley to the floodplain of the Clearwater River in Fort McMurray. The width of the river in the lower reaches attains approximately 30 m as the channel becomes more sinuous with straight sections, and the substrate becomes increasingly dominated by rubble and boulders (Tripp and Tsui 1980). Longnose Sucker (*Catostomus catostomus*) is the most abundant species in the lower reaches, although Lake Chub (*Couesius plumbeus*) and Longnose Dace (*Rhinichthys cataractae*) are also fairly abundant (AOSERP 1980). More recent data from the FWMIS database suggest that minnow species dominate the lower Hangingstone River Basin, though Arctic Grayling, Burbot (*Lota lota*), Mountain Whitefish (*Prosopium williamsoni*), Northern Pike (*Esox lucius*), Walleye (*Sander vitreum*) and White Sucker (*Catostomus commersoni*) have also been captured in the lower Hangingstone River (AESRD 2015).

Saline Creek, a major tributary of the Hangingstone River in the lower section of the watershed, originates as outflow from a wetland complex south of the Fort McMurray International Airport and is fed by springs along its course. Saline Creek flows into the Hangingstone River approximately 670 m upstream of the river's confluence with the Clearwater River in the town of Fort McMurray. Sportfish and coarse fish species are known to utilize Saline Creek, and include Arctic Grayling, Burbot, Brook Stickleback, Finescale Dace, Fathead Minnow (*Pimephales promelus*), Lake Chub, Longnose Sucker, Northern Pike, Northern Redbelly Dace, Slimy Sculpin, Trout-Perch and White Sucker (AESRD 2015).

2.3 Human Influences

2.3.1 Historic Resources

The Hangingstone River Basin falls within a region utilized for its natural resources by human occupants over the course of the past 10,000 years.

Ancient flooding events within the Fort McMurray region drastically altered the landscape for its first inhabitants. Geological and paleo-environmental evidence, along with archaeological site data, suggest early people utilized terrain stable enough to support the plant and animal resources and water resources they required for survival. Such areas included high, dry terrain away from postglacial lakes and ancient waterways and included such features as raised terraces, beaches, dunes and glaciofluvial bars. As the ancient waters receded, the Athabasca River valley emerged that provided prime hunting grounds. Thus, the region adjacent to the Athabasca River and its tributaries is rich in archaeological sites and historical materials.

Archaeological work undertaken for infrastructure development in areas located north of Fort McMurray resulted in the identification and recovery of cultural material deposited over the past 10,000 years. Excavations at the Aurora, Nezu, and Cree Burn Lake sites yielded the recovery of tens of thousands of artifacts and revealed the area's extended use under human occupation. These prehistoric lithic materials indicate that survival strategies in the region included hunting and fishing. The earliest inhabitants were comprised of hunters and gatherers whose tools were constructed from materials such as rock, antler, bone and wood. They trapped and hunted animals; their success at hunting ultimately affected their success at survival. Furs and hides provided clothing and shelter. Fish and plants were harvested for food and medicinal purposes. Analysis of large quantities of waste lithic materials generated by the production of cores, preforms and formed tools at large quarry sites along the Athabasca River reveal environmental adaptations, changes in early hunting techniques and subsequent lithic tool manufacturing processes. As well, insight into the settling of the area by different culture groups is revealed. The earliest significant groups in the region include the Dene, Woodland Cree, Chipewyan and Beaver. The first use of oil sands (found on exposed river banks) was by the Cree who mixed it with spruce tree sap to create a birch bark canoe sealant as well as in smudge fires to ward off biting insects. In the vicinity of the Hangingstone River basin, stone tools dating to the Oxbow period were recovered at sites near Gregoire Lake and along the Athabasca River.

The post-contact period is characterized by several stages of advancement spurred by exploration, settling and economic development. The written history of the region begins in the late 1770s with the arrival of explorers and adventurers such as Peter Pond, Alexander MacKenzie and Alexander Henry. During the push by the British government to explore and claim new lands in Canada, the Northwest Trading Company and the Hudson's Bay Company competed to gain control of as much land as possible and establish trade routes for coveted goods such as furs and firearms. Early travel routes relied heavily on the significant waterways in the area, in particular, the Athabasca and Clearwater Rivers. These hydrological features played significant roles in the development of the region by supporting early exploration and transportation activities. They were also utilized during the construction of railways and roads. Early settlements, inherently at risk by flooding, were established along the banks of these rivers. In time, and in an effort to open up the region to outside trade networks and facilitate the arrival of new settlers and industry, railways, roads, and later an airport, were constructed in the region. Remnants of the Historic Period in western Canada typically include North West Mounted Police outposts, structures from the fur-trade era and homesteading period, and European goods including firearm technology and metal tools. The Athabasca River was designated a Canadian Heritage River in 1989.

Although the Hangingstone River Basin is less developed than areas north of Fort McMurray where significant archaeological work has occurred, the potential to discover previously unrecorded cultural resource sites is high when future assessments are made for areas of proposed development. This potential is reflected in Alberta Culture's Listing of Historic Resources ([the Listing] Alberta Culture 2015) which identifies areas of archaeological, palaeontological, and/or historical significance, both known and potential, and includes potential mitigation recommendations.

Figure 7 outlines the location of lands within the Basin that have been identified in the Listing as having a Historic Resource Value. Predictably, due to the prehistoric and historical reliance upon watercourses, the bulk of the triggered lands are adjacent to the lower reaches of the Hangingstone River and Saline Creek, within proximity of the larger Athabasca and the Clearwater Rivers.

2.3.2 Existing and Future Development

Historically, development within the basin started along the lower reaches downstream of Highway 63 and along the lower reaches of Saline Creek. Existing urban development extends along Highway 63 (east side) north of Highway 69 and from Grayling Terrace (upstream of Highway 63) to the mouth. Some of the older development in this area is being considered for redevelopment or has been redeveloped, particularly within the City Core Area.

In addition to housing part of the southern districts of Fort McMurray's population, the Hangingstone Basin is a popular recreation area for activities including fishing, hunting and camping. This usage is largely due to close proximity to and ready access from Highway 63 which bisects the basin and has two major river crossings of the Hangingstone River. Highway 881 also provides access to adjacent parts of the basin and Gregoire Lake to the east. Recreational activities are available at Gregoire Lake Provincial Park and the Hangingstone River Forest Recreation Trail area, both located within the basin.

With the exception of the Fort McMurray urban service area and Highway 63 and 881 corridors which are heavily used by industrial traffic within the oil sands region, the majority of the basin remains as wetlands or vegetated with limited linear disturbances related to oil sands activities. Oil sands exploration activities to date have included access roads, seismic lines and cleared areas at specific leases but much of the basin remains inaccessible wetlands. This is expected to change over time as more leases are developed, although there is expected to be phasing of these facilities as all are not expected to be operating at the same time.

Figure 8 shows areas of existing and future development within the basin, and a land use breakdown is given in Table 6. Existing development is subdivided as being either urban or dispositions. Existing urban development is actually a subset of the "urban area" shown on Figure 8, and was determined by digitizing areas where existing development was apparent from recent aerial photos. Outside of the Fort McMurray urban area boundary, existing development was determined from AltaLis 2012 disposition data which identifies an assortment of uses including easements, license of occupation, mineral and miscellaneous leases, pipelines and roadways. Roadways account for the majority of the existing dispositions in the Hangingstone basin outside of the urban area.

Anticipated future urban development in the Hangingstone Basin consists of buildout within the existing urban area boundary, and then expansion into the Urban Development Sub Region (UDSR) shown on Figure 8. The UDSR includes the existing urban boundary plus additional lands that have been allocated by the province to accommodate future urban growth.

Anticipated future development outside of the UDSR boundary consists of the planned development of oil sands projects, in particular the Suncor Meadow Creek project which has the single largest development footprint within the basin. Given the depth of oil sands deposits in the area, future development is expected to consist of SAGD operations and not open pit mining. If mining of deposits were to be carried out, parts of the basin would no longer contribute runoff temporarily which may reduce flows marginally. Upon completion or resource extraction and full reclamation as required, no change in runoff response would be expected.

Existing and future urban development by area and percentage of the basin are shown in Table 6. In general, the urbanized proportion of the Hangingstone and Saline Creek basins will be under 10% for both existing and future conditions. The highest percentage will be in Saline Creek at 9% and the main Hangingstone Basin at 3%.

Land use disturbances from oil sands development activities do not generally affect the peak hydrology of the basin, as the runoff response is largely dictated by the extensive wetlands. In addition, as new oil lease areas are developed, proponents are required to have their own stormwater management controls which include on-site runoff ponds to collect site drainage. Stormwater management for plant and well site pads is required to follow provincial guidelines for industrial runoff and require that water can be released to the environment only after chemical testing has been completed that confirms acceptable water quality. As a result, facility site flows are delayed significantly and generally do not coincide with the storm event peak runoff from undisturbed natural areas.

Stormwater Criteria in Urban Areas

Under present conditions, urban stormwater management within the Hangingstone Basin consists of a collection and conveyance system, without peak flow detention or water quality facilities. City GIS information show collection systems with outfalls to the Hangingstone River. Information was not available for a desktop assessment of collection systems or outfalls in the Saline Creek sub-basin.

It is generally recognized that land use development, especially in urban areas, can have significant adverse effects caused by the greatly increased flow rates and volumes that result when natural areas are converted to compacted and impervious surfaces. In the US, early stormwater guidelines to mitigate for the effects of urban development were based primarily on flood conveyance criteria, such as by requiring detention storage to control development runoff from a 100-year storm to the pre-development 100-year runoff rate. During the 1990s, it was recognized that this approach did not provide sufficient environmental protection because it allowed significant increases to the duration of erosive flows which in turn can result in channel instability manifested by degradation (downcutting) and/or bank erosion accompanied by downstream aggradation (sedimentation) and loss of flow conveyance capacity.

Stormwater guidelines now in effect in Washington State provide an example of a very high level of environmental protection. These were initially developed in response to the proposed federal listing of salmon as a federally-protected threatened or endangered species. The final (current) guidelines require sufficient detention to meet a requirement that the duration curves for post-development flows do not exceed pre-development flow durations for all discharges above an erosion threshold set at one half of a two-year pre-development flow. Current stormwater management guidelines in Alberta are at least two decades behind those in use in Washington State.

Stormwater management research in Washington State also produced a finding that adverse effects of land development became generally apparent only after land use conversion of more than about 10% of the total basin area. Also, it was recognized that detention was not required for discharges to major receiving waters which could easily absorb the stormwater releases. Foreseeable urban development within the Hangingstone Basin will be below the 10% threshold at the location of urban stormwater outfalls and there is no obvious risk of accelerated channel erosion that would warrant flow controls. This finding should be reconsidered for developments that drain to Saline Creek, which has a higher level of development and where there have been recurring sedimentation problems in the lower reach.

Existing and foreseeable future urban development is located at the bottom parts of the Hangingstone River and Saline Creek basins. Relatively rapid runoff from the urban areas might help to reduce total streamflows, because the urban runoff hydrograph will likely precede the peak of the flood hydrograph from the much larger upstream basin. There is a potential that runoff detention storage in these area could delay peak flows and coincide more closely with peak flows from the larger upper basin areas with a later flood peak. This could result in higher peak flows in the lower reaches and adversely affect flood protection measures implemented in the lower Hangingstone basin using current hydrology or increase bank erosion.

Considering all of the above, peak flow controls are not necessary in the lower basin future development areas with drainage to the Hangingstone River. It may be necessary to implement flow control through storage ponds or other methods where there are existing capacity constraints within the drainage system prior to entering the main receiving watercourses. Furthermore, appropriate erosion control measures will be necessary at discharge points to the river to ensure runoff is safely conveyed to the river level and the outfall is protected from erosion. The same conclusions might apply for Saline Creek, but further assessment of current erosion control and stormwater management practices in the Saline Creek basin is recommended to determine the causes of recent sedimentation problems in the lower portion of the creek.

In all new development areas, water quality control measures will be required to the provincial standard of the day. This should include consideration of low impact development (LID) measures, oil/grit separators, runoff infiltration, vegetated conveyance systems and settling basins.

Stormwater Criteria in Remainder of Basin

Outside of the Fort McMurray urban area, there are extensive linear disturbances but these are not expected to have a significant effect on the peak hydrology or response of the river. Much of any significant future development is expected to be related to oil sands expansion. Development at existing and future oil sands leases will be largely isolated from the basin as these are widely distributed and will have their own on-site controls as required to meet provincial guidelines. Not all parts of the basin have current oil leases but this may change over time. Oil sands exploration activities to date have consisted of access roads, seismic lines and cleared area at specific leases which require on-site runoff controls. These surface disturbances do not generally affect the hydrology of the basin as the runoff response is dictated by the extensive wetlands. More importantly, as new lease areas are developed, they are required to have their own runoff controls which include on-site runoff ponds to collect site drainage which can be released to the basin only after chemical testing has been completed that confirm runoff meets regulatory requirements. This delays the peak flow from these areas significantly and does not compound with the peak hydrograph from the remainder of the basin.

2.4 Hydrogeology

2.4.1 Geological History

The Hangingstone River Basin is situated within the Western Canada Sedimentary Basin and drains a basin which extends approximately 65 km south from Fort McMurray. Figures 9 and 10 illustrate the Bedrock Geology and the Surficial Geology, respectively.

The basin lies within the undeformed structural portion of the Western Canadian Sedimentary Basin, consisting of a wedge of Phanerozoic sedimentary rocks above Precambrian crystalline basement rocks. The wedge is thickest in the west and thins to the east. In the Fort McMurray area, the sedimentary rocks are on the order of 500 m in thickness (Mossop, G. and Shetsen, I., 1994).

The Phanerozoic sedimentary rocks consist of predominantly carbonate with shale sequences deposited from Precambrian to Devonian time in shallow seas on the western edge of the North American continent. Overlying the Devonian deposits are sequences consisting of interbedded sandstones and shales that are predominantly Lower Cretaceous in age. These are represented at the base by McMurray-Wabiskaw Sandstones which are the primary oil sands deposit.

The sedimentary rock sequences subcropping in the Hangingstone Basin can provide significant aquifer potential where porosity and permeability is sufficiently developed (Ozoray, G.F. 1974). The bedrock subcrop in the Hangingstone plains is interpreted to slope gently towards the Athabasca River and the topography of the bedrock subcrop is highly influenced by the thalweg of buried channels (Andriashek, L.D., 2003).

Overlying the Phanerozoic sedimentary rock sequences are Late Tertiary – Quaternary age sediment sequences. Pre-glacial Tertiary sequences are most commonly concentrated in buried valleys of the bedrock subcrop. However, lower Quaternary Empress Formation sands and gravels, also common as pre-glacial valley fill, can provide significant aquifer potential in the area.

Extensive sequences of glacial sediment were deposited across the basin in the Quaternary during repeated glacial and interglacial periods, the last being about 10,000 years ago. These deposits are most commonly represented by glacial till and glaciofluvial (riverine) sediments. The tills are generally fine grained and form aquitards while the glaciofluvial deposits lying between the tills may form aquifer systems if continuous. Interspersed in the till deposits, coarse glaciofluvial gravels and sands, outwash sediments and fluvial sediments, where well developed, can form significant aquifer potential on a local scale (Andriashek, L.D., 2003).

Since the most recent glacial period, erosional processes have re-shaped the surficial landforms. Post glacial deposits are most commonly dominated by fluvial sediments along rivers in the basin. The deposits associated with the river systems may be important sources of groundwater where porosity and permeability is well developed. Furthermore, where the Hangingstone valley deepens north of the Highway 881 intersection, groundwater discharge from sand lenses in the valley wall can result in slope instability and slumping conditions. Both active and historical landslides are evident on aerial photos within the lower reaches. This phenomena is particularly evident in areas upstream of Tolen Drive where major areas of instability are evident. These slopes can be further impacted by undercut erosion from the river.

2.4.2 Regional Hydrogeology and Water Use

Regionally, the elevated areas of the Hangingstone Basin in the Stoney Mountain Uplands in the southeast part of the basin represents a significant recharge zone for groundwater as overall groundwater flow is radially away from the uplands. To the west of the uplands, there are extensive wetland areas which retain flows and moderate runoff response. Shallow groundwater flow is anticipated to be towards local base levels represented by the main stem of the river, other watercourses, lakes, and wetland areas. Surface water interaction with local shallow groundwater systems is anticipated in areas where there are surficial coarse-grained deposits (sands, gravels, etc.).

Figure 10 illustrates the Surficial Geology within and adjacent to the Hangingstone River Basin (Bayrock, 2005). Of note are the extensive clay and silt deposits in the northern part of the basin where extensive wetland areas are identified on National Topographic System Maps (Figure 1). The original mapping identified very limited areas of wetland in the relatively well-drained areas south of Highway 63 where soils consist of more coarse-grained materials. However, the provincial wetland inventory shown on Figure 4, based on the Alberta Merged Wetland Inventory (AESRD 2014a), has identified similar wetland areas over the coarse-grained materials as well.

Water wells drilled in the basin are concentrated in populated and industrial water use areas. Water well records available on the AESRD database (2015) are provided on Figure 11 and show a relatively low number of wells in the basin area, primarily for localized industrial use. These wells are clustered along Highways 63 and 881 and within the Suncor Meadow Creek Lease (Figure 8).

2.4.3 Groundwater and Surface Water Interaction

Figure 11 shows locations of groundwater wells and areas where groundwater is most susceptible to contamination from surface water. Selected geological and hydrogeological references as well as Alberta Environment (AENV) information and databases were used to compile the map to illustrate how groundwater and surface water potentially interact.

The following information is shown on this map:

- surface water features represented by perennial, recurring and indefinite streams, lakes, reservoirs, and oxbows;
- permeable surficial deposits, where groundwater may be under the direct influence of surface water, including aeolian, fluvial, lacustrine and glacial deposits, coarse sediments, stream and slope wash eroded deposits, sandstone, siltstone, limestone bedrock (adapted after Bayrock, 2005); and
- water well water allocation (AESRD Groundwater Information Centre Water Well Record Database).

As previously noted, recharge occurs in the elevated areas of the basin with mineral soils, and shallow groundwater flows to the major rivers and streams within sub-basins. Three main sources of shallow groundwater are identified in unconsolidated sediments that overlie bedrock in the basin. These include recent stream alluvium (fluvial deposits), outwash and meltwater channels and aeolian sands.

Shallow fluvial aquifer potential may be well developed where coarse sediments are deposited along major rivers. Examples include sands and gravels along the rivers and Willow Lake. These aquifers, which are directly connected to surface water, can be extensive and are an important source of supplemental water flows in the basin.

Potential aquifers also occur in pre-glacial bedrock valleys. These aquifers have the potential to yield significant quantities of water and are generally not connected to surface water directly. The major bedrock valleys (thalwegs) are shown on Figure 9.

3.0 RIVER BASIN ASSESSMENT

3.1 Regulated Flood Hazard Area for Lower Hangingstone

The primary cause of historic flooding in the Lower Hangingstone River, near its confluence with the Clearwater, is backwater from ice jams on the Athabasca River. The ice jam flood risk has been assessed in prior studies which have culminated in the adoption of a regulatory 100-year flood level of 250.0 m which is applied as a level pool along the lower reaches of the Clearwater and Hangingstone rivers. Appendix B contains a copy of the report by Alberta Environmental Protection (1993) which was submitted to the Technical Committee of the Canada – Alberta Flood Damage Reduction Program to support the adoption of this regulatory flood level.

This section of the report deals exclusively with the regulated flood hazard area which is associated with Athabasca River ice jam floods. Hangingstone River open water flood hazards, which are presently not regulated by AESRD, are assessed in Sections 3.2 through 3.4 which follow.

Figure 2 shows AESRD's flood fringe and floodway lines for the lower Hangingstone River, which correspond to the regulatory flood level of 250.0 m and are the same lines which can be accessed online from AESRD's flood hazard map application (AESRD, 2015). The flood fringe line marks the outer extent of inundation for the regulatory flood level. For the lower Hangingstone River, this water level is associated with widespread flooding downstream (east) of Tolen Drive, which is built up along the 250.0 m contour. Upstream (west) from Tolen Drive, the 250.0 m water level extends to the upper end of Grayling Terrace, but is mostly contained within the channel banks and does not present a flood risk to adjacent lands.

The AESRD floodway lines, also shown on Figure 2, define a high-risk subset of the 100-year flood hazard area which is identified in accordance with provincial flood hazard mapping guidelines (AENV, 2011) to have special regulatory significance. The AENV (2011) definitions for flood hazard, floodway and flood fringe are presented below for reference.

Flood hazard area – This is the area of land that will be flooded during the design flood event. The flood hazard area is divided into two zones: (i) the floodway and (ii) the flood fringe.

(i) **Floodway –** the area within which the entire design flood can be conveyed while meeting certain water elevation rise, water velocity and water depth criteria. Typically the floodway includes the river channel and some adjacent overbank areas.

(ii) **Flood Fringe –** the land along the edges of the flood hazard area that has relatively shallow water (less than 1 m deep) with lower velocities (less than 1 m/s). In Calgary the mapping uses the term floodplain for the flood fringe area.

In Alberta, flood hazard assessments are based on 100-year events which have a 1% probability of exceedance in any given year. Fort McMurray historic flood levels presented in Appendix B include two events over the past 140 years with observed water levels greater than 250.0 m after adjustment for the mitigation effects of the Snye Dyke which was constructed in 1966 near the confluence of the Athabasca and Clearwater rivers. The adjusted water levels for the two highest events are 252.0 m and 250.1 m which occurred in 1875 and 1936, respectively. The flood study for Fort McMurray included a "perception-stage" analysis which involved filling of data gaps in the historic record since 1875, and used for a frequency analysis on the extended record which yielded a 100-year flood level of 250.5 m. However, this higher value was not adopted for regulatory purposes so as to be consistent with standard methods being used for other communities with relatively short periods of flow and water level records.

The 1993 flood study shows that flood levels in Fort McMurray have historically exceeded 250.0 m, and that the adopted 250.0 m flood hazard elevation may have an annual risk of exceedance that is slightly greater than 1%.

It is important to recognize that construction or floodproofing to the regulatory flood level does not make the property "safe" from flood damage. In circumstances where affordable insurance is not available to cover flood damage to valuable improvements, it is prudent to design floodproofing measures to a higher level, either by use of a higher design standard or a conservative factor of safety as is applied in some other jurisdictions. For example, Environment Canada (2013) reports that Saskatchewan uses a 500-year design flood with an additional freeboard for hydrologic and hydraulic uncertainties, and British Columbia uses a 200-year design flood with an additional freeboard for hydrologic and hydraulic uncertainties.

Alberta's current flood hazard and floodplain management programs are based on "An Agreement Respecting Flood Damage Reduction and Flood Risk in Alberta", (the Agreement) made in April 1989 between the Government of Canada and the Government of the Province of Alberta, with equally shared costs not to exceed $5,500,000.00. This agreement is published as Appendix A of the AENV (2011) Flood Hazard Mapping Guidelines and a partial copy, excluding technical guidelines, is provided in Appendix C. Much of the preamble, definitions, and agreements in this document are relevant and applicable to the current study which seeks to reduce future flood damage costs for Fort McMurray.

Relevant excerpts from the Agreement include WHEREAS clauses which begin:

1. Floodplains are land areas adjacent to lakes and watercourses which are subject to natural inundation by floodwaters and the use of which by man invites risk to life and inevitable damage to property in the event of a flood;

2. In Alberta, many communities, large and small, are situated in otherwise attractive river valley locations for both historical and municipal water supply reasons;

3. The increase in potential and actual flood damage through greater utilization of flood risk areas has resulted in public pressure on Alberta to construct or provide financial assistance towards the construction of protective works; and

4. These works, which include dams, diversions, dykes and modifications to channels, are costly to construct, operate and maintain, do not generally provide complete protection against all possible flood damage and tend to attract additional investment in, and use of, areas prone to flooding with the result that the potential for loss of life and property is further increased.

The above is followed by a description of then-existing flood risk and disaster assistance programs. The agreement notes that, in special circumstances, structural measures are the most appropriate means of reducing flood damage potential to existing development and may be eligible for cost sharing by Alberta and Canada.

Many terms and technical procedures for the Flood Damage Reduction and Flood Risk program, such as distinguishing between regulatory floodplain and floodway areas, are similar to terms and procedures used for flood risk management in the United States. In the US, floodplain and floodway mapping is administered by the United States Federal Emergency Management Agency (FEMA), and there is a National Flood Insurance Program, also administered by FEMA, which makes flood insurance available to individual property owners in communities that participate in the national program. Canada does not have an equivalent government-sponsored flood insurance program, and affordable private insurance for flood damage losses is generally not available.

In the absence of a flood insurance program, the Agreement relies on eligibility for disaster relief funding as a primary means to encourage appropriate development in flood-prone areas and to therefore limit flood damage losses. Upon the regulatory designation of a flood risk area, such as by adoption of the 1993 Flood Hazard Study for Fort McMurray, the Agreement imposes the following restrictions:

- Section 11.(1).(b) – Canada shall ensure that its programs of financial assistance to third parties are administered so that no assistance is given to any further undertakings in a designated or interim designated area that are vulnerable to flood damage. The same language is echoed for Alberta in Section 11.(2).(b).
- Section 11.(1).(c) – Canada shall encourage the appropriate authorities under its jurisdiction to impose land use restrictions that will prohibit further undertakings in a designated area or interim designated area that are vulnerable to flood damage, or where appropriate, make such undertakings subject to requirements for adequate floodproofing. The same language is echoed for Alberta in Section 11.(2).(c).
- Section 12.(1) – Subject to prior clauses, assistance under any Alberta or Canada disaster assistance program shall not extend to costs and losses incurred as the result of a flood, with respect to any undertaking commenced, or moveable placed, within any area after its designation or interim designation as a flood risk area.

The above is followed in the Agreement by confirmation that flood-related disaster assistance will be available in those circumstances in which the prerequisites for assistance are met. Eligible circumstances specifically include damage to properties located outside of regulated flood hazard areas, and to properties that have been adequately floodproofed within flood fringe areas outside of the floodway. Provision of additional disaster assistance would be considered to be warranted only under extraordinary circumstances in a particular situation.

Figure 2 shows large areas of developed land along the lower Hangingstone River that are within the regulated flood hazard area. Nearly all of the hazard area is designated as floodway. In accordance with the above-cited Agreement, any post-designation "undertakings" commenced, or moveable placed, in the floodway will not be eligible for federal or provincial flood disaster assistance funding. The term "undertaking" is broadly defined as "the construction, erection, extension or alteration of any structure" other than temporary structures for agriculture use or open air buildings for recreational use or structures or works associated with flood control measures.

The lower Hangingstone River flood downstream and east of Tolen Drive is a designated flood hazard area because of backwater from ice jams on the Athabasca River. There is nothing that can be done in the upper Hangingstone Basin that will reduce or alter this high water flood risk.

3.2 The June 2013 Open Water Flood

3.2.1 Chronology of the Flood Event

A major open water flood occurred on the Hangingstone River in June 2013, resulting in damage in the lower reaches due to both channel erosion and high water conditions which overtopped the river bank in places. Figure 12 shows the lower reach on a post-flood orthophoto image taken in July/August 2013, with annotations to indicate areas of reported flood damage and the approximate pre-flood edge of bank corresponding to the pre-flood image shown on Figure 2.

The flood event resulted in the evacuation of over 400 people, with flood damage to basements in the Grayling Terrace area, Heritage Park and the Syncrude Centre for Sport and Wellness[2]. Keyano College was flooded when river water flowed straight down the road (King Street and Penhorwood Street) after storm sewers filled to capacity, and there was also flood damage to the Home Hardware store[3].

[2] http://www.fortmcmurraytoday.com/2013/06/29/flood-recovery-program-for-fort-mcmurray-to-launch-july-2

[3] http://www.cbc.ca/news/canada/edmonton/state-of-emergency-declared-in-fort-mcmurray-1.1309326

A chronology of significant events is presented below, based primarily on the RMWB's records. Additional information was obtained online from various media and government sources including AESRD archived flood forecasts.

June 9, 2013 (Sunday)[4]

- 21:30 – Highway 63 was shut down about 32 km south of Fort McMurray, due to flooding with 60 cm deep water near the Hangingstone River just after the junction with Highway 881. About 12 hours later, Highway 881 was also closed because a bridge near Morris Creek lost fill and was unsafe.

June 10, 2013 (Monday)

- 01:30 – RMWB receives a call that the RCMP is evacuating Amaco Road in Anzac due to flooding, with the road in danger of becoming impassable. Anzac is located just outside of the Hangingstone River basin east of Willow Lake (Gregoire Lake).
- 14:30 – Alberta River Forecast Centre (RFC) issues Flood Watch Warning: "The Hangingstone River at Fort McMurray is approaching bankfull conditions and is expected to peak sometime this evening."
- Equipment failure at WSC Hangingstone River gauge; the orifice was taken out by the high flows.
- 22:00 – RMWB notes concern over erosion of bank near Ptarmigan Park, and begins hourly inspections.

June 11, 2013 (Tuesday)

- 02:00 – RMWB receives notice from Keyano College about imminent flooding.
- 06:15 – Time of the Hangingstone River maximum water level reading, 249.87 m, from RMWB manual measurement in parking lot of Firehall No. 1, adjacent to the Hangingstone River, directly opposite from the WSC gauge.
- 09:45 – The RFC flood advisory for the Hangingstone is downgraded to a Flood Warning, stating: "Flooding and bank erosion has been reported along the Hangingstone River near the confluence with the Clearwater River in Fort McMurray. The water level on the Hangingstone River in Fort McMurray is currently reported as steady."
- 17:40 – Mandatory evacuation order for Ptarmigan Court
- 18:00 – Evacuation alert given for all of Waterways, Draper, and Grayling Terrace.

June 12, 2013 (Wednesday)

- 05:43 – Heritage Park side of Hangingstone footbridge washed out.
- 07:30 – WSC Hangingstone River gauge repaired. Water level measured at 249.28 m (4.278 m above local datum), and flood high water mark determined to be 249.89 m (4.893 m above local datum).
- 15:21 – Slumping of Beacon Hill slope observed (along Hangingstone River opposite from Grayling Terrace).

[4] http://edmonton.ctvnews.ca/hwy-63-opened-hwy-881-still-closed-after-flooding-1.1319312

- 16:00 – Approximate time of Clearwater River peak water level from RMWB measurements. Peak levels were 243.88 m at Waterways Outfall (upstream from the Hangingstone confluence), and 242.67 m at Alberta Drive Pier.
- 21:00 – Construction begins placing concrete Lego-type blocks in the Hangingstone near Tolen Drive to protect bank.

June 13, 2013 (Thursday)

- 10:00 – Water Survey streamflow measurement on Hangingstone River; discharge = 98.6 m^3/s with the water level having fallen to 0.99 m less than the peak.
- 16:15 – Mandatory evacuation of Grayling Terrace due to deterioration of opposite Beacon Hill slope. Mandatory evacuation of southernmost end of Draper Road (local drainage not part of Hangingstone or Saline Creek basins) due to deterioration of road.

June 14, 2013 (Friday)

- Flood response and cleanup continues. Premier visits the Regional Emergency Operations Centre and areas affected by the floods.
- 21:00 – Construction begins placing concrete Lego blocks in the Hangingstone at Grayling Terrace to protect bank.

June 15, 2013 (Saturday)

- 10:00 – Reports of Saline Creek having jumped its banks and encroaching on the homes in Ptarmigan Court. Decision to maintain mandatory evacuation for Ptarmigan Court until the water recedes.
- 13:30 – Evacuation downgraded to voluntary for Grayling Terrace and south end of Draper Road.

June 16, 2013 (Sunday)

- 07:15 – Work to fortify Hangingstone River at Grayling, Tolen and Ptarmigan has been completed.
- 08:00 – Evacuation order for Ptarmigan Court downgraded to a voluntary evacuation.
- 12:00 – Highway 881 closed due to flooding of the Gregoire River Bridge (just outside Hangingstone River basin).

Captioned Photos 1 through 13 show conditions along the Hangingstone River which were most greatly affected during the flood event. Images were selected from a large photo archive provided by the RMWB for June 12 through 15, 2013. Photo date and time stamps are as digitally preserved with the photos, which may not necessarily reflect the actual time.

3.2.2 2013 Flood Event Rain and Water Level Records

Rain gauge stations in the vicinity of the Hangingstone River Basin were identified from online databases that are maintained by Alberta Agriculture (2015) and the Regional Aquatics Monitoring Program (RAMP, 2015). Rainfall and other data obtained from the RAMP program for use in the present study is reproduced under license and permission by RAMP through its internet site located at www.ramp-alberta.org.

Four rain gauge stations were identified that had records for the flood event period in June 2013. Figure 1 shows the locations of these stations: RAMP Stations S31 and C5, and Environment Canada Stations Fort McMurray CS and Fort McMurray A. Both of the Environment Canada stations are located at the Fort McMurray Airport.

Table 7 presents a summary of the daily rain amounts associated with the 2013 flood event, and also the maximum accumulated amounts prior to the Hangingstone River reaching flood stage in Fort McMurray. Significant rain amounts were recorded in the three days prior to the peak flows, with three-day accumulations of 30.8 mm, 122.2 mm, and 79.5 mm, respectively at the RAMP S31, RAMP C5, and Fort McMurray Airport stations

Through a subsequent analyses of Environment Canada records of Fort McMurray historic rainfall records, it was determined that the 3-day accumulation at the RAMP S31 site was uneventful, less than a 2-year occurrence. In contrast, the 3-day rainfall accumulations at Fort McMurray and the RAMP C5 sites had return periods of approximately 15 years and 200 years, respectively. Environment Canada archived weather radar images were reviewed in an effort to determine the spatial extent of the storm. However, the information available for the nearest station, Jimmy Lake near Cold Lake, was inconclusive due to radar blockage by high ground between the radar station and the Hangingstone Basin.

A request was made to WSC for preliminary water level and flow data for the Hangingstone River gauge for the 2013 event, as well as for station history information. It was learned that a gauge malfunction occurred during the event such that no water level records were obtained during the period June 10 through 12 when the peak flow occurred, and that further processing of the raw sensor data would be required before preliminary 15-minute hydrograph information could be released.

WSC field notes for June 12, 2013, when the gauge was repaired, mention flowing debris, large standing waves in the channel, and 100 mm wave action which affected the direct water level measurement. Field notes for June 13, 2013, when a direct flow measurement was made, mention flowing debris on the left bank and throughout the channel, as well as a 100 mm surge. Field notes for June 20, 2013, apparently for station repairs, mention that the orifice block was found out of water, in debris, and that pre-repair readings were not valid.

WSC informally reported that the event peak flow, based on a high water mark at the gauge site and extrapolation of the prior rating curve, was approximately 206 m^3/s. However, this is not an official estimate because an adjustment to the measured high water mark might be required to account for surge effects, and the amount of extrapolation required was greater than would normally be allowed under WSC procedures. Further processing by WSC is required to determine the peak discharge for 2013 which will then be published as part of the official station record.

Presently-available water level data for the June 2013 event are comprised of point water level data for the three WSC site visits identified above, plus RMWB manual water level measurements taken on the Hangingstone River at Firehall No. 1, located opposite of the WSC gauge. Photo 1 shows the location of the Firehall relative to the WSC gauge. Figure 13 shows the flood event water level hydrograph based on the available data. The average rate of water level rise preceding the peak was about 5 cm per hour.

3.2.3 AESRD and Other High Water Marks

Following the 2013 flood, surveys of visual high water marks along the lower Hangingstone were made by AESRD (2014d) and an independent survey of highwater marks for the same reach was made in support of a study by Northwest Hydraulic Consultants (2014). These supplement the high water marks described above for the WSC Hangingstone River gauge site and Firehall No. 1 on the opposite bank.

The AESRD report identified a discrepancy between its surveys (which included a tie-in to the local benchmark for the WSC Hangingstone River gauge) and the elevation used by WSC for that benchmark. The Northwest Hydraulic

Consultants (NHC) report, described further in Section 3.2.5 below, determined that its independent high water mark surveys were consistent with the WSC datum, but not the AESRD elevations. NHC found that the data sets could be brought into vertical alignment by reducing (lowering) the AESRD elevations by 0.56 m.

As part of the present study, additional checks were made of the AESRD high water mark levels against the high water elevation reported by RMWB at Firehall No. 1, and also the Digital Elevation Model for Fort McMurray that was derived from LiDAR data acquired in August 2010 (and obtained from RMWB for use in the present study). Also, the LiDAR-derived ground elevation in the vicinity of the closest AESRD benchmark was compared to the AESRD benchmark elevation. The LiDAR ground elevation is consistent with the AESRD-reported benchmark elevation. However, the LiDAR-derived elevation for the edge of high water line at the firehall parking lot, clearly visible on Photo 1, is in agreement with the RMWB, WSC and NHC elevations, but not AESRD's.

Resolution of the datum discrepancy is of critical importance to ensure proper design, construction and performance of floodproofing measures. If, for example, the AESRD datum is used to construct floodproofing measures (i.e., top of dykes) equal to the ice jam flood level of 250.0 m, there is a risk that the floodproofing measures would be too low by 0.56 m and therefore fail to achieve their design objectives. This assumes that the discrepancy identified with the 2013 flood studies would also exist relative to the datum(s) used to establish the regulatory 100-year flood level.

3.2.4 Post-Flood Repairs

Post-flood repairs and mitigation works that have been completed since the conclusion of the June 2013 flood include removal of temporary measures (sandbagging and berms), and construction of bank stabilization works and conveyance improvements in some areas. Restoration activities at the hard-hit Heritage Park are expected to be completed in time to resume normal operations by summer 2015.

Photos 7 and 11 show locations where emergency bank stabilization repairs were conducted along the Hangingstone River at Ptarmigan Court, Tolen Drive, and Grayling Terrace, within the initial days after the flood peak.

Subsequent engineered channel restoration and bank protection projects were tendered by RMWB as presented below in chronological order.

- 2013 Flood Recovery Bridge and Culvert Works; drawings prepared by Associated Engineering and issued for tender and construction on Feb 10, 2014. This work involved relocation and re-installation of the Hangingstone River pedestrian bridge adjacent to Ptarmigan Court, and a second pedestrian bridge over Saline Creek.
- Flood Recovery Hangingstone River Bank Reconstruction; drawings prepared by Urban Systems and issued for tender on May 12, 2014. This work involved riprap bank protection at two sites along the Hangingstone River: (1) a reach segment including the locally eroding bank shown in Photo 10 just downstream from Heritage Park, and (2) a reach segment downstream of Prairie Loop Boulevard which includes the eroded trail adjacent to Tolen Drive and the upper part of Ptarmigan Court.
- 2013 Flood Recovery Saline Creek Restoration; drawings prepared by Associated Engineering and issued for tender and construction on July 23, 2014. This work involved excavation of the Saline Creek channel which had substantially filled with sediment, and constructing a longitudinally-stepped gabion wall to maintain separation between Ptarmigan Court and the creek.
- Grayling Terrace Hangingstone River Flood Recovery and Erosion Control Work; drawings prepared by MMM Group and issued for construction on November 20, 2014. The work had two distinct elements. First, work was undertaken to lessen the landslide hazard of the high slope opposite of Grayling Terrace; this was primarily

a geotechnical assignment but included placement of riprap at the toe of slope along the Hangingstone River. Second, Hangingstone River conveyance improvements were made along the entire length of Grayling Terrace, involving removal of riparian vegetation, grading, and placement of riprap armour to a design level corresponding to a 200-year flood level shown on the engineering plans. Photo 14 shows the riprap installation prior to landscape restoration which was to follow.

3.2.5 Observations and Lessons Learned

Highway washouts in the Hangingstone River basin upstream of Fort McMurray occurred about one day prior to the onset of damaging flows and high water at Fort McMurray.

The AESRD River Forecast Centre issued a flood warning for the Hangingstone River about 6 hour prior to the first noted concerns over river bank erosion at Ptarmigan Court and about 12 hours prior to the first report of imminent flooding at Keyano College.

The critical period of rapidly rising waters, culminating in the peak flood stage for the event, occurred in the middle of the night.

Graying Terrace was not inundated by surface water during the flood event. Reported basement flooding was therefore likely associated with high groundwater conditions which would require mitigation by means other than sandbagging or berms.

Much of the flood water damage that occurred in Fort McMurray in 2013 was associated with a left bank overflow which originated in the vicinity of Heritage Park. Emergency response construction of temporary berms in the vicinity of the overflow happened too late to prevent flood damage to Heritage Park and downhill properties including but not limited to Keyano College.

The timing of conditions of Saline Creek flooding at Ptarmigan Court suggest that the high water was due primarily to sedimentation rather than high flows. The large amount of sediment in the stream was probably associated with erosion from disturbed areas of the basin, especially from sites that were under construction (cleared and graded but not yet stabilized) at the time of the event.

Lessons learned from the above observations are included in the recommendations of this report.

3.3 Post-Flood Studies and Reports

Since the 2013 flood, two reports have been completed by others which address Fort McMurray flood hazards along the Hangingstone and Athabasca/Clearwater Rivers.

- Golder Associates (Golder, 2014) was retained by the Government of Alberta, Southern Alberta Flood Recovery Task Force, to undertake the Athabasca River Basin Feasibility Study published in February 2014. This report assessed flood hazards and mitigation options for the entire Athabasca River Basin, including but not limited to the Fort McMurray area.
- Northwest Hydraulic Consultants (NHC, 2014) was retained by the Regional Municipality of Wood Buffalo to undertake the Fort McMurray Flood Protection Conceptual Design study published in August 2014. This report was specifically focused on Fort McMurray.

With respect to the Athabasca/Clearwater ice jam flood level, Golder and NHC both updated the frequency analysis from the 1993 study to include subsequent years of record. Both studies used Pearson III distributions for the analyses which both yielded 100-year water level estimates slightly below 100-year level of 250.0 m as presently regulated, but with too little confidence to warrant a revision to the regulated level.

Copies of the Golder and NHC plots of updated Athabasca/Clearwater Rivers ice jam water level frequency curves are presented on Figure 14. It is visually apparent that the upper end of the computed frequency curve does not follow the data points for the two highest events in 1936 and 1875. A manual adjustment to improve the visual fit would shift the curve upward and result in a 100-year level of at least 250.0 m or higher.

Fort McMurray is in the process of designing and building dykes to provide a 1:100 year level of protection for ice jam floods, and this is being accomplished, in part, by ring roads and berms will be constructed with a top elevation at the regulatory 100-year ice jam level of 250.0 m. The NHC report recommended that berms be constructed with at least 0.5 m freeboard to guard against settlement and unforeseen flood events, but this was not accepted by the RMWB. The Golder report prepared for the Government of Alberta considered "value added" dyke options which would raise ring roads and secondary embankment dykes by 1 m to provide freeboard consistent with generally accepted engineering standards for dyke construction.

With respect to the Hangingstone River design flows and water levels, Golder and NHC used different frequency analysis approaches which yielded different results. Golder applied a 3-Parameter Log Normal distribution to 43 years of record from 1970 to 2013 and concluded that the Hangingstone River 2013 flood had a return period of about 50 years (with the statistical 100-year flood being 242 m^3/s). NHC applied a Pearson III distribution to 48 years of record from 1965 to 2013, excluding 1978, and concluded that the 2013 flood was representative of a 100-year event (statistically 186 m^3/s).

An independent assessment of the flood frequency characteristics for the Hangingstone River at Fort McMurray is presented in Section 3.4 which substantially concurs with the NHC evaluation.

The NHC study included development of a HEC-RAS one-dimensional hydraulic model of the Hangingstone River extending from the Clearwater River confluence to the upper end of Grayling Terrace. This model was developed with cross-sections from various surveys conducted prior to the 2013 flood and, therefore, does not accurately reflect existing conditions, especially in the lower reach where new bridges have been constructed at and beside Saline Creek Drive, and adjacent to the Longboat Landing development where considerable channel shifting occurred. Notwithstanding these limitations, the model was calibrated to WSC's two highest post-flood discharge measurements (including the highest measured flow of 98.6 m^3/s on June 13, and then used to estimate the 2013 peak flow as 197 m^3/s based on matching the high water mark data. This model was obtained "as-is" and used for additional hydraulic assessments described in Section 3.5.

3.4 Hydrology

Frequency analyses were conducted on Hangingstone River at Fort McMurray peak flow data for 49 years of record from 1965 through 2013. The analysis used the WSC published instantaneous flows when available. For 2013, a peak flow of 200 m^3/s was assumed on the basis of the WSC and NHC estimates. Peak flows for other years were estimated as the published maximum daily flow times a 1.07 multiplier corresponding to the average ratio of annual maximum instantaneous to daily values. Daily maximum flows for years 1965 through 1969, and 1978, were obtained from the WSC annual summaries of daily flows. Figure 15 shows the time series plot of annual peak flows.

Table 8 and Figure 16 present the results of the frequency analysis for Hangingstone River peak flows using the Log Pearson III distribution recommended by the US Geological Survey's Bulletin 17B, Guidelines for Determining Flood Flow Frequency. The 100-year flood is computed to be 184 m^3/s.

The Log Pearson III results were checked against other distributions and found to be similar to results from both Lognormal and Generalized Extreme Value distributions. Results were lower than from a Three Parameter Lognormal distribution which yielded a 100-year flow of 228 m^3/s versus 184 m^3/s from Log Pearson III.

The influence of the 2013 event on the computed frequency curves was checked by comparing results with and without this event, e.g., for analyses of periods ending in 2012 versus 2013. The 2013 event was determined to have caused an upward shift of the upper end of the frequency curves with 100-year values that were about 20% higher than from curves without the event. Prior to 2013, a flow of 200 m^3/s would have been associated with about a 500-year event from a Log Pearson III distribution and about a 100-year event from a Three Parameter Lognormal distribution.

The Hangingstone River 2013 flood peak had a return period of about 1 in 150 years based on the Log Pearson III distribution for all 49 years of record. It is, however, recommended that the 2013 flood be adopted as the basis for design of mitigation measures for Hangingstone River open water flood conditions, even though this exceeds the normal regulatory requirement for a 1% exceedance event.

3.5 Hydraulics / Flood Hazard Assessment

The Hangingstone River HEC-RAS model, originally developed by NHC with pre-flood cross-sections and calibrated to WSC post-flood flow measurements, was run for 2-year through 500-year flows from Table 8. High water marks from 2013 are also shown. This model had been prepared on the basis of pre-flood cross-sections and therefore does not reflect current conditions, nor did it include the new pedestrian bridge adjacent to Heritage Park where the most damaging overflow occurred. From subsequent review of bridge design drawings, it was determined that the low chord of the pedestrian bridge was above the 2013 high water level and that the bridge likely had little or no effect on the flood level. Figure 17 presents model results for the main flow quantiles and a line for the 2013 flood in place of the 100-year event.

Figure 18 presents open water flood hazard lines from Figure 16 that transition to same-risk ice jam flood levels for the lower reach. For the lower reach starting at the confluence with the Clearwater River, ice jam conditions are associated with the greatest flood risk. For 100-year ice jam conditions, the transition point where the open water design flood level (2013 flood) intersects the ice ham level is located just downstream from Highway 63. This is more or less at the location of the WSC Hangingstone River gauge and RMWB Firehall No. 1 on the opposite bank.

The implication of the above is that flood mitigation works constructed for areas upstream of Highway 63 should be designed for open water conditions, where the design 100-year open water levels are higher than the design 100-year ice jam levels. Downstream of Highway 63, the design (2013) open water flood levels were substantially contained within the main channel except for a short reach adjacent to Heritage Park. Except for this one location with a confirmed open water flood risk which warrants remediation, other flood mitigation works downstream of Highway 63 should primarily be designed to withstand ice jam flood levels, while being resilient to episodic channel movement associated with open water floods.

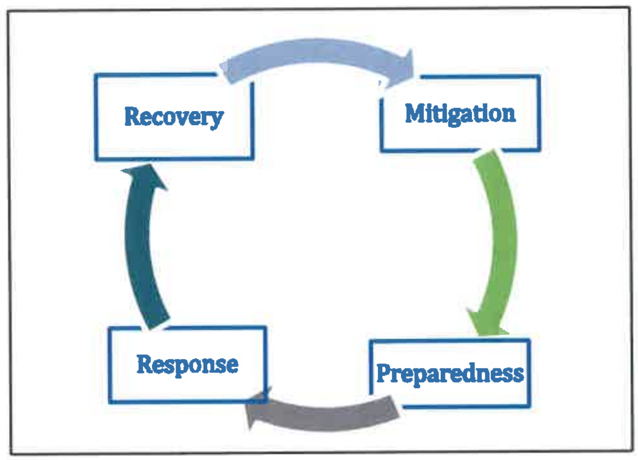
If flood hazard mitigation is to be narrowly based on providing protection for a 100-year risk, then the mitigation for future open water events can be based on lessons learned from the 2013 event. If a higher standard is sought, it should be applied equally to the open water and ice jam risks.

4.0 FLOOD RISK MANAGEMENT APPROACHES AND GUIDELINES

4.1 Overview

Flood Risk is a probability of the occurrence of a flood hazard; the vulnerability of individuals, society, and the environment; and the consequences that result from a flood event (IWR et al. 2011). Flood Risk Management is a cycle of mitigation, preparedness, response, and recovery to manage flood risk. In this cycle each step leads into the next as the flood risk is continually reduced to an acceptable level.

Mitigation is the avoidance of risk. This step in the cycle would encompass the studies and assessment to understand the possible risk as well as the planning, design, and implementation of measures to reduce risks. The studies and assessments include technical analyses such as hydrologic, hydraulic, and geomorphic studies to better understand the flood risk. Mitigation measures can be both structural as well as non-structural. Common measures used to reduce flood risk are discussed in Section 4.3 (Flood Protection Works).



Preparedness is becoming ready to respond to a disaster. This includes having manpower, equipment ready and procedures in place before the event occurs. It also includes educating individuals (government, business, residents, industrial facilities) on steps that should be taken to ensure personal preparedness. An example of this would be a family having supplies ready in the home for use during an event if the plan was to shelter-in-place rather than to evacuate.

Response focuses first on meeting basic human survival needs. This is an important step to have significant coordination among the responses and several organizations (in United States, such as the FEMA and the American Red Cross) are routinely involved. At an individual level the response step can include evacuation or shelter-in-place, a decision ideally made during the preparedness step.

Recovery is the intent to return an area back to its "normal" state. The time it takes to return to that normal state or the level to which normalcy can be regained can vary greatly. An assessment of the consequences of the event which can be seen during the recovery step should feed the planning stages of the mitigation step.

The following sections focus on the Mitigation aspect of the flood risk management cycle. Perspectives from a variety of nations are presented. Based on what information was readily available, perspectives from Japan, Netherlands, United Kingdom, and United States are most heavily represented.

4.2 Design Risk Level / Return Period

Determining an acceptable risk level to dictate the design target of a flood risk reduction project varies widely between countries as well as within countries. However, assessing risk level rather than simply defining a return period to a storm event is becoming more widespread.

4.2.1 Canada

As per the Environment Canada website[5], "The aim of the Flood Damage Reduction Program (FDRP) in Canada is to discourage future flood vulnerable development. The federal government initiated this program in 1975 to curtail escalating disaster assistance payments in known flood risk areas, as well as the reliance on costly structural measures. The FDRP is carried out jointly with the provinces under cost sharing agreements. Once a flood risk area is mapped and designated both governments agree not to build or support (e.g., with a financial incentive) any future flood vulnerable development in those areas. Zoning authorities are encouraged to zone on the basis of flood risk. New development is not eligible for disaster assistance in the event of a flood."

Alberta joined the FDRP in 1989 signing a combined General and Mapping Agreement. Appendix C provides a partial copy of this agreement, excluding technical guidelines. Under the Agreement, flood risk areas are identified based on 100-year flood conditions. These designated flood risk areas are then divided into two zones, the floodway, where further development is discouraged, and the flood fringe where flood proofed development is possible.

4.2.2 United States

Within the United States, the US Army Corps of Engineers (USACE), a federal agency, employs a risk-based approach to defining the design level. *EM 1110-2-1913* (USACE 2000) indicates that the nominal top-of-protection of a levee should be established using a risk-based analysis to account for hydraulic uncertainties. A deterministic analysis, rather than a risk-based analysis, is used to account for geotechnical and construction issues. The current design criteria contained in *EM 1110-2-1619* (USACE 1996) and in *ER 1105-2-101* (USACE 2006) suggest that the following procedures be followed for a risk-based analysis:

- Determine the appropriate equivalent record length to describe uncertainty in the flood-frequency curve (hydrologic uncertainty).
- Determine the uncertainty in the stage-discharge relationship by estimating the standard deviation (hydraulic uncertainty).
- Based on the uncertainty in the hydrology and hydraulics, determine the exceedance probability of the levee height.

Procedures relying on a risk-based analysis were adopted beginning in 1996. Prior to that time, the USACE often relied on an event of a specified return period or historical event to determine the design level. The concept of freeboard was incorporated with the event (or return period). Freeboard is the additional height built into the design to account for uncertainties. For example, a trapezoidal channel required 2 ft (0.6 m) of freeboard while a levee required 3 ft (0.9 m) of freeboard based on USACE standards.

The USACE has focused on assessing the level of risk associated with dams in the form of Dam Safety Action Classifications (DSAC). Recently, this concept has been applied to levees in the form of a Levee Safety Action Classification (LSAC). This allows the relative risk of these structures to be communicated across all owners and to allow the USACE to prioritize facilities for rehabilitation.

FEMA, a federal agency, relies on an event that has a 1% annual chance of exceedance (i.e. the 100-year storm event) to define floodplain limits. FEMA also applies freeboard to the determined water surface elevation at levees. It is important to note that FEMA does not define a **design** standard but defines a standard used to determine premiums for flood insurance purposes. In January 2015, the United States President signed Executive Order

[5] http://www.ec.gc.ca/eau-water/default.asp?lang=En&n=0365F5C2-1

13690 which ensures that agencies consider a higher level of protection when using federal money to implement a project. This Order allows for multiple options for compliance, including incorporating climate change science, ensuring all construction is built 3 ft (0.9 m) above the water surface elevation associated with the 100-year flood, or building to the 500-year flood elevation.

Within the United States at a state and local level, a variety of design level standards are employed. These standards are often tied to a certain recurrence level that usually ranges from the 50-year flood to the 200-year flood. A proactive floodplain management strategy is to allow for future increases in the level of protection provided by a flood risk reduction project. This can include building underground features (such as caissons to support a floodwall) to a higher standard or establishing an easement that is large enough to allow for future development (i.e. enlarging an earthen levee to gain additional height.) In addition to design targets established by a specific agency, each community that participates in the National Flood Insurance Program through FEMA (which is most of the United States), must adopt minimum local floodplain ordinances which require all developments to be constructed at or above the 100-year flood elevation.

4.2.3 Netherlands

In the Netherlands, the level of protection offered by dikes and dams is based on a semi-quantitative approach, developed by the first Delta Committee in the 1960s. For the area of Central Holland, covering the highly urbanized and flood prone area bounded by Amsterdam, The Hague and Rotterdam, a cost benefit analysis was performed. In this analysis, the investments necessary to improve the level of protection were compared with the avoided damage of flooding. Damage of flooding was calculated as direct and indirect economic damage, multiplied by a factor of 2, to account for fatalities and non-monetary damage to nature and cultural assets. The conclusion was that a design level, equivalent to an annual 1/10,000 storm surge level, offered adequate protection against flooding. For less populated coastal areas south and north of Central Holland, the Delta Committee proposed a protection level of 1/4,000 per year. In the 1980s, riverine areas, which have a better potential for evacuation, received a protection level of 1/1,250 per year. According to the "Flood Risk Management Approaches" report (IWR et al. 2011), there is a range in legislated level of protection of 1:250 to 1:10,000 in the Netherlands.

4.2.4 Japan

Japan has a long-term goal of 100- to 200- year protection along major rivers. Of these, about 40% meet this criteria. The Ara River in the Tokyo Metropolitan Area is one such system.

Japan has various types of natural hazards (earthquakes, floods, volcanos, landslides, tsunamis) with a long tradition of addressing them. Japan is mountainous and a majority of the development is in the floodplain and low-lying coastal areas. Large cities such as Tokyo, Osaka, and Nagoya are situated in low-lying coastal area where risks of inundation caused by levee breaches and flooding are quite high.

Flood damage is difficult to prevent because of torrential rainfall events resulting from typhoons and seasonal fronts combined with the relatively steep and short rivers. Structural flood damage reduction measures have been strongly and consistently promoted however, the present safety level is still far below its planned targets. As a result, Japan is seeking policies covering the entire "safety chain" (prevention, protection, preparedness, response and recovery). For instance, in rivers where their basins have been rapidly urbanized, "comprehensive flood control measures" are promoted. The measures combine various components including the construction and maintenance of flood risk reduction measures such as levees, flood fighting activities, runoff control in catchment areas, preparation of hazard maps and provision of river information, and other measures.

4.2.5 United Kingdom

The United Kingdom (UK) has adopted a risk-based approach to flood risk management. This approach to flood risk management distributes responsibility between a range of different parties. Various levels of government take responsibility for long-term planning and fund activities (including warning as well as flood protection works) for relevant sources of risk. There is no specific design requirement or level of protection and much of the residual risk is borne by individuals and transferred through private sector insurance. These insurance policy terms are increasingly risk-based and incentivize individuals to reduce risk.

According to the "Flood Risk Management Approaches" report (IWR et al. 2011), the National Flood Risk Assessment (NaFRA) in the UK produces a large scale assessment of the likelihood of flooding from rivers that have drainage areas greater than 3 km^2 and coastal areas. The assessments have been completed for the entire UK. The risk assessments were undertaken for 85 river catchments and coastal cells, where a cell is an area of land measuring 50 m^2. This approach allows for a comparison of the relative risks and their distribution within each of these catchments, rather than a detailed, local assessment of the risk at a specific location. It is based on a source-pathway-receptor conceptual model of risk and considers the probability that any defenses will overtop or breach. The calculations provide an indication of the likelihood of flooding at the centre of each cell. These results are then placed into three risk categories as used by the UK insurance industry. These are:

- Low – the chance of flooding each year is 0.5% (1 in 200) or less
- Moderate – the chance of flooding in any year is 1.3% (1 in 75) or less but greater than 0.5% (1 in 200)
- Significant – the chance of flooding in any year is greater than 1.3% (1 in 75)

This information is shared under license with Local Authorities and other partners for spatial planning and emergency planning purposes and can be accessed by the public via the Environment Agency website. There are no specific design standards, but the above along with more detailed analyses can be used to plan and implement flood risk reduction measures.

4.3 Flood Protection Works

Flood Protection Works or Flood Risk Reduction Projects can be designed for a variety of design levels as discussed in the previous section. The types of projects can include both non-structural and structural options.

4.3.1 Non-Structural Measures

The most common non-structural measures include the following:

- Elevation of land or structures
- Relocation
- Buyout/Acquisition
- Dry flood proofing
- Wet flood proofing
- Low Impact Development (LID)
- Watershed Restoration

4.3.2 Non-Structural Programs

Non-structural programs can also be employed to reduce flood risk. The most common non-structural programs include the following:

- Flood Warning Systems
- Flood Insurance
- Floodplain Mapping
- Flood Emergency Preparedness Plans
- Land Use Regulation
- Zoning
- Evacuation Plans
- Inspections during Floods
- Pre-Flood Inspections
- Risk Communication

4.3.3 Structural Measures

Traditional structural measures include the following:

- Channels (Enlargement, Diversions, Bypasses)
- Dams/Flood Storage
- Floodwalls
- Rapid Deployable Floodwalls
- Levees/dikes
- Shoreline Stabilization
- Storm Surge Barriers
- Gates
- Sandbags
- Backflow prevention devices
- Interior drainage pump stations
- Ice Booms

A recent study by the USACE North Atlantic Coast Comprehensive Study: Resilient Adaptation to Increasing Risk (USACE 2015) describes several of these measures and provides feasibility level costs associated with each measure. This study can be found at the following location: http://www.nad.usace.army.mil/compstudy.

Floodwalls are structures used to reduce risk in relatively small areas or areas with limited space for flood risk management against lower levels of flooding. They can be similar to seawalls and are usually constructed from concrete. Unlike wider, more stable levees, narrow floodwalls require significant reinforcement and anchoring construction to prevent collapse from hydrostatic pressure. The significant amounts of steel sheeting and/or reinforced concrete used in constructing a typical wall make the feature extremely heavy. Because construction in a flood prone area, such as near a river or estuary, may occur on soft organic soil, pile reinforcement may be required under the base of the wall. The combination of steel sheeting, reinforcement, concrete, and pile support make a floodwall a much more costly structural risk management measure than a similar length and height levee. (USACE 2015).

Rapid Deployment Floodwalls are structures that are temporarily erected along the banks of a river or estuary, or in the path of floodwaters to prevent water from reaching the area behind the structure. After the storm or flood, the structures are removed. This category also includes permanently installed, deployable flood barriers that rise into position during flooding due to the buoyancy of the barrier material and hydrostatic pressure. Some systems, such as stop logs, require a permanent base or footing, while others may be deployed without a base. (USACE 2015).

Levees and Dikes are embankments constructed along a channel or waterfront to prevent flooding in relatively large areas. They are typically constructed by compacting soil into a large berm that is wide at the base and tapers towards the top. Grass or some other type of non-woody vegetation is usually planted on the levee/dike to add stability to the structure. If a levee or dike is located in an erosive environment, revetments may be needed on the water side to reduce impacts from erosion, or in cases of extreme conditions, the dike face may be constructed entirely of rock. Levees may be constructed in urban areas or coastal areas; however, large tracts of real estate are usually required due to the levee width and required setbacks. The height and width usually limit access to the water for recreation and commercial activities, and like floodwalls, impact the view shed of adjacent properties. In some cases levees have been incorporated into trail systems and frequently include amenities such as benches, street lighting and jogging paths. (USACE 2015).

The USACE (2015) document also includes discussion of shoreline stabilization and storm surge barriers for coastal areas which are not relevant to the flood protection works which would be considered in the Hangingstone River basin.

4.4 Design Guidance

Within the United States, design standards are established at a national level by the U.S. Army Corps of Engineers. These documents generally include Engineering Manuals (EMs), Engineering Regulations (ERs), and Engineering Technical Letters (ETLs) which are often also used to guide designs in Canada and other jurisdictions. These documents can be found at the following:

http://www.publications.usace.army.mil/USACEPublications/EngineerManuals.aspx
http://www.publications.usace.army.mil/USACEPublications/EngineerRegulations.aspx
http://www.publications.usace.army.mil/USACEPublications/EngineerTechnicalLetters.aspx

The following table identifies which EM, ER, and/or ETL is applicable to the design of each aspect of a typical flood risk reduction project.

Item	Reference
Levee Height	*ER 1105-2-101 Risk Analysis for Flood Damage Reduction Studies* *EM 1110-2-1619 Risk-Based Analysis for Flood Damage Reduction Studies* *EM 1110-2-1913 Design and Construction of Levees*
Vegetation	*ETL 1110-2-583 Guidelines for Landscape Planting and Vegetation Management at Levees, Floodwalls, Embankment Dams, and Appurtenant Structures*
Levee Geometry	*EM 1110-2-1913 Design and Construction of Levees*
Access Road	*EM 1110-2-1913 Design and Construction of Levees*
Erosion Protection	*EM 1110-2-1601 Hydraulic Design of Flood Control Channels* *ETL 1110-2-120 Coastal Riprap Revetment Design* *ETL 1110-2-334 Design and Construction of Grouted Riprap*
Structural (Floodwall)	*ER 1110-2-1150 Engineering and Design for Civil Works Projects* *ER 1110-2-1806 Earthquake Design and Evaluation for Civil Works Projects* *EM 1110-2-2100 Stability Analysis of Concrete Structures* *EM 1110-2-2104 Strength Design for Reinforced-Concrete Hydraulic Structures* *EM 1110-2-2502 Retaining and Flood Walls*
Structural (Slope Paving)	*ER 1110-2-1150 Engineering and Design for Civil Works Projects* *EM 1110-2-2007 Structural Design of Concrete Lined Flood Control Channels* *EM 1110-2-2104 Strength Design for Reinforced-Concrete Hydraulic Structures*
Structural (Side-Drainage Structures)	*EM 1110-2-1913 Design and Construction of Levees* *EM 1110-2-2100 Stability Analysis of Concrete Structures* *EM 1110-2-2104 Strength Design for Reinforced-Concrete Hydraulic Structures* *EM 1110-2-2502 Retaining and Flood Walls* *EM 1110-2-2902 Conduits, Culverts, and Pipes*
Borings/Laboratory Testing	*EM 1110-2-1913 Design and Construction of Levees*
Stability	*EM 1110-2-1902 Slope Stability* *EM 1110-2-1913 Design and Construction of Levees*
Embankment Seepage	*EM 1110-2-1901 Seepage Analysis and Control for Dams* *EM 1110-2-1913 Design and Construction of Levees*
Settlement	*EM 1110-1-1904 Settlement Analysis* *EM 1110-2-1913 Design and Construction of Levees*
Seismic	*ER 1110-2-1806 Earthquake Design and Evaluation for Civil Works Projects* *EM 1110-2-1913 Design and Construction of Levees*
Spillway Design	*EM 1110-2-1603 Hydraulic Design of Spillways*
Instrumentation	*EM 1110-2-1908 Instrumentation of Embankment Dams and Levees*
Gravity Dam Design	*EM 1110-2-2200 Gravity Dam Design*
Arch Dam Design	*EM 1110-2-2201: CECW-ED, Arch Dam Design*

Additional, non USACE engineering design guidance include:

- Construction Industry Research and Information Association (CIRIA), France Ministry of Ecology, Sustainable Development and Energy, U.S. Army Corps of Engineers (USACE). The International Levee Handbook. 2013.
- Federal Emergency Management Agency (FEMA). FEMA 65, Federal Guidelines for Dam Safety: Earthquake Analyses and Design of Dams. 2005.

- FEMA. Technical Manual: Conduits through Embankment Dams (FEMA 484). 2005.
- FEMA. Technical Manual: Plastic Pipe Used in Embankment Dams (FEMA P-675). 2007.
- FEMA. Technical Manual: Overtopping Protection for Dams DVD (FEMA P-1015). 2015.
- United States Department of Agriculture Natural Resources Conservation Service (NRCS). National Engineering Handbook (NEH). 1997.
- USDA NRCS. Technical Release No. 60 – Earth Dams and Reservoirs. 2005.
- United States Department of the Interior, Bureau of Reclamation. Design of Small Dams; Third Edition. 1987.

4.5 Flood Proofing Successes and Failures

The USACE National Non-structural Flood Proofing Committee has developed a report documenting Flood Proofing Performance – Successes and Failures (USACE 1998), which provides a case study of 98 floodproofed structures and their performance. The document includes general guidance matrix[6] that discusses the applicability of some common flood protection works with relation to flooding characteristics, site characteristics, building characteristics and recreational/social characteristics.

The report includes a lesson learned from each of the case studies, and synthesizes these into a list of 61 Do's and Don'ts of Flood Proofing. The following lessons were "found to be critical to success or failure of the flood proofing measures" for riverine (non-coastal) settings and at least some of these will be applicable to the success or failure of flood mitigation works for Fort McMurray.

- #1. Do install an internal drainage system as an integral part of any dry, levee, or floodwall flood proofing measure. The drainage system must be adequate to evacuate water accumulated in the protected areas not only from seepage through or under the flood proofing measure but also from rainfall within the protected area. The drainage system must also be large enough to reduce hydrostatic force if dry flood proofing is used to flood proof a basement.
- #3. Do remember that flood proofing measures that are barriers (levees, floodwalls, and dry measures) can be overtopped. When this happens, damages happen that are equal to, if not worse than, those that would occur if the flood proofing measure was not present. A false sense of security can develop. Freeboard should be included as a factor of safety.
- #7. Do make certain that all utility entry points through the flood proofing system are properly sealed, and have check valves installed in sewer lines.
- #9. Do design an internal drainage system using a sump pump with a "backup" power supply consisting of batteries or a generator in case utility electric power fails or is purposely disconnected.
- #11. Do remember that structures having full basements with walls designed to resist hydrostatic force must also have the floor reinforced to resist uplift due to hydrostatic force.
- #12. Don't attempt to dry flood proof basements unless no other alternative exists. Reliable dry flood proofing of basements is extremely difficult to attain due to the hydrostatic force that can cause wall and floor failure or

[6] http://cdm16021.contentdm.oclc.org/cdm/ref/collection/p16021coll11/id/363

structure buoyancy. If dry flood proofing a basement is employed, be sure to install designer "blowout plugs" that will fail prior to total floor and wall failure or buoyancy.

- #27. Don't construct levees with sideslopes steeper than 1 vertical to 2 horizontal. A sideslope of 1 vertical to 3 horizontal is preferable.
- #28. Do relocate from the flood plain whenever possible.
- #29. Don't remain in a flood proofed structure during a flood event. Staying in a structure to fight the flood results in trading a reduction in flood damages by human intervention with increasing the potential for loss of life.
- #30. Do shut off natural gas or propane utilities to a flood proofed structure in preparation for the flood event. Electricity should be shut off if possible if it is not needed to make the flood proofing system functional. Fires do occur in flooded areas because of electrical "shorts" and gas line ruptures.
- #32. Don't forget to take into consideration the size of footings supporting a floodwall and their ability to resist tipping when adding height either permanently to a floodwall or temporarily during a flood fight.
- #33. Don't forget to "practice" each flood proofing system that requires human intervention on an annual basis.
- #46. Do install a "factor of safety" in those flood proofing measures that can be overtopped.
- #50. Do seek professional help from engineers, contractors, and so forth before implementing flood proofing.
- #51. Don't forget that all flood proofing measures require maintenance after implementation to ensure success.
- #52. Do purchase flood insurance for flood proofed structures and contents.
- #54. Do compact backfill placed under floodwalls where excavations have been made for utilities to prevent piping.
- #55. Do design redundancy into a sump pump system so the system can continue to operate without human intervention and without electrical power from a powerline source. Generators or battery backup is required.
- #56. Do remember that all flood proofing systems are only as good as the weakest part of the system.
- #59. Do install floodshields so hydrostatic force will make the seal tighter. Always install a seal around the edge of the floodshield.
- #60. Do consider elevating a structure as high as possible to provide the most flood protection. Costs to elevate several feet are normally not much more than elevating one or two feet. The only exception to this are in those cases where wind and/or seismic forces cause costs to increase as structure elevation height becomes greater.

Some of the above recommendations are known to already be a part of the emergency preparedness for flood event response, such as shutting off of utilities to a flood-affected area. However, recommendations to include freeboard as a factor of safety, and elevate structures as high as possible, are not presently reflected in either RMWB's development guidelines or flood mitigation plans for Fort McMurray's flood hazard areas.

The recommendation to purchase flood insurance for flood proofed structures and contents is not applicable in Alberta (or elsewhere in Canada) due to the unavailability of such insurance. Furthermore, within designated floodway portions of flood hazard areas, post-designation improvements would normally be ineligible for either federal or provincial disaster assistance regardless of any flood proofing measures in place at the time of the loss.

In 2005, in the United States, substantial losses to life and property occurred in New Orleans after Hurricane Katrina and the subsequent failure of structural measures that were relied upon to provide flood protection. In southern Alberta in 2013, the majority of flood damage in the hard-hit communities of Calgary and High River was to areas which had been previously mapped by AESRD as flood risk areas. The lessons to be learned from these experiences are that extreme events can and do occur which exceed the design basis for structural flood mitigation works and that the risk level is more properly described as a probability of exceedance rather than a recurrence interval.

A 100-year design flood as has been adopted for provincial flood hazard mapping in Alberta, and is also the "base flood" for federal flood hazard mapping in the United States. This gives the impression of an event which will only be experienced once in 100 years, whereas the correct statistical interpretation is that this design flood has a 1% chance every year of being exceeded. It is statistically certain that regulatory 100-year or greater floods will occur; it is only a question of when.

5.0 FLOOD PROTECTION FOR THE HANGINGSTONE RIVER BASIN

The lower reaches of the Hangingstone River at Fort McMurray are susceptible to flooding from: (1) backwater from downstream Athabasca River ice jams, and to (2) separately-occurring open water floods from summer precipitation events over the watershed. The ice jam flood risk well-documented, with published AESRD flood-hazard mapping which shows the floodway and flood fringe areas where certain regulatory restrictions apply. The Hangingstone River open water flood risk has not been formally assessed by AESRD, and this flood hazard was largely overlooked prior to the major flood that occurred in June 2013.

The June 2013 flood had a recurrence interval slightly greater than the 100-regulatory standard typically used in Alberta for flood hazard assessments. This event therefore provides direct recent experience of what a 100-year open water flood entails, and easy identification of where mitigation would be useful in withstanding a future similar-magnitude flood. It was determined from the hydrology and land use assessments that the 2013 flood was associated with a major 3-day storm event with localized extreme (200-year) precipitation just southeast of the basin. The flood appears to have been the natural basin response to a major storm event, and anthropogenic (human) influences on the peak flow were likely minor.

100-year ice jam water levels are approximately equal to Hangingstone River 100-year open water levels at the Highway 63 bridge. In the downstream reach from the Highway 63 bridge to the confluence with the Clearwater River, ice jam flood levels are higher than open water flood levels, by as much as 5 m. Upstream from the Highway 63 bridge, the 100-year open water level is higher than the ice jam level.

The following discussion of flood mitigation and flood protection is concerned with avoidance of overtopping flows resulting in overland flooding of urban residential, industrial, and other improvements which would be vulnerable to water damage. It is assumed that necessary flood repair bank restoration and stabilizations projects to protect existing edge of bank infrastructure (bridges, outfalls) have already been completed, and that future water edge infrastructure will be designed with adequate elevation and erosion protection.

Based on the 2013 open water flood and prior ice jam flood hazard mapping, urban areas at flood risk in the Hangingstone River are limited to the reach from the upper end of Grayling Terrace to the confluence with the Clearwater River.

The open water flood hazard at Grayling Terrace which existed prior the 2013 flood has since been largely mitigated by: (1) work to stabilize the landslide hazard slope on the opposite bank, and (2) conveyance and bank stabilization improvements which were designed to a 200-year open water flood level. Further mitigation is not required to address 100-year overtopping. The basement flooding which occurred during at Grayling Terrace during the 2013 event was presumably associated with temporary high groundwater levels during the flood and cannot be mitigated by surface measures. Owners should be advised of the residual flood risk and encouraged to consider future preparedness such as by installing sump pumps or appropriate waterproofing techniques.

Much of the overland flood inundation damage in 2013 was associated with overbank flow at Heritage Park, on the left (north) bank just downstream from Tolen Drive which then continued downhill to flood additional properties. Mitigation at this location should ideally be designed to protect against the 100-year ice jam flood level, 250.0 m (plus freeboard) rather than the open water 2013 flood level, 249.3 m (plus freeboard).

It is recommended that a flood mitigation project near Heritage Park at this location, probably a berm or levee, be prioritized for construction because of the double flood risk along this section of channel.

Detailed designs for ice jam flood protection works in the vicinity of the Hangingstone were in progress by others at the same time as this basin study, and study resources were allocated to provide on-call services requested by

RMWB to support the detailed design. These services included recommendations for Hangingstone River berm heights and buffer setbacks which are presented below.

Figures 19 to 22 show the main factors that were considered in determining riparian buffers to be preserved during the design and construction of flood protection works.

Figure 19 shows waypoints from a ground survey performed in 2013 by Tetra Tech EBA for RMWB to establish an Environmental Reserve along the Clearwater River downstream from the Hangingstone. The points were established by a biologist to mark the approximate transition from riparian to upland vegetation species. This is a science-based approach to identify and preserve sustainable riparian habitat.

Figure 20 shows pre- and post-flood positions of the Hangingstone River channel bank, from which the direction and rate of erosion can be determined. Flood protection works located in the path of eroding banks will eventually require companion bank protection works. Decisions on whether to provide such works now or to defer this can be made on the basis of the rate of bank movement.

Figure 21 shows lines that are digitally offset to be 30 m from the post-flood edge of bank. A 30-metre buffer from edge of bank is commonly required in both Canada and the United States for protection of riparian and aquatic habitat along major fish-bearing streams. However, some existing development exists within the 30 m buffer which will presumably need to be accommodated by the final alignment of flood protection works.

Figure 22 presents a preliminary buffer line which was provided to RMWB for guidance in determining the alignment of flood protection works. The line seeks to preserve existing riparian areas and a 30 m buffer from edge of bank where possible, but is constrained by the presence of existing roads and structures. Adjustments to this preliminary buffer are expected to be made in response to other constraints including but not limited to geotechnical considerations and land acquisition costs where flood protection works would encroach onto private property.

6.0 CONCLUSIONS

1. A major flood event occurred on the Hangingstone River in June 2013 which resulted in flood damage in Fort McMurray in areas which had not previously been identified as being at risk for open water flood hazard. A desktop study of the basin was conducted to assess the condition of the basin, the reasons for the flood, the risk of future open water floods, and to propose mitigation measures.

2. The lower reaches of the Hangingstone River had previously been designated as a flood hazard area associated with ice jams on the Athabasca River near its confluence with the Clearwater River. Flood mitigation works under design to address the ice jam hazard need to be reconsidered to address the additional open water flood risk.

3. With respect to the Fort McMurray urban area, the Hangingstone River basin has three sub-basins: (1) the main basin draining 966 km^2 upstream from the Water Survey of Canada Hangingstone River stream gauge located immediately downstream from Highway 63; (2) the Saline Creek sub-basin draining 137 km^2 upstream from Tolen Drive, and (3) a small sub-basin draining 2.0 km^2 downstream of the WSC gauge and Saline Creek tributary.

4. The dominant hydrologic characteristic of the Hangingstone River basin is that more than 90% of the basin is occupied by wetlands, according to the 2014 Alberta Merged Wetland Inventory. The mapped wetlands include approximately 16,000 ha of bog, 68,000 ha of fen, 650 ha of marsh, 475 ha of open water, and 21,000 ha of swamp. Older National Topographic System mapping had identified a much smaller wetland area of area of only 27,700 ha (25% of the basin) mostly north and west of Highway 63.

5. As of 2013, the Hangingstone River basin remained in a primarily vegetated state, excluding the Fort McMurray urban area development and the Highway 63 and 881 corridors. Other anthropogenic land use disturbance in the basin to date is mostly limited to seismic cut lines and other work for resource investigations. The footprint and nature of existing land used disturbance is too small and too distributed to have had an identifiable influence on the basin hydrologic response during the 2013 flood event.

6. Planned future development in the basin mostly consists of expansion of the Fort McMurray urban area and development of oil sands leases. Future urban expansion is not expected to worsen basin-scale flooding because of the small footprint and location at the downstream end of the basin where urban area peak runoff will most likely not be coincident with upper basin peak runoff which results from relatively long-duration events. Future oil sands development is not expected to worsen basin-scale flooding because most the areas of most hydrologically significant development (compacted plant sites and well pads) will be subject to industrial stormwater control standards which require that site runoff be retained on-site until after the storm has passed and the water quality is confirmed to be suitable for release.

7. The 2013 flood on the Hangingstone River is associated with a major 3-day storm event with localized extreme (200-year) precipitation south and east of the basin. The 3-day rainfall accumulation at the Fort McMurray Airport had a return period of approximately 15 years. The available rain gauge and radar records are insufficient to accurately determine the spatial extent of the storm.

8. Warnings of the impending 2013 flood at Fort McMurray included: (1) highway washouts in the upstream Hangingstone River basin about one day prior to the onset of urban area flooding; (2) an AESRD River Forecast Centre flood warning issued about 6 hour prior to the first noted concerns over river bank erosion at Ptarmigan Court and about 12 hours prior to the first report of imminent flooding at Keyano College. The critical period of rapidly rising waters and onset of out-of-bank flooding, occurred in the middle of the night.

9. The 2013 peak flow on the Hangingstone River at the WSC gauge was approximately 200 m^3/s; an official value has not yet been published by WSC. The flow is slightly higher than a 100-year flow of 184 m^3/s based on evaluation of the 49 years of station record, 1965-2013, with a Log Pearson III frequency distribution. For practical purposes, the 2013 flood was substantially equivalent to a 100-year design event and can be used to guide the design of flood mitigation measures for 100-year protection.

10. The open water design flood profile can be taken directly from the high water marks from the 2013 event. This profile intersects the regulatory 100-year ice jam level, at the Highway 63 bridge over the Hangingstone River. Upstream of the bridge, the design open water flood profile is higher than the 100-year ice jam level. Downstream of the bridge, the 100-year ice jam level is higher than the open water flood profile. Flood protection works at a given location should be designed to the higher of the ice jam and open water flood levels.

11. The areas of Heritage Park and down-gradient properties have a double flood risk because inundation will occur under both ice jam and open water design events, each of which has an independent 1% chance of exceedance in any year. In all other areas, the inundation flood risk is associated with only one of the two high water conditions.

12. Flood risk concerns developed for the lower reach of Saline Creek in the vicinity of Ptarmigan Court because of severe sedimentation which substantially filled the main channel and reduced its conveyance capacity. Post-flood conveyance improvements were made, but the specific underlying causes of this sedimentation have not been identified. It is possible that changes to sediment control and/or flow control in the urban area portions of the Saline Creek basin will be required to prevent future recurrences of this problem.

13. Channel conveyance improvements were completed in 2015 for the Hangingstone River along Grayling Terrace located upstream from Highway 63. Construction drawings for this work show a "Top of Rock Protection" line that corresponds to a 200-year water surface elevation that is about 0.4 m above a line indicating the 100-year surface elevation.

14. There is a residual open water flood risk at Grayling Terrace due to flood-related high groundwater conditions which will not be mitigated by the channel conveyance improvements. Flood water damage at Grayling Terrace in 2013 was reportedly associated with basement flooding rather than overland flow.

15. Downstream from Heritage Park, the 100-year flood inundation hazard is associated exclusively with Athabasca River ice jam conditions. There is nothing that can be done in the upper Hangingstone Basin that will reduce or alter this flood risk.

16. Ice jam flood levels at Fort McMurray have been partially mitigated by the Snye Dyke which was constructed in 1966 near the confluence of the Athabasca and Clearwater rivers, lowering the estimated 100-year flood level by 1 m to 250.0 m.

17. The Fort McMurray ice jam flood hazard area identified by AESRD is divided into two sub-areas with distinct AESRD regulatory expectations. In "flood fringe" areas, new undertakings are allowed but are required to be adequately floodproofed to avoid damage for water levels up to and including the regulatory 250.0 m stage. In "floodway" areas, new development is discouraged by AESRD but RMWB is understood to have received an exemption to this rule for Fort McMurray and allows new development that is floodproofed to the same 250.0 m stage.

18. Flood hazard mapping in Alberta is for 100-year flood events which some might interpret as a flood that is not expected to happen for about 100 years. This common interpretation is dangerously wrong. The correct statistical interpretation is that, every year, there is a 1% chance that the design flood will be exceeded. It is

statistically certain that design level floods will occur in provincially-designated flood hazard areas; it is only a question of when.

19. The decision to allow development in designated floodway areas in Fort McMurray will invoke a not-eligible-for-disaster-assistance consequence from the 1989 agreement between the Government of Canada and the Government of the Province of Alberta for Flood Damage Reduction and Flood Hazard Mapping in Alberta. Section 12 of the Agreement contains provisions which indicate that that post-designation "undertakings" commenced, or moveable placed, in the floodway will not be eligible for either federal or provincial flood disaster assistance funding. The term "undertaking" is broadly defined as "the construction, erection, extension or alteration of any structure" other than temporary structures for agriculture use or open air buildings for recreational use or structures or works associated with flood control measures.

7.0 RECOMMENDATIONS

1. Further study of construction site erosion control and stormwater management practices in the Saline Creek Basin is recommended to identify and rectify sources and causes of excessive sediment deposition that caused capacity problems in the lower reach near Ptarmigan Court.

2. Further investigation is required to resolve the datum discrepancy between RMWB control elevations and those used by AESRD for its survey of Hangingstone River 2013 flood high water marks. The AESRD River Forecast Section has been made aware of this issue.

3. Flood mitigation work to reduce the risk of overtopping at Heritage Park, resulting in flooding of the Park as well as down-gradient properties, should be prioritized because of the double risk of flooding that presently exists from this location.

4. Homeowners in the Grayling Terrace neighbourhood should be notified that the recently-completed channel conveyance improvements will not mitigate flood-event high groundwater which may be responsible for basement flooding that occurred in 2013.

5. The RMWB emergency response plan should be revisited in light of the timeline of events for the 2013 event, and whether a different response would be indicated.

6. Berms and floodwalls under consideration to provide flood protection should be designed with freeboard allowance of at least 0.5 m above target design levels to allow for settlement, and both hydrologic and hydraulic uncertainties.

7. New and retrofit development within the flood hazard areas should be encouraged to elevate flood-susceptible improvements to be above the 100-year flood level. Developments might consider building to the historic maximum documented flood level of 252.0 m after adjustment for mitigation effects of the Snye Dyke.

8. Proponents (including RMWB) of new developments within designated floodway areas should be aware that such development would not normally be eligible for flood damage disaster assistance from either the provincial or federal governments.

9. See Section 4.5 of this report for additional general recommendations developed from documented successes and failures of riverine flood protection works in the United States.

8.0 CLOSURE

We trust this report meets your present requirements. If you have any questions or comments, please contact the undersigned.

Sincerely,
Tetra Tech EBA Inc.

PROFESSIONAL ENGINEER WILLIAM A. ROZEBOOM ALBERTA

July 14, 2015

Prepared by:
Bill Rozeboom, P.Eng.
Principal Specialist – Water Resources
Environment Practice
Direct Line: 780.451.2130 x263
Bill.Rozeboom@tetratech.com

PROFESSIONAL ENGINEER BRIAN C. ADENEY ALBERTA

July 14 2015

Reviewed by:
Brian Adeney, P.Eng.
Vice President – Water & Environment
Environment Practice
Direct Line: 780.451.2130 x258
Brian.Adeney@tetratech.com

/sy

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TETRA TECH EBA INC.
Signature
Date July 14 2015
PERMIT NUMBER: P245
The Association of Professional Engineers and Geoscientists of Alberta

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TABLES

Table 1 - Hydrometric, Climate, and Water Quality Stations

Hydrometric STATION #	STATION NAME	Type	Basin km²	Status	Record start	Record end	Years of Record	Latitude	Longitude
WSC 07CD001	CLEARWATER RIVER AT DRAPER	Flow & Level	30791.6	active	1930	2013	57	56.68528	-111.2554
WSC 07DA001	ATHABASCA RIVER BELOW MCMURRAY	Flow & Level	132585	active	1957	2012	55	56.78035	-111.4022
WSC 07CD004	HANGINGSTONE RIVER AT FORT MCMURRAY	Flow	962	active	1965	2012	46	56.70897	-111.3564
WSC 07CD005	CLEARWATER RIVER ABOVE CHRISTINA RIVER	Flow	17016.6	active	1966	2012	46	56.66361	-110.9287
WSC 07CE001	GREGOIRE LAKE NEAR FORT MCMURRAY	Level	261.5	active	1969	2012	43	56.48356	-111.1801
WSC 07CD002	CLEARWATER RIVER BELOW WATERWAYS	Level	31900	discontinued	1950	1975	26	56.71944	-111.3472
WSC 07CC002	ATHABASCA RIVER AT MCMURRAY	Level	100000	discontinued	1937	1959	23	56.73	-111.38
WSC 07CD003	CLEARWATER RIVER AT UPPER WINGDAM	Level	30800	discontinued	1960	1974	15	56.7	-111.3333
WSC 07CE004	ROBERT CREEK NEAR ANZAC	Flow	54.1	discontinued	1982	1995	14	56.38361	-111.0283
WSC 07CC001	HORSE RIVER AT ABASANDS PARK	Flow	2130	discontinued	1930	1979	7	56.70806	-111.3944

Climate STATION #	STATION NAME	Type	Elev (m)	Status	start	end	Years of Record	Latitude	Longitude
EC 3062693	Fort McMurray A	Climate	369.1	replaced	1944	2008	65	56.650000°	-111.216667°
EC 3062696	Fort McMurray CS	Climate	368.8	active	1996	2014	19	56.651111°	-111.213333°
EC 3062697	Fort McMurray A	Climate	369.1	active	2011	2014	4	56.653333°	-111.223333°
RAMP C5	Surmont Climate Station	Climate	560	n/a	2011	2013	3	56.223575°	-110.959006°
RAMP S31	Hangingstone at North Star	Rainfall	655	n/a	2010	2013	4	56.268719°	-111.487872°
EC 3062695	Ft McMurray	Climate	252.7	discontinued	1908	1944	33	56.733333°	-111.383333°

Water Quality SITE ID	SITE NAME	Type	Elev (m)	Status	start	end	Years of Record	Latitude	Longitude
RAMP HAR-1	Hangingstone R Upstream of Ft McMurray	Water Quality	352	n/a	2004	2014	7	56.630093°	-111.347959°
RAMP HAR-1A	Hangingstone R Downstream of Ft McMurray	Water Quality	244	n/a	2013	2014	2	56.705813°	-111.347220°
RAMP CLR-1	Clearwater R Upstream of Ft McMurray	Water Quality	246	n/a	2001	2014	14	56.698984°	-111.316640°

Stations Operations
- WSC - Water Survey of Canada
- EC - Environment Canada
- RAMP - Regional Aquatics Monitoring Program

Table 2 - Fort McMurray Climate Data

	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec	Annual
TEMPERATURES, 1981-2010 Climate Normal Period													
Daily Average (°C)	-17.4	-13.3	-6.2	3.3	9.9	14.6	17.1	15.4	9.5	2.3	-8.6	-15.1	1
Daily Maximum (°C)	-12.2	-7.1	0.6	10	16.9	21.5	23.7	22.2	15.8	7.4	-4.3	-10.1	7
Daily Minimum (°C)	-22.5	-19.5	-12.9	-3.5	2.8	7.7	10.5	8.6	3.2	-2.8	-12.9	-20	-5.1
TEMPERATURES, Station Extremes													
Extreme Maximum (°C)	15.1	15	20.1	30.2	34.8	36.8	35.6	**37**	32.4	28.6	18.9	10.7	
Date (yyyy/dd)	2003/ 07	1968/ 28	2004/ 30	1980/ 29	1986/ 26	2002/ 27	1955/ 18	**1991/ 10**	1981/ 09	1987/ 02	1949/ 04	1999/ 24	
Extreme Minimum (°C)	-50	**-50.6**	-44.4	-34.4	-17.3	-4.4	-3.3	-3.1	-15.6	-24.5	-37.8	-47.2	
Date (yyyy/dd)	1950/ 25	**1947/ 01**	1962/ 02	1954/ 02	2002/ 04	1946/ 10	1951/ 13	2004/ 22	1944/ 30	1984/ 30	1955/ 28	1951/ 19	
PRECIPITATION, 1981-2010 Climate Normal Period													
Rainfall (mm)	0.4	0.7	2.1	11	33.5	73.3	80.7	57.1	38.8	15.6	2.6	0.7	316.3
Snowfall (cm)	23.8	18.4	19.1	11.9	3.5	0	0	0	0.9	12.2	22.9	21.3	133.8
Precipitation (mm)	17.7	13.2	16.7	21.4	36.5	73.3	80.7	57.1	39.7	26.2	19.9	16.4	418.6
Average Snow Depth (cm)	27	30	23	4	0	0	0	0	0	1	10	20	10
Median Snow Depth (cm)	27	30	24	2	0	0	0	0	0	0	9	20	9
Snow Depth at Month-end (cm)	30	29	14	1	0	0	0	0	0	3	16	22	10
PRECIPITATION, Station Extremes													
Extreme Daily Rainfall (mm)	6.4	4.8	8.4	15.4	38.4	50	57.5	**94.5**	60.5	29.4	15.2	8.4	
Date (yyyy/dd)	1944/ 17	1956/ 08	1991/ 22	1990/ 24	1966/ 22	1991/ 12	2005/ 23	**1976/ 26**	1970/ 02	1983/ 14	1983/ 04	1985/ 22	
Extreme Daily Snowfall (cm)	16.3	15.2	**29.7**	26.2	15.2	0.3	0	0.2	27.9	17.2	18	22.6	
Date (yyyy/dd)	1973/ 02	1994/ 18	**1951/ 16**	1985/ 20	1977/ 16	1957/ 09	1944/ 01	1984/ 28	1972/ 22	1984/ 16	1990/ 29	1961/ 21	
Extreme Daily Precipitation (mm)	16	13.2	29.7	26.8	39.4	50	57.5	**94.5**	60.5	29.4	15.7	22.6	
Date (yyyy/dd)	1973/ 02	1950/ 26	1951/ 16	1985/ 20	1970/ 17	1991/ 12	2005/ 23	**1976/ 26**	1970/ 02	1983/ 14	1967/ 22	1961/ 21	
COMPUTED LAKE EVAPORATION, 1980-2009													
Average Lake Evaporation (mm)	-2	0	24	63	104	123	134	102	46	15	-2	-4	592
Maximum Lake Evaporation (mm)	-1	4	41	83	130	143	153	141	65	20	3	1	676
Minimum Lake Evaporation (mm)	-8	-8	4	45	77	102	104	74	32	9	-9	-11	488

Table 3 - Vegetation Elements of Conservation Concern

Rare Plants and Rare Ecological Communities Known to Occur within the Central Mixedwood and Lower Boreal Highlands Natural Subregions

Scientific Name	English Name	GSAWS[1]	SARA[2]	SRank[3]	NRank[4]	GRank[5]	Habitat[6,7,8]
Agrostis exarata	spike redtop	May be At Risk	-	S2	N5	G5	moist alpine slopes
Alnus incana ssp. tenuifolia / Matteuccia struthiopteris shrubland	river alder / ostrich fern shrubland	N/A	N/A	S2?	NNR	N/A	shrubland
Anemone quinquefolia	wood anemone	May be At Risk	-	S1	NNR	G5	moist woods
Arabidopsis salsuginea	mouse-ear cress	May be At Risk	-	S1	NNR	G4G5	Saline shores and flats
Arctagrostis arundinacea	polar grass	Sensitive	-	S2S3	N4	G5T5	marshy ground and moist meadows
Astragalus bodinii	Bodin's milk vetch	May be At Risk	-	S1	NNR	G4	moist meadows and gravel banks
Betula neoalaskana / Ledum groenlandicum	Alaska birch / common Labrador tea	N/A	N/A	S1S2	NNR	N/A	forest/woodland
Blysmus rufus	Red Bulrush	Sensitive	-	S1	N4	G5	saline marshes
Boschniakia rossica	ground-cone	May be At Risk	-	S1	NNR	G5	green alder shrubby areas (parasitic)
Botrychium crenulatum	scalloped grapefern	May be At Risk	-	S1	N2N3	G3	wet areas in Alberta (only known to occur in Banff National Park)
Botrychium hesperium	western grape fern	Undetermined	-	SU	N2N3	G4	wooded areas
Botrychium lanceolatum	lance-leaved grape fern	Sensitive	-	S2	N4	G5	mountain slopes
Botrychium oneidense	blunt-lobe grape-fern	Sensitive	-	S1	N3	G4	moist to wet, acidic, shady woods and swamps
Botrychium pinnatum	northwestern grapefern	Sensitive	-	S3	N4	G4?	open moist to mesic sites in montane, subalpine, alpine zones
Calamagrostis lapponica	Lapland reed grass	Sensitive	-	S1	N5	G5	moist to dry alpine slopes
Campanula aparinoides	marsh bellflower	May be At Risk	-	S1	N5	G5	wet meadows and marshes
Cardamine parviflora	small bitter cress	May be At Risk	-	S1	N5	G5	Sandy ground and dry, open mixed woodlands
Carex adusta	browned sedge	May be At Risk	-	S1	NNR	G5	dry, acidic sandy soil, under pine trees
Carex arcta	narrow sedge	May be At Risk	-	S1	N5	G5	moist woods
Carex heleonastes	Hudson Bay sedge	Sensitive	-	S2	N3	G4	fens and marshes
Carex hystericina	porcupine sedge	May be At Risk	-	S1	N5	G5	shade, mucky soils
Carex lacustris	lakeshore sedge	May be At Risk	-	S2	N5	G5	marshes and swampy woods
Carex limosa - Menyanthes trifoliata - Cardamine pratensis	mud sedge - buck-bean - meadow bitter cress	N/A	N/A	S1S2	NNR	N/A	herbaceous
Carex limosa - Scheuchzeria palustris / Sphagnum teres - S. subsecundum	mud sedge - scheuchzeria / thin-leaved peat moss	N/A	N/A	S1	NNR	N/A	herbaceous
Carex oligosperma	few-fruited sedge	Sensitive	-	S3?	N5	G5	wet meadows and bogs
Carex pedunculata	stalked sedge	May be At Risk	-	S1	N5	G5	rich, relatively dry woods
Carex retrorsa marsh	turned sedge marsh	N/A	N/A	S1S2	NNR	N/A	herbaceous
Carex rostrata marsh	beaked sedge marsh	N/A	N/A	S2	NNR	N/A	protected bays; herbaceous
Carex scoparia	broom sedge	May be At Risk	-	S1	N5	G5	moist to wet sites
Carex umbellata	umbellate sedge	Undetermined	-	S2	N5	G5	open woods and sandy areas
Carex vulpinoidea	fox sedge	May be At Risk	-	S2	N5	G5	swamps and wet meadows
Chrysosplenium iowense	golden saxifrage	Sensitive	-	S3?	N3	G3?	moist shady sites; richs soils, wetlands
Cypripedium acaule	stemless lady's-slipper	Sensitive	-	S3	N5	G5	wetlands, woods, sand dunes
Cystopteris montana	mountain bladder fern	May be At Risk	-	S2	N3N4	G5	damp calcareous sites
Danthonia spicata	poverty oat grass	May be At Risk	-	S2	N5	G5	sandy, rocky sites, mostly in dry woods
Diphasiastrum sitchense	ground-fir	May be At Risk	-	S2	N5	G5	open woods and barrens
Doellingeria umbellata var. pubens	flat-topped white aster	May be At Risk	-	S2	N5	G5T5	Moist soils, clearings, thickets, margins of forests and near streams, prairies
Dryopteris cristata	crested shield fern	May be At Risk	-	S1	N5	G5	marshes, swamps, most woods, thickets.
Dryopteris filix-mas	male fern	May be At Risk	-	S1	N5	G5	marshes, swamps, moist woods
Elatine triandra	waterwort	May be At Risk	-	S1	N3N4	G5	shallow water and mudflats
Eleocharis elliptica	slender spikerush	Undetermined	-	S2?	N5	G5	wet places
Elodea canadensis	Canada waterweed	-		SU	N5	G5	sloughs, ponds, and lakes
Epilobium halleanum	willowherb	May be At Risk	-	S1	N2?	G5	moist grounds
Epilobium lactiflorum	willowherb	May be At Risk	-	S2	NNR	G5	montane stream banks and moist slopes
Eupatorium maculatum	spotted Joe-pye weed	May be At Risk	-	S1S2	N5	G5	wet to moist meadows and open woods
Gentianopsis detonsa ssp. raupii	northern fringed gentian	Sensitive	-	S1	N1	G3G5T3T5	wet meadows and saline flats
Geranium carolinianum	Carolina wild geranium	Sensitive	-	S1	NNR	G5	clearings and disturbed sites
Gymnocarpium jessoense	northern oak fern	May be At Risk	-	S1	N3N4	G5	acidic to neutral rock crevices, cliffs and moist woods
Hedyotis longifolia	long-leaved bluets	May be At Risk	-	S2	NNR	G4G5	sandy soil in open woods
Hypericum majus	large Canada St. John's-wort	Sensitive	-	S2	NNR	G5	moist slopes
Isoetes echinospora	northern quillwort	May be At Risk	-	S2	N5	G5	aquatic
Juncus brevicaudatus	short-tail rush	Sensitive	-	S2	N5	G5	marshes and shores, northeastern corner of province.
Juncus nevadensis	Nevada rush	May be At Risk	-	S1	NNR	G5	shorelines and other wet sites
Juncus stygius var. americanus	marsh rush	May be At Risk	-	S2	NNR	G5T5	fens
Lactuca biennis	tall blue lettuce	May be At Risk	-	S2	N5	G5	moist woods and clearings
Liparis loeselii	Loesel's twayblade	May be At Risk	-	S1	NNR	G5	wet organic soils in fens and woods
Luzula acuminata	wood-rush	May be At Risk	-	S1	N5	G5	moist woodland, disturbed sites
Luzula rufescens	reddish wood-rush	Sensitive	-	S1	N2N3	G5	damp grassy slopes, edges of bogs and marshes
Malaxis paludosa	bog adder's-mouth	May be At Risk	-	S1	N3	G4	mossy ground in bogs and fens
Mimulus guttatus	yellow monkeyflower	Secure	-	S2S3	N5	G5	wet meadows, springs, streambanks
Monotropa hypopithys	pinesap	May be At Risk	-	S2	NNR	G5	rich, shaddy coniferous forests
Muhlenbergia racemosa	marsh muhly	May be At Risk	-	S2	N4N5	G5	dry sand hills, slopes, eroded banks
Najas flexilis	slender naiad	May be At Risk	-	S2	N5	G5	ponds and streams
Nymphaea leibergii	pygmy water-lily	May be At Risk	-	S1S2	N5	G5	ponds, lakes, quiet streams
Nymphaea tetragona	white water-lily	May be At Risk	-	S1	N5	G5	ponds, lakes, quiet streams
Pellaea glabella	smooth cliff brake	May be At Risk	-	S2	N4	G5	calcareous cliffs and ledges
Pellaea glabella ssp. simplex	smooth cliff brake	May be At Risk	-	S2	N3N4	G5T4?	calcareous cliffs and ledges
Phegopteris connectilis	northern beech fern	May be At Risk	-	S2	N5	G5	moist woodlands, moderately to stronly acidic soils
Picea glauca / Equisetum scirpoides forest	white spruce / dwarf scouring-rush forest	N/A	N/A	SU	NNR	N/A	forest/woodland
Picea mariana / Cladina stellaris	black spruce / star-tipped reindeer lichen	N/A	N/A	S1	NNR	N/A	forest / woodland
Pinguicula villosa	small butterwort	Sensitive	-	S2	NNR	G4	sphagnum hummocks in peatlands
Plantago maritima	sea-side plantain	May be At Risk	-	S1	N5	G5	saline marshes and alkaline soi
Polygala paucifolia	fringed milkwort	May be At Risk	-	S1	NNR	G5	moist coniferous or mixedwoods
Populus balsamifera / Alnus incana ssp. tenuifolia - Cornus stolonifera / Equisetum pratense	balsam poplar / river alder - red-osier dogwood / meadow horsetail	N/A	N/A	S3	NNR	N/A	forest/woodland
Populus balsamifera / Rhamnus alnifolia / Equisetum arvense	balsam poplar / alder-leaved buckthorn	N/A	N/A	S1	NNR	N/A	forest/woodland
Populus balsamifera / Viburnum opulus / Matteuccia struthiopteris	balsam poplar / high-bush cranberry / ostrich fern	N/A	N/A	S1S2	NNR	N/A	forest/woodland
Populus tremuloides / Rosa acicularis / Apocynum androsaemifolium forest	aspen / prickly rose / spreading dogbane forest	N/A	N/A	S1S2	NNR	N/A	forest/woodland
Populus tremuloides / Rubus parviflorus / Aralia nudicaulis	aspen / thimbleberry / wild sarsaparilla	N/A	N/A	S2S3	NNR	N/A	forest/woodland
Populus tremuloides / Vaccinium myrtilloides woodland	aspen / common blueberry woodland	N/A	N/A	S2?	NNR	N/A	forest/woodland
Potamogeton foliosus	leafy pondweed	Secure	-	S2	N5	G5	shallow standing water
Potamogeton obtusifolius	blunt-leaved pondweed	Sensitive	-	S2	N4N5	G5	shallow lakes and ponds; organic sediment
Potamogeton robbinsii	Robbins' pondweed	Sensitive	-	S1	NNR	G5	shallow to deep lakes and ponds; organic muck
Potamogeton strictifolius	linear-leaved pondweed	Sensitive	-	S2	N4	G5	shallow lakes and ponds
Potentilla multifida	branched cinquefoil	May be At Risk	-	S1	NNR	G5	gravel bars and open slopes
Puccinellia nuttalliana - Suaeda calceoliformis - Spergularia marina barren	Nuttall's salt-meadow grass - western sea-blite - salt marsh sand spurry barren	N/A	N/A	S2	NNR	N/A	sparsely vegetated
Rhynchospora capillacea	slender beak-rush	May be At Risk	-	S1	NNR	G4	fens, meadows, swamps.
Sagittaria latifolia	broad-leaved arrowhead	May be At Risk	-	S2	N5	G5	ponds, lakes, ditches
Salicornia rubra emergent marsh	samphire emergent marsh	N/A	N/A	S2	NNR	G2G3	sparsely vegetated
Salix drummondiana / Scirpus microcarpus - Calamagrostis canadensis	Drummond's willow / small-fruited bulrush - bluejoint	N/A	N/A	S1	NNR	N/A	shrubland
Salix sitchensis	Sitka willow	May be At Risk	-	S1	NNR	G5	alluvial soil on the Athabasca River flood plain
Scirpus pallidus	pale bulrush	May be At Risk	-	S1	NNR	G5	marshes and wet meadows
Sisyrinchium septentrionale	pale blue-eyed grass	Sensitive	-	S3	N3N4	G3G4	moist meadows, grassy stream banks
Sparganium glomeratum	bur-reed	May be At Risk	-	S1	N2	G4?	cool lakes, ponds and slow streams
Sparganium hyperboreum	northern bur-reed	Sensitive	-	S1	NNR	G5	alpine lakes, in shallow water
Spartina pectinata	prairie cord grass	May be At Risk	-	S1	NNR	G5	saline shores and marshes
Spergularia salina	salt-marsh sand spurry	May be At Risk	-	S2S3	N5?	G5	mud flats, alkaline fields, sandy river bottoms
Sphenopholis obtusata	prairie wedge grass	May be At Risk	-	S2	NNR	G5	moist sites in meadows and open woods
Spiranthes lacera	northern slender ladies'-tresses	May be At Risk	-	S1	N5	G5	dry, rocky, open woods and grassy areas
Stellaria crispa	wavy-leaved chickweed	May be At Risk		S2	NNR	G5	moist montane woods
Streptopus roseus	rose mandarin	May be At Risk	-	S1	N5	G5	moist coniferous woods and stream banks
Symphoricarpos albus - Amelanchier alnifolia shrubland	snowberry - saskatoon shrubby slope	N/A	N/A	S2?	NNR	N/A	shrubland
Trichophorum clintonii	Clinton's bulrush	May be At Risk	-	S1	NNR	G4	fens
Triglochin maritima - Carex praegracilis spring fen	seaside arrow-grass - graceful sedge spring fen	N/A	N/A	S1S2	NNR	N/A	herbaceous
Viola pallens	Macloskey's violet	Sensitive	-	S2S3	NNR	G5T5	moist woods, coniferous stands and bogs
Wolffia columbiana	watermeal	Sensitive	-	S2	NNR	G5	beaver ponds in hummocky moraines.

[1]GSAWS - General Status of Alberta Wild Species 2010 (Government of Alberta 2010b)
[2]SARA - Species At Risk Act (Government of Canada 2002)
[3]SRank - Subnational Conservation Status Rank.
[4]NRank - National Conservation Status Rank
[5]GRank - Global Conservation Status Rank
[6] Rare Vascular Plants of Alberta (Kershaw et al. 2001)
[7]Flora of Alberta (Moss 1959)
[8]Plant of the Western Forest: Alberta, Saskatchewan, and Manitoba Boreal and Aspen Parkland (Johnson et al. 1995

Rank	Definition
S1	Known from five or fewer occurrences or especially vulnerable to extirpation because of other factor(s).
S2	Known from twenty or fewer occurrences or vulnerable to extirpation because of other factors.
S3	Known from 100 or fewer occurrences, or somewhat vulnerable due to other factors, such as restricted range, relatively small population sizes, or other factors.
S#S#	A numeric range rank is used to indicate any range of uncertainty about the status of the taxon. Example - S2S3 or S1S3.
SU	Taxon is currently unrankable due to lack of information or substantially conflicting information. Example - native versus non-native status not resolved.
S#?	Inexact numeric rank. Applied when a specific rank is most likely appropriate but for which some conflicting information or unresolved questions remain. Example - S2? believed to be 6 - 20 occurrences but some uncertainty.

(Government of Alberta 2014)

Table 4 - Wildlife Species of Management Concern

Common Name	Scientific Name	GSAWS[1]	FWMIS[2]	ESCC[3]	AWA[4]	COSEWIC[5]	SARA[6]	ESRD Recommended Setback (m)[7]	CWS Recommended Setback (m)[8]	Setback Timing	Habitat
Birds											
American White Pelican	*Pelecanus erythrorhynchos*	Sensitive	-	-	-	Not at Risk	-	-	-	-	Wetland/Lake/River
Black-backed Woodpecker	*Picoides arcticus*	Sensitive	-	-	-	-	-	-	-	-	Forest
Horned Grebe	*Podiceps auritus*	Sensitive	-	-	-	Special Concern	-	200-500	100	April 1 to August 31	Wetland
Pied-billed Grebe	*Podilymbus podiceps*	Sensitive	-	-	-	-	-	100	-	April 15 to July 31	Wetland
Pileated Woodpecker	*Dryocopus pileatus*	Sensitive	-	-	-	-	-	100	-	April 1 to July 15	Forest
Sharp-tailed Grouse	*Tympanuchus phasianellus*	Sensitive	-	-	-	-	-	-	-	-	Grassland/Agriculture
Sora	*Porzana carolina*	Sensitive	-	-	-	-	-	-	-	-	Wetland
Yellow Rail	*Coturnicops noveboracensis*	Undetermined	-	-	-	Special Concern	Special Concern	-	100-350	May 1 to Jul 15	Wetland
American Bittern	*Botaurus lentiginosus*	Sensitive	-	-	-	-	-	-	-	-	Wetland
American Kestrel	*Falco sparverius*	Sensitive	-	-	-	-	-	-	-	-	Grassland/Agriculture
Bald Eagle	*Haliaeetus leucocephalus*	Sensitive	Yes	-	-	-	-	50-1000	-	Year Round (nesting site)	Forest/Shoreline
Baltimore Oriole	*Icterus galbula*	Sensitive	-	-	-	-	-	-	-	-	Forest
Bank Swallow	*Riparia riparia*	Secure	-	-	-	Threatened	-	-	-	-	Shoreline/Open Habitat
Barn Swallow	*Hirundo rustica*	Sensitive	-	-	-	Threatened	-	-	100	May 1 to Aug 31	Open Habitat/Anthropogenic Habitat
Barred Owl	*Strix varia*	Sensitive	Yes	Special Concern	-	-	-	100-500	-	Year Round (nesting site)	Forest
Bay-breasted Warbler	*Setophaga castanea*	Sensitive	Yes	Recommended Special Concern	-	-	-	-	-	-	Forest
Black Tern	*Chlidonias niger*	Sensitive	-	-	-	Not at Risk	-	200-1000	-	Year Round (nesting site)	Wetland
Black-throated Green Warbler	*Setophaga virens*	Sensitive	Yes	Special Concern	-	-	-	-	-	-	Forest
Brown Creeper	*Certhia americana*	Sensitive	-	-	-	-	-	-	-	-	Forest
Canada Warbler	*Cardellina canadensis*	Sensitive	Yes	-	-	Threatened	Threatened	-	50-300	May 1 to Jul 31	Forest
Cape May Warbler	*Setophaga tigrina*	Sensitive	Yes	Recommended Special Concern	-	-	-	-	-	-	Forest
Common Nighthawk	*Chordeiles minor*	Sensitive	-	-	-	Threatened	Threatened	-	50-200	May 1 to Aug 31	Open Habitat/Anthropogenic Habitat
Common Yellowthroat	*Geothlypis trichas*	Sensitive	Yes	-	-	-	-	-	-	-	Wetland/Shrubland
Eastern Phoebe	*Sayornis phoebe*	Sensitive	-	-	-	-	-	-	-	-	Forest/Anthropogenic Habitat
Golden Eagle	*Aquila chrysaetos*	Sensitive	-	-	-	-	-	50-1000	-	Year Round (nesting site)	Grassland/Tundra/Agriculture
Great Blue Heron	*Ardea herodias*	Sensitive	Yes	-	-	-	-	-	-	-	Wetland
Great Grey Owl	*Strix nebulosa*	Sensitive	Yes	-	-	-	-	-	-	-	Forest/Edge
Least Flycatcher	*Empidonax minimus*	Sensitive	Yes	-	-	-	-	-	-	-	Forest
Lesser Scaup	*Aythya affinis*	Sensitive	-	-	-	-	-	-	-	-	Wetland/Lake
Northern Goshawk	*Accipiter gentilis*	Sensitive	Yes	-	-	-	-	200-500	-	Year Round (nesting site)	Forest
Northern Harrier	*Circus cyaneus*	Sensitive	-	-	-	-	-	-	-	-	Grassland/Wetland
Northern Pintail	*Anas acuta*	Sensitive	-	-	-	-	-	-	-	-	Wetland
Olive-sided Flycatcher	*Contopus cooperi*	Sensitive	-	-	-	Threatened	Threatened	-	50-150	May 1 to Aug 31	Wetland/Edge
Osprey	*Pandion haliaetus*	Sensitive	Yes	-	-	-	-	200-750	-	Year Round (nesting site)	Lake/River
Rusty Blackbird	*Euphagus carolinus*	Sensitive	-	-	-	Special Concern	Special Concern	-	50-100	May 1 to Jul 31	Forest/Wetland
Sandhill Crane	*Grus canadensis*	Sensitive	Yes	-	-	-	-	-	-		Wetland/Agriculture
Short-eared Owl	*Asio flammeus*	May Be At Risk	-	-	-	Special Concern	Special Concern	-	100-200	Apr 1 to Jul 31	Open Habitat
Western Tanager	*Piranga ludoviciana*	Sensitive	Yes	-	-	-	-	-	-	-	Forest/Open Habitat
White-winged Scoter	*Melanitta fusca*	Sensitive	Yes	Special Concern	-	-	-	-	-	-	Coastline/Lake
Whooping Crane	*Grus americana*	At Risk	-	Endangered	Endangered	Endangered	Endangered	-	500-1000	May 1 to Nov 1	Wetland/Open Habitat
Western Wood-Pewee	*Contopus sordidulus*	Sensitive	-	-	-	-	-	-	-	-	Forest/Edge
Amphibians											
Canadian Toad	*Anaxyrus hemiophrys*	May Be At Risk	Yes	-	-	-		100	-	-	Wetlands, forests
Mammals											
American Bison	*Bos bison*	At risk	-	-	Endangered	Threatened	-	-	-	-	Grassland/Forest
Canadian Lynx	*Lynx canadensis*	Sensitive	Yes	-	-	Not at Risk	-	-	-	-	Forest
Caribou	*Rangifer tarandus*	At risk	-	-	Threatened	Threatened	-	-	-	-	Forest/Tundra
Fisher	*Martes pennanti*	Sensitive	Yes	-	-	-	-	-	-	-	Forest
Hoary Bat	*Lasiurus cinereus*	Sensitive	-	-	-	-	-	-	-	-	Forest/Edge
Wolverine	*Gulo gulo*	May Be At Risk	Yes	-	-	Special Concern	-	-	0-500	-	Forest

Notes

[1]GSAWS - General Status of Alberta Wild Species 2010 (Government of Alberta 2010).
[2]FWMIS - Fisheries and Wildlife Information Management System (Government of Alberta 2014).
[3]ESCC - Endangered Species Conservation Committee (Government of Alberta 2012a).
[4]AWA - Alberta *Wildlife Act* (Province of Alberta 2000).
[5]COSEWIC - Committee on the Status of Endangered Wildlife in Canada (Government of Canada 2014).
[6]SARA - *Species At Risk Act* (Government of Canada 2002).
[7]ESRD - Alberta Environment and Sustainable Resource Development (Government of Alberta 2013b).
[8]CWS - Canadian Wildlife Service - Environment Canada

Table 5 - Fish Species Recorded in the Hangingstone River Basin

Fish Species	Scientific Name	Conservation Status
Arctic Grayling	*Thymallus arcticus*	Sensitive
Brook Stickleback	*Culaea inconstans*	
Burbot	*Lota lota*	
Fathead Minnow	*Pimephales promelus*	
Flathead Chub	*Platygobio gracilus*	
Finescale Dace	*Phoxinus neogaeus*	
Goldeye	*Hiodon alosoides*	
Lake Chub	*Couesius plumbeus*	
Longnose Dace	*Rhinichthys cataractae*	
Longnose Sucker	*Catostomus catostomus*	
Mountain Whitefish	*Prosopium williamsoni*	
Ninespine Stickleback	*Pungitius pungitius*	
Northern Redbelly Dace	*Phoxinus Eos*	Sensitive
Northern Pike	*Esox lucius*	
Pearl Dace	*Margariscus margarita*	
Slimy Sculpin	*Cottus cognatus*	
Spoonhead Sculpin	*Cottus ricei*	May Be At Risk
Trout-Perch	*Percopsis omiscomaycus*	
Walleye	*Sander vitreum*	
White Sucker	*Catostomus commersoni*	
Yellow Perch	*Perca flavescens*	

Table 6 - Land Use Summary for Existing and Future Conditions

Existing Conditions (2015)			
Watershed	**Area**	**Existing Urban**	**Existing Non-urban Developed****
Hangingston River*	964 km^2	7.8 km^2 (0.8 %)	45.2 km^2 (4.7 %)
Saline Creek	137 km^2	1.5 km^2 (1.1 %)	4.0 km^2 (2.9 %)

Future Conditions			
Watershed	**Area**	**Future Urban*****	**Future Oil and Gas******
Hangingston River*	964 km^2	27.3 km^2 (2.8 %)	213.8 km^2 (22 %)
Saline Creek	137 km^2	12.4 km^2 (9.1 %)	3.4 km^2 (2.5 %)

Notes:

* Excludes 2 km^2 at mouth of Hangingstone River.
** Much (but not all) of the existing non-urban developent is within the footprints of future urban and oil and gas areas
*** Future urban area boundary includes the existing urban area
**** Oil and gas development will be phased, with only a portion of the total lease areas being disturbed at a given time.

Table 7 - Rainfall Records for June 2013 Flood Event

	Daily Precipitation Amounts, mm				Flood Occurrence
Date	RAMP S31	RAMP C5	Fort Mcmurray CS	Fort Mcmurray A	
1-Jun-13	1.9	0.2	5.2	5.8	
2-Jun-13	0	2.8	0.4	0.3	
3-Jun-13	0	0.3	0	0	
4-Jun-13	0	0.3	0	0	
5-Jun-13	18.8	8.4	2.6	3.3	
6-Jun-13	9.9	8.4	12.3	12.3	
7-Jun-13	2.1	4.6	2.9	3	
8-Jun-13	**8.9**	**47.8**	**34.5**	**35.3**	
9-Jun-13	**3.1**	**49.1**	**38.9**	**40.1**	Hwy 63 shut down
10-Jun-13	**0.2**	**25.3**	**3.4**	**4.1**	WSC Hangingstone Gauge Failure
11-Jun-13	0	0	5.6	6.4	Hangingstone Peak WL @ 6:15
12-Jun-13	0.7	24.6	0.7	0.8	
13-Jun-13	0.3	2.8	8.3	8.5	
14-Jun-13	0	0.7	0.2	0	
15-Jun-13	0	15.1	8.2	8.6	Hwy 881 washout

Event Maximum Accumulation Amounts, mm

	RAMP S31	RAMP C5	Fort Mcmurray CS	Fort Mcmurray A
1-day	18.8	49.1	38.9	40.1
2-day	28.7	96.9	73.4	75.4
3-day	30.8	122.2	76.8	79.5
4-day	39.7	126.8	88.6	85.9
5-day	42.8	135.2	92	94.8
6-day	43	143.6	97.6	101.2
7-day	43	143.9	100.2	104.5

Notes: Station locations shown on Figure 1.
Bold font identifies the three days with heavy rain preceeding the peak flow on June 11

Table 8 - Hangingstone River Peak Flow Frequency Results

Log-Pearson type 3 (Method of moments (BOB), base = 10)
49 observations, 1965-2013

Parameters

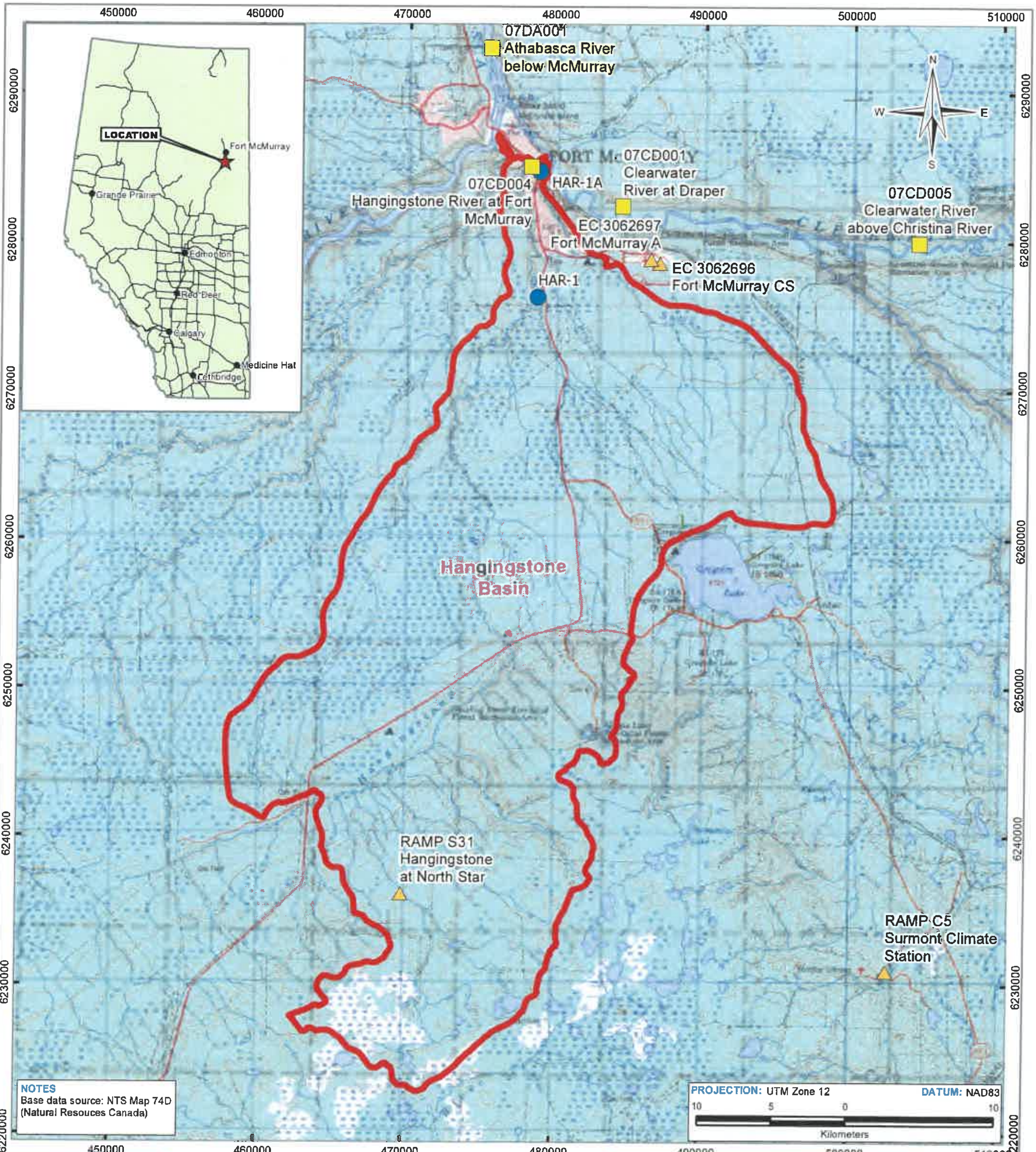
alpha -16.412707
lambda 32.317862
m 3.517472

Quantiles

Return Period	Non-Exceedance	Discharge	95% Confidence
Years (T)	Probability	m^3/s	Interval
10000	0.9999	378	N/D
2000	0.9995	308	N/D
1000	0.999	279	N/D
500	0.998	249	N/D
200	0.995	212	N/D
100	0.99	184	N/D
50	0.98	156	94.4 - 218
20	0.95	121	84.1 - 158
10	0.9	95	67.9 - 122
5	0.8	69.9	50 - 89.7
3	0.6667	51.8	38 - 65.6
2	0.5	37	28 - 46.1
1.4286	0.3	24.1	16.9 - 31.3
1.25	0.2	18.4	10.6 - 26.2
1.1111	0.1	12.4	3.65 - 21.2
1.0526	0.05	8.83	-0.141 - 17.8
1.0204	0.02	5.94	-2.63 - 14.5
1.0101	0.01	4.51	N/D
1.005	0.005	3.49	N/D
1.001	0.001	2.01	N/D
1.0005	0.0005	1.61	N/D
1.0001	0.0001	0.984	-2.98 - 4.94

FIGURES

Note – Figures that accompany the pdf version of this report are provided at low resolution to reduce file size. At full resolution, many of the individual figures, especially those with orthophoto bases, are 6 MB or larger. Full resolution figures are available upon request.



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LEGEND

- Water Quality Monitoring Site
- Climate Station
- Active Water Survey of Canada Streamflow Station
- Hangingstone Basin Boundary

Base Map: National Topographic System 1:250,000 scale. Map 74D, Fort McMurray. Published in 1993, based on information current as of 1977 and checked against satellite imagery obtained in 1987.

HANGINGSTONE RIVER BASIN STUDY

Basin Location Plan and Data Stations

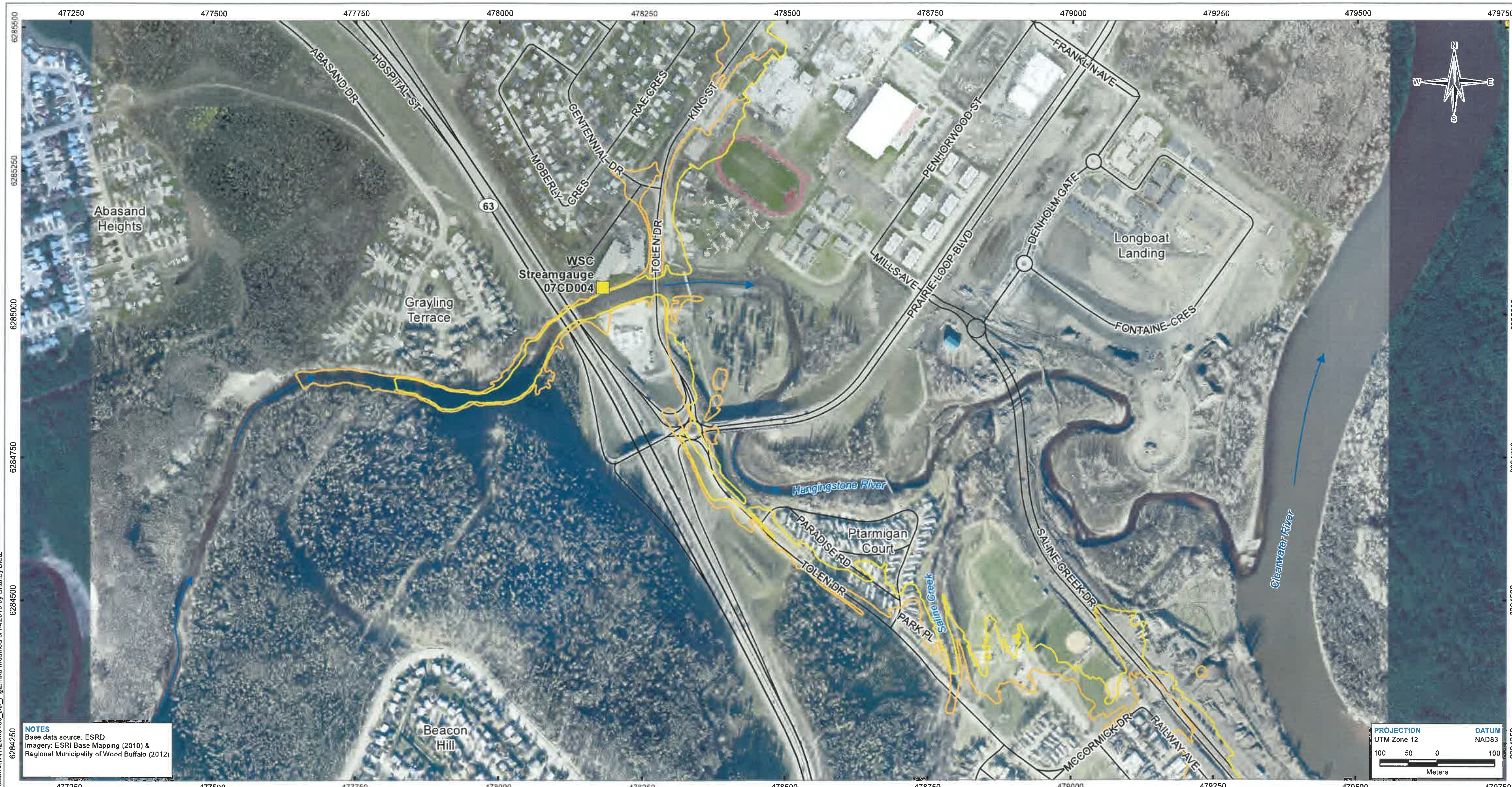
TETRA TECH EBA

CLIENT: Regional Municipality of Wood Buffalo

PROJECT NO.	DWN	CKD	APVD	REV
ENVH2O03100-01	BB	MS	BR	0

OFFICE	DATE
Tt EBA-CAL	May 4, 2015

Figure 1



LEGEND

- Streamgauge
- ESRD Floodway
- ESRD Flood Fringe (follows 250.0 m elevation contour)
- Flow Direction
- Road
- Highway

HANGINGSTONE RIVER BASIN STUDY

Lower Hangingstone Location Plan and ESRD Flood Hazard Area

TETRA TECH EBA

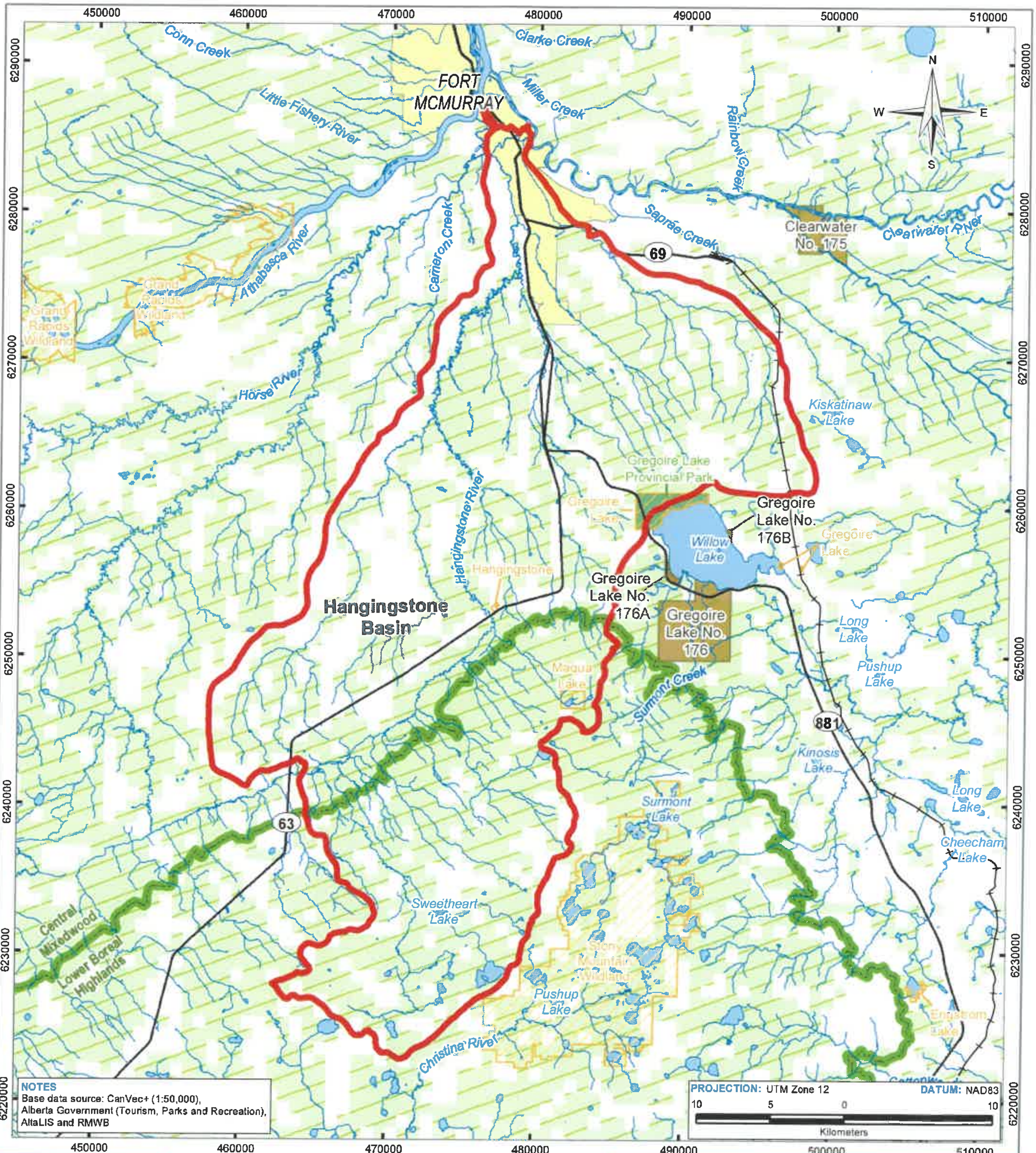
CLIENT: Regional Municipality of Wood Buffalo

PROJECT NO.	DWN	CKD	APVD	REV
ENVH2O03100	BB	MS	BR	0

OFFICE	DATE
Tt EBA-CAL	May 13, 2015

Figure 2

M:\ENVIRONMENTAL\H2O\H2O03100\Maps\031\Basin Description\ENVH2O03100_BD_Fig2.mxd modified 5/14/2015 by Brittney.Bietz



LEGEND

- Hangingstone Basin Boundary
- Railway
- Highway
- First Nations Reserve
- Urban Area
- Provincial Park
- Protected Area
- Environmentally Significant
- Natural Region Boundary
- Watercourses
- Waterbody

HANGINGSTONE RIVER BASIN STUDY

Natural Regions and Environmentally Significant Areas

TETRA TECH EBA

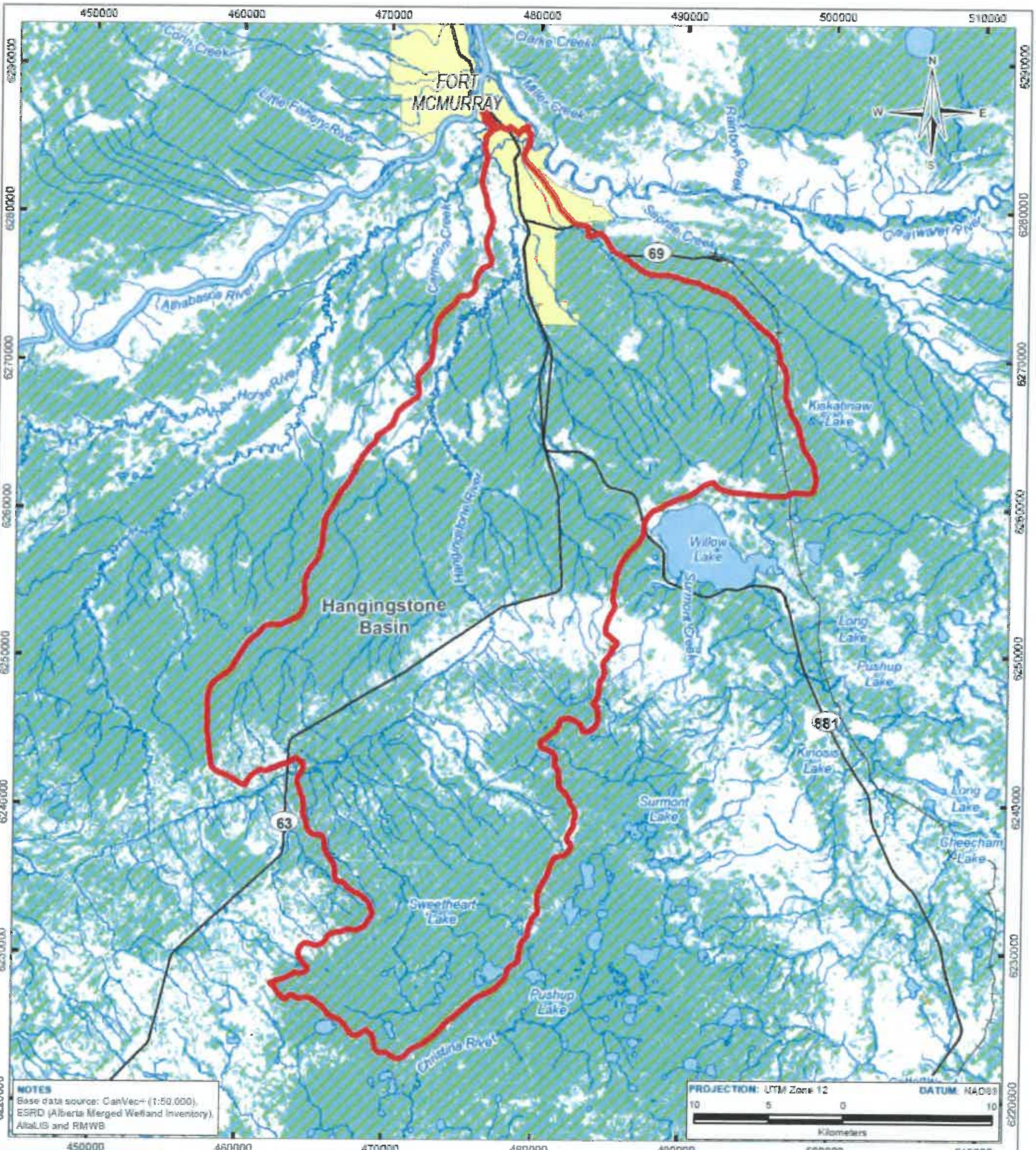
CLIENT: Regional Municipality of Wood Buffalo

PROJECT NO.	DWN	CKD	APVD	REV
ENVH2O03100-01	BB	MS	BR	0

OFFICE	DATE
Tt EBA-CAL	May 8, 2015

Figure 3

M:\ENVIRONMENTAL\H2O\H2O03100\Maps\003\Basin Description\ENVH2O03100_BD_Fig3.mxd modified 5/8/2015 by Brittney.Bietz



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LEGEND

- Hangingstone Basin Boundary
- Railway
- Highway
- Urban Area
- Watercourses
- Waterbody
- Wetland

HANGINGSTONE RIVER BASIN STUDY

Wetlands

TETRA TECH EBA

CLIENT: Regional Municipality of Wood Buffalo

PROJECT NO.	DWN	CKD	APVD	REV
ENVH2O03100-01	BB	MS	BR	0

OFFICE	DATE
TtEBA-CAL	April 24, 2015

Figure 4

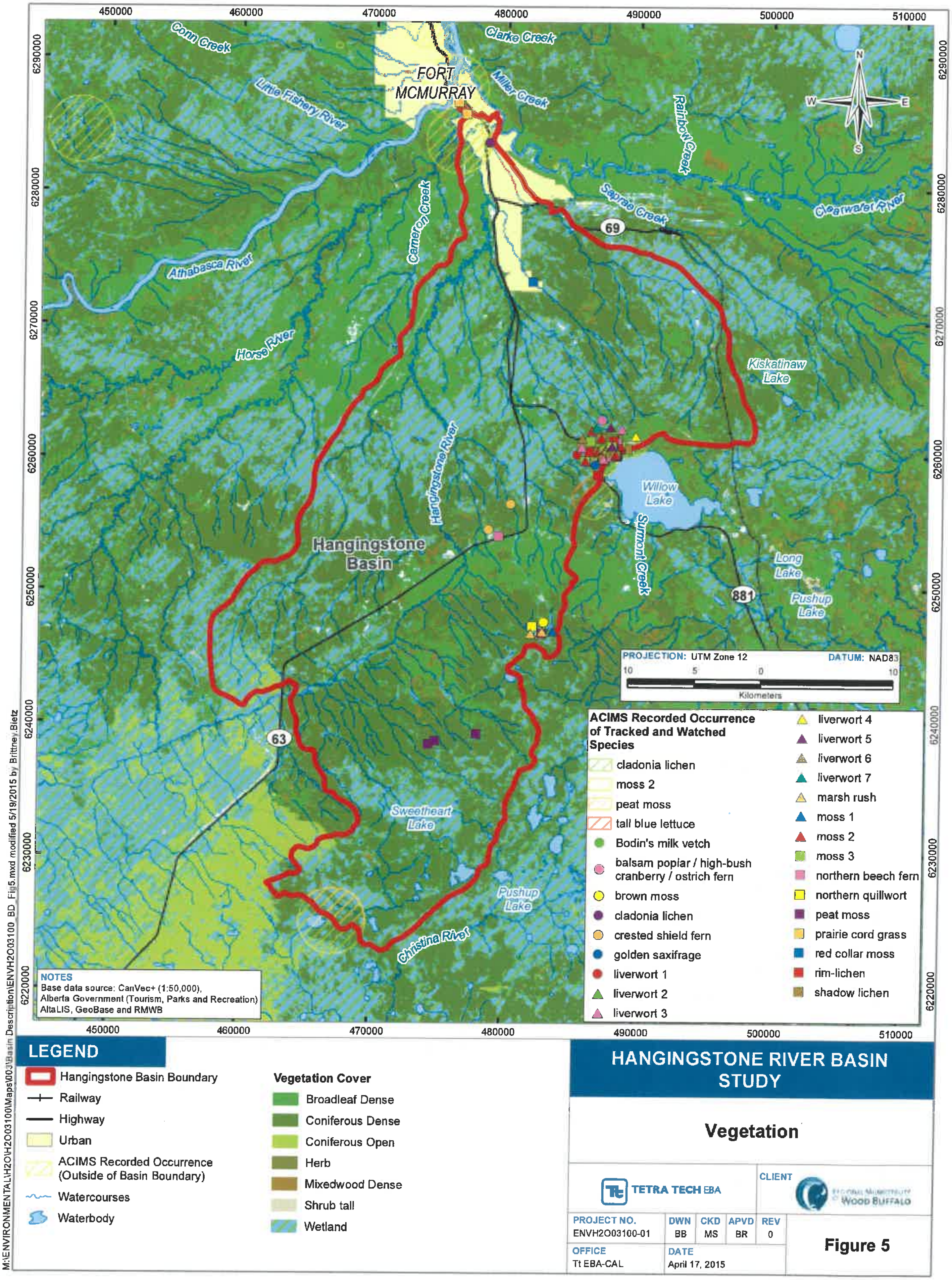
HANGINGSTONE RIVER BASIN STUDY
Vegetation
FORT MCMURRAY
Hangingstone Basin
Conn Creek
Clarke Creek
Miller Creek
Little Fishery River
Rainbow Creek
Saprae Creek
Clearwater River
Athabasca River
Cameron Creek
Horse River
Kiskatinaw Lake
Hangingstone River
Willow Lake
Surmont Creek
Long Lake
Pushup Lake
Sweetheart Lake
Christina River
69
63
881
PROJECTION: UTM Zone 12
DATUM: NAD83
10 5 0 10
Kilometers
ACIMS Recorded Occurrence of Tracked and Watched Species
cladonia lichen
moss 2
peat moss
tall blue lettuce
Bodin's milk vetch
balsam poplar / high-bush cranberry / ostrich fern
brown moss
cladonia lichen
crested shield fern
golden saxifrage
liverwort 1
liverwort 2
liverwort 3
liverwort 4
liverwort 5
liverwort 6
liverwort 7
marsh rush
moss 1
moss 2
moss 3
northern beech fern
northern quillwort
peat moss
prairie cord grass
red collar moss
rim-lichen
shadow lichen
NOTES
Base data source: CanVec+ (1:50,000), Alberta Government (Tourism, Parks and Recreation) AltaLIS, GeoBase and RMWB
LEGEND
Hangingstone Basin Boundary
Railway
Highway
Urban
ACIMS Recorded Occurrence (Outside of Basin Boundary)
Watercourses
Waterbody
Vegetation Cover
Broadleaf Dense
Coniferous Dense
Coniferous Open
Herb
Mixedwood Dense
Shrub tall
Wetland
TETRA TECH EBA
CLIENT
PROJECT NO. ENVH2O03100-01
DWN BB
CKD MS
APVD BR
REV 0
OFFICE Tt EBA-CAL
DATE April 17, 2015
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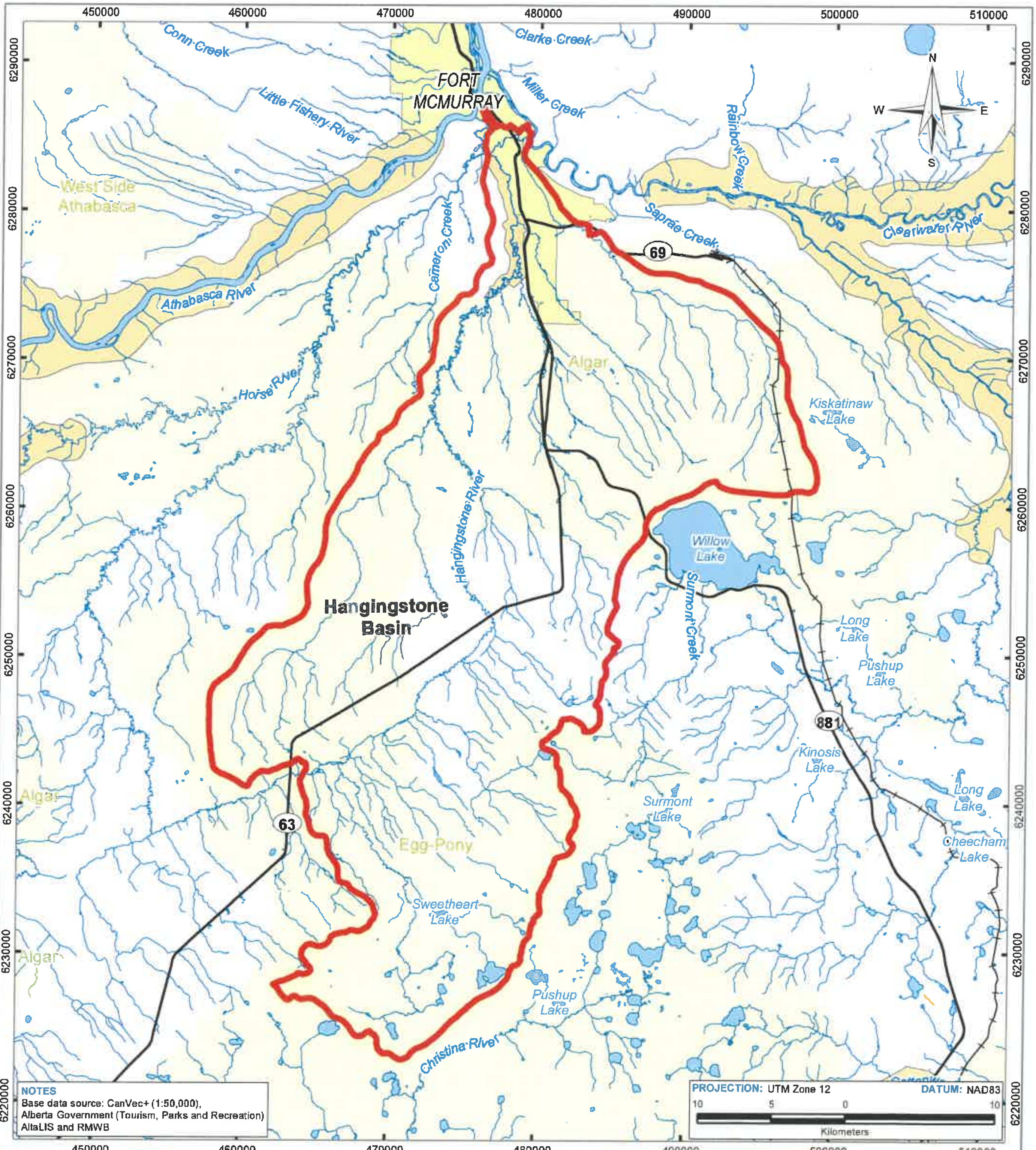
Figure 5



LEGEND

- Hangingstone Basin Boundary
- Railway
- Highway
- Urban Area
- Key Wildlife and Biodiversity Zone
- CaribouRange
- Watercourses
- Waterbody

HANGINGSTONE RIVER BASIN STUDY

Wildlife Zones and Ranges

TETRA TECH EBA

CLIENT: Regional Municipality of Wood Buffalo

PROJECT NO.	DWN	CKD	APVD	REV
ENVH2O03100-01	BB	MS	BR	0

OFFICE	DATE
Tt EBA-CAL	April 17, 2015

Figure 6

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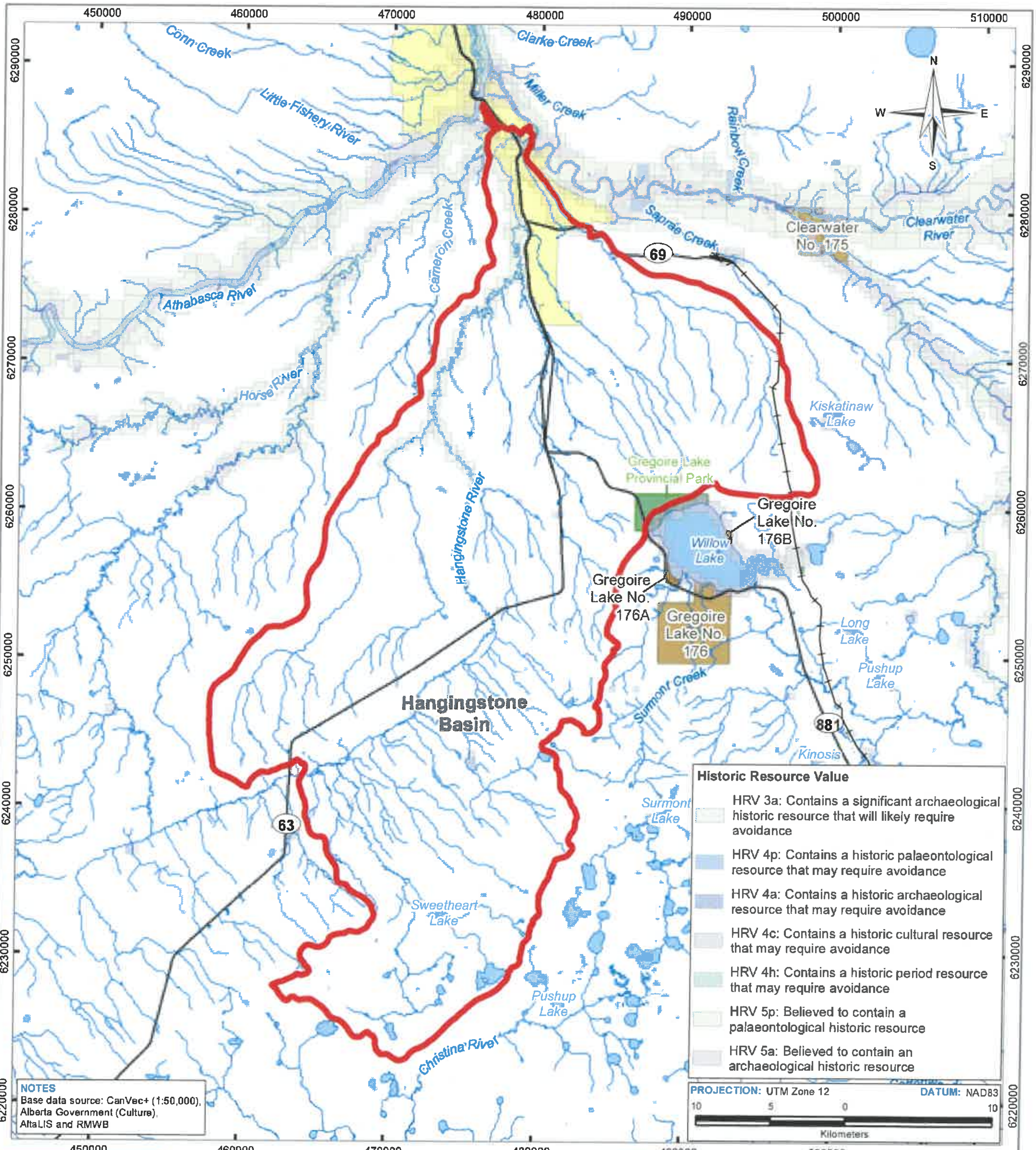


M:\ENVIRONMENTAL\H2OH2O03100\Maps\003Basin Description\ENVH2O03100_BD_Fig7.mxd modified 5/8/2015 by Brittney.Bietz

LEGEND

- Hangingstone Basin Boundary
- Railway
- Highway
- Urban Area
- First Nations Reserve
- Provincial Park
- Watercourses
- Waterbody

HANGINGSTONE RIVER BASIN STUDY

Historic Resources

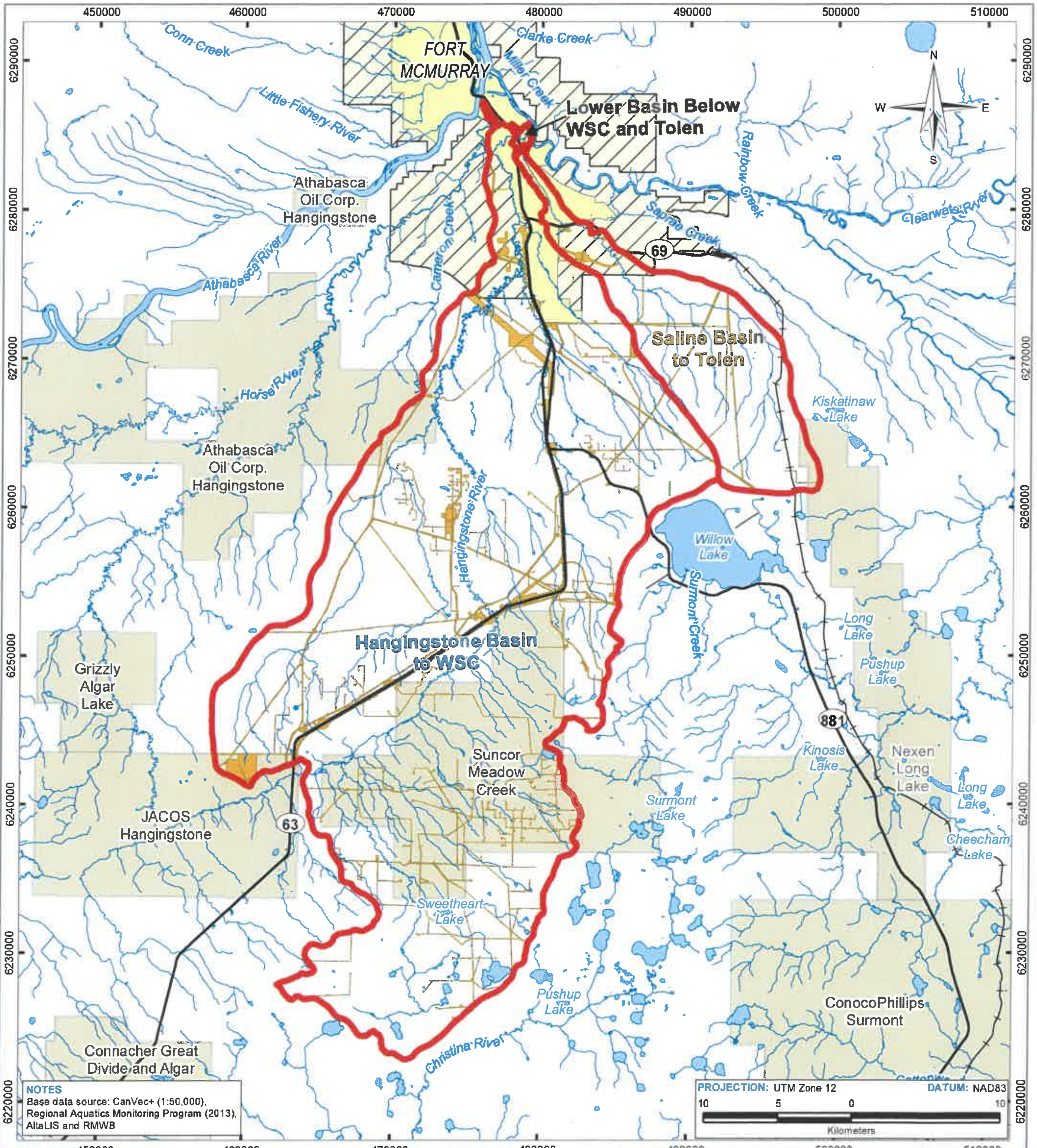
TETRA TECH EBA

CLIENT: Regional Municipality of Wood Buffalo

PROJECT NO.	DWN	CKD	APVD	REV
ENVH2O03100-01	BB	MS	BR	0

OFFICE	DATE
Tt EBA-CAL	April 24, 2015

Figure 7



LEGEND

- Hangingstone Basin Boundary
- Railway
- Highway
- Urban Area
- Urban Development Sub-Region, allocated land from the province to accommodate new residential, commercial, and light industrial growth.
- Oil Sands Lease
- Dispositions
- Watercourses
- Waterbody

HANGINGSTONE RIVER BASIN STUDY

Existing and Proposed Development

TETRA TECH EBA

CLIENT: Regional Municipality of Wood Buffalo

PROJECT NO.	DWN	CKD	APVD	REV
ENVH2O03100-01	BB	MS	BR	0

OFFICE	DATE
Tt EBA-CAL	May 21, 2015

Figure 8

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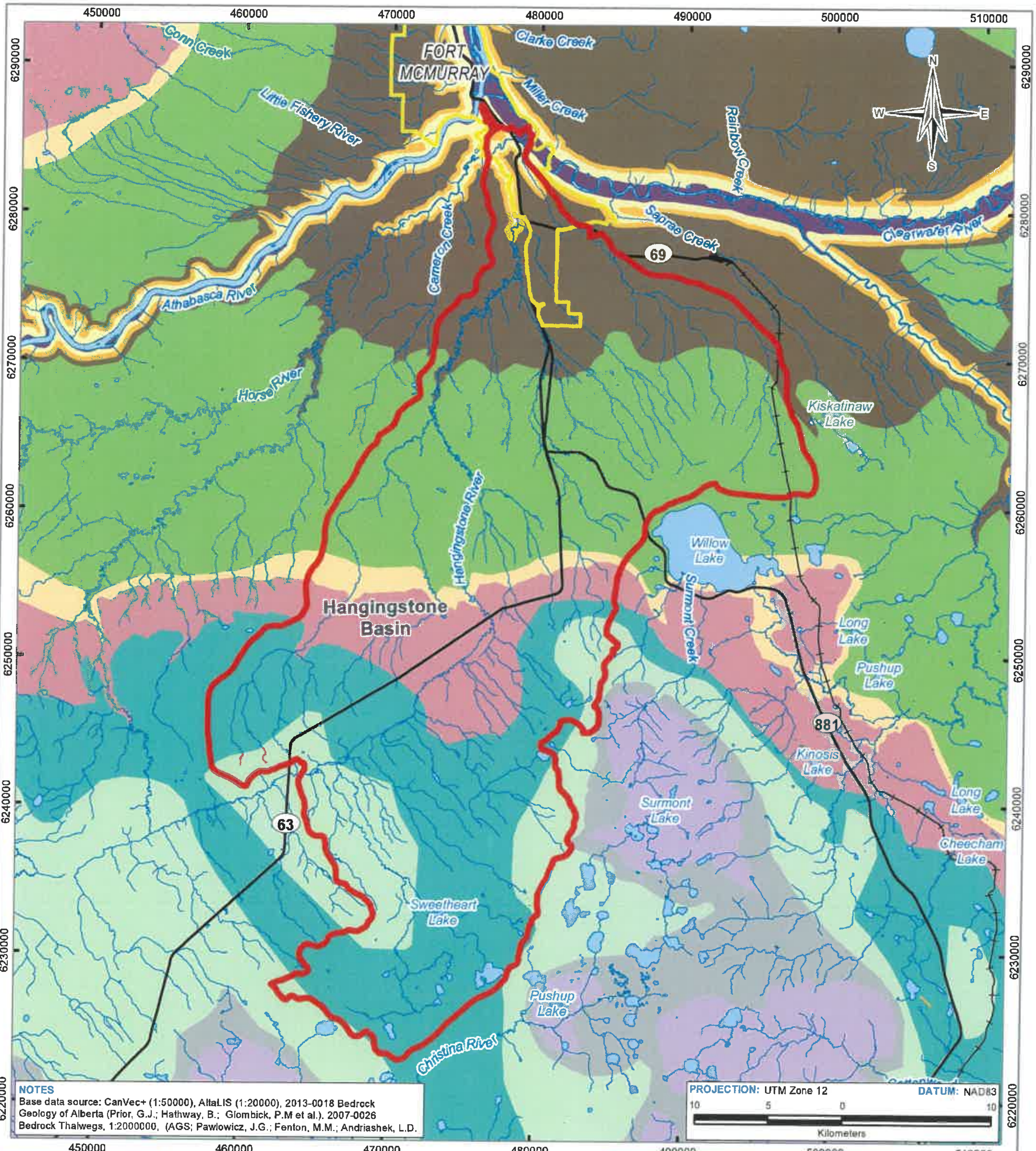

LEGEND

- Hangingstone Basin Boundary
- Railway
- Highway
- Urban Area
- Watercourses
- Waterbody

Bedrock Geology

- Clearwater Formation
- Fish Scales and Belle Fourche Formations
- Grand Rapids Formation
- Joli Fou Formation
- Lea Park Formation
- McMurray Formation
- Pelican Formation
- Second White Specks, Carlile, and Niobrara Formations
- Wabiskaw Member
- Waterways Formation
- Westgate Formation

HANGINGSTONE RIVER BASIN STUDY

Bedrock Geology

TETRA TECH EBA

CLIENT: Regional Municipality of Wood Buffalo

PROJECT NO.	DWN	CKD	APVD	REV
ENVH2O03100-01	BB	MS	BR	0

OFFICE	DATE
Tt EBA-CAL	May 8, 2015

Figure 9

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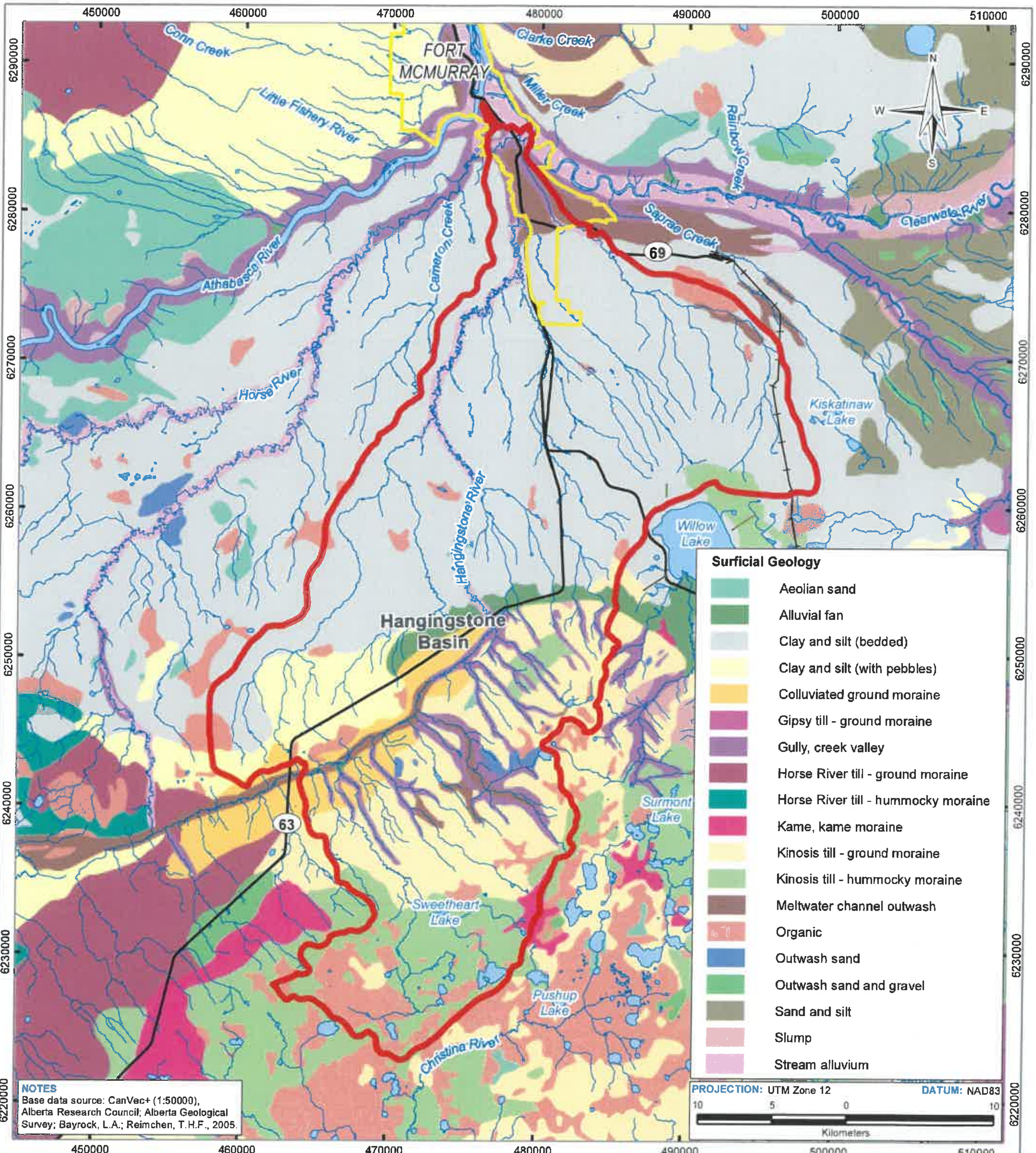

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LEGEND

- Hangingstone Basin Boundary
- Railway
- Highway
- Urban Area
- Watercourses
- Waterbody

HANGINGSTONE RIVER BASIN STUDY

Surficial Geology

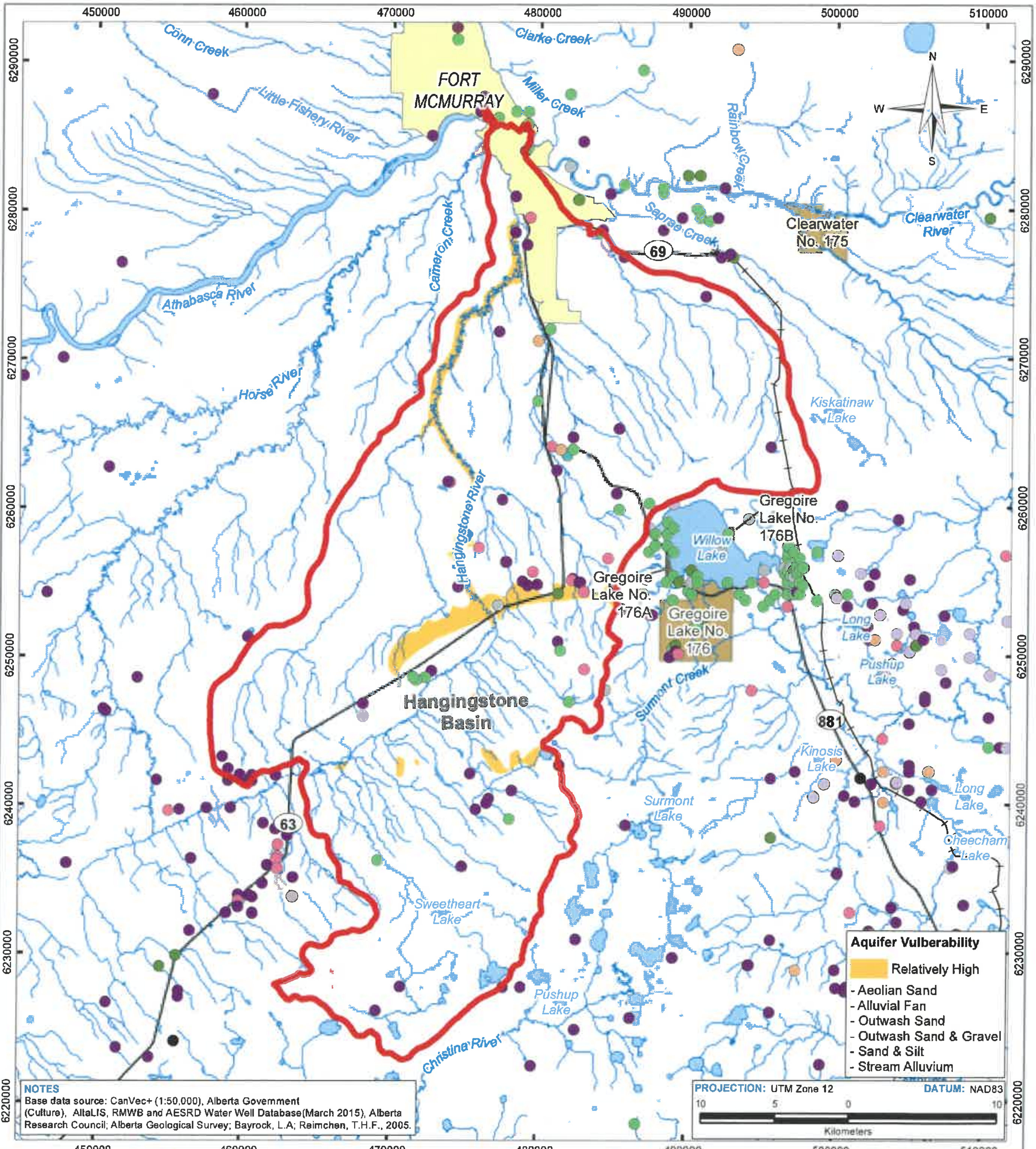
TETRA TECH EBA

CLIENT: Regional Municipality of Wood Buffalo

PROJECT NO.	DWN	CKD	APVD	REV
ENVH2O03100-01	BB	MS	BR	0

OFFICE	DATE
Tt EBA-CAL	May 8, 2015

Figure 10



LEGEND

- Hangingstone Basin Boundary
- Railway
- Highway
- Urban Area
- First Nations Reserve
- Watercourses
- Waterbody

Well Use Allocation

- Commercial
- Domestic
- Domestic & Industrial
- Domestic & Stock
- Industrial
- Industrial Camp
- Injection
- Investigation
- Monitoring
- Municipal
- Observation
- Other
- Stock
- Unknown

HANGINGSTONE RIVER BASIN STUDY

Water Wells

TETRA TECH EBA

CLIENT: Regional Municipality of Wood Buffalo

PROJECT NO.	DWN	CKD	APVD	REV
ENVH2O03100-01	BB	MS	BR	0

OFFICE	DATE
Tt EBA-CAL	April 24, 2015

Figure 11

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LEGEND

- Streamgauge
- Pre-flood Edge of Bank
- Flow Direction
- Road
- Highway

HANGINGSTONE RIVER BASIN STUDY

Lower Hanginstone
2013 Flood Damage Locations

TETRA TECH EBA

CLIENT: Regional Municipality of Wood Buffalo

PROJECT NO.	DWN	CKD	APVD	REV
ENVH2O03100	BB	MS	BR	0

OFFICE	DATE
Tt EBA-CAL	May 13, 2015

Figure 12

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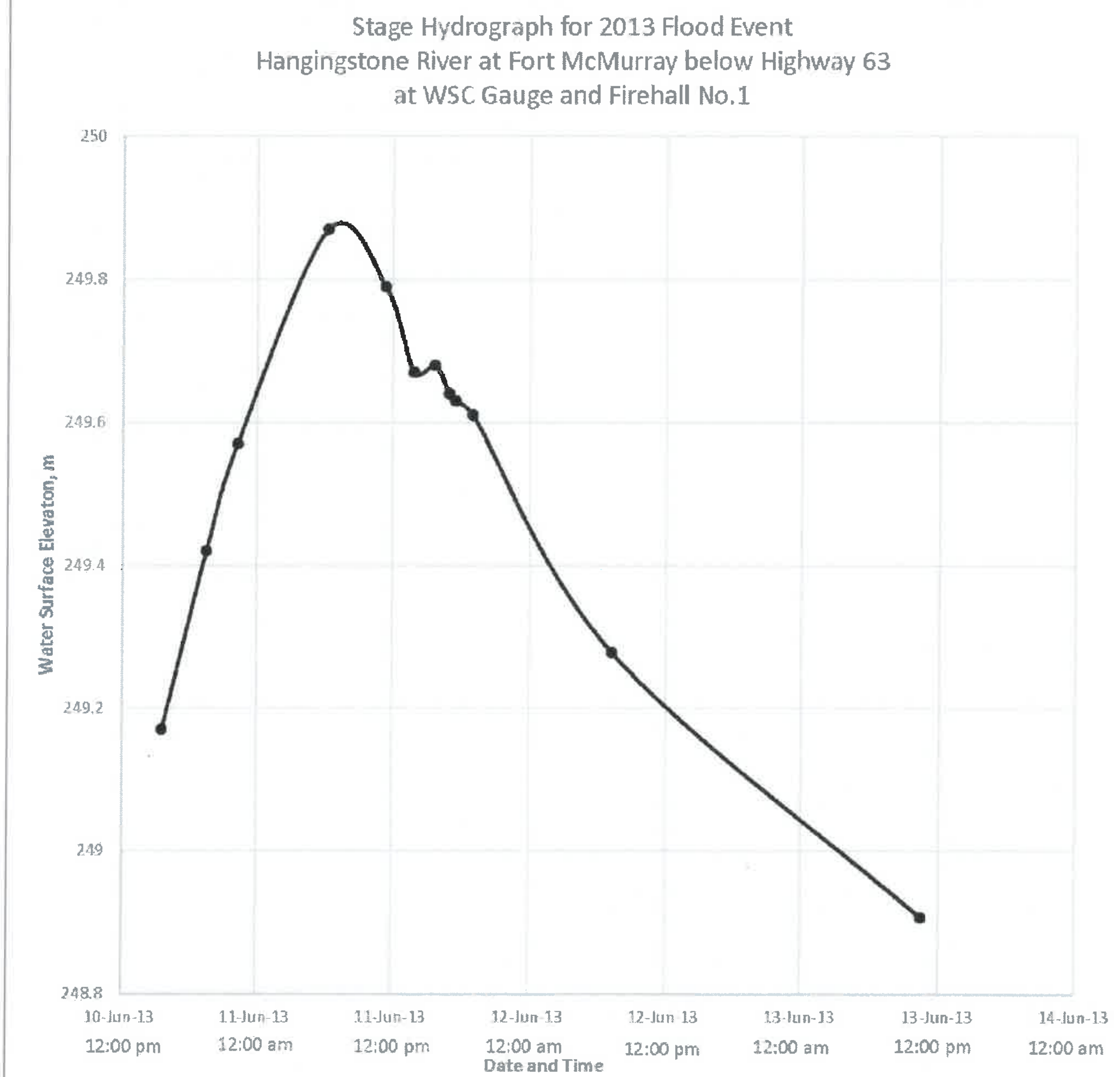

LEGEND

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HANGINGSTONE RIVER BASIN STUDY

2013 Flood Stage Hydrograph
Hangingstone River at Fort McMurray

TETRA TECH EBA

CLIENT: Regional Municipality of Wood Buffalo

PROJECT NO.	DWN	CKD	APVD	REV
ENVH2O03100-01	BB	MS	BR	0

OFFICE	DATE
Tt EBA-CAL	May 20, 2015

Figure 13

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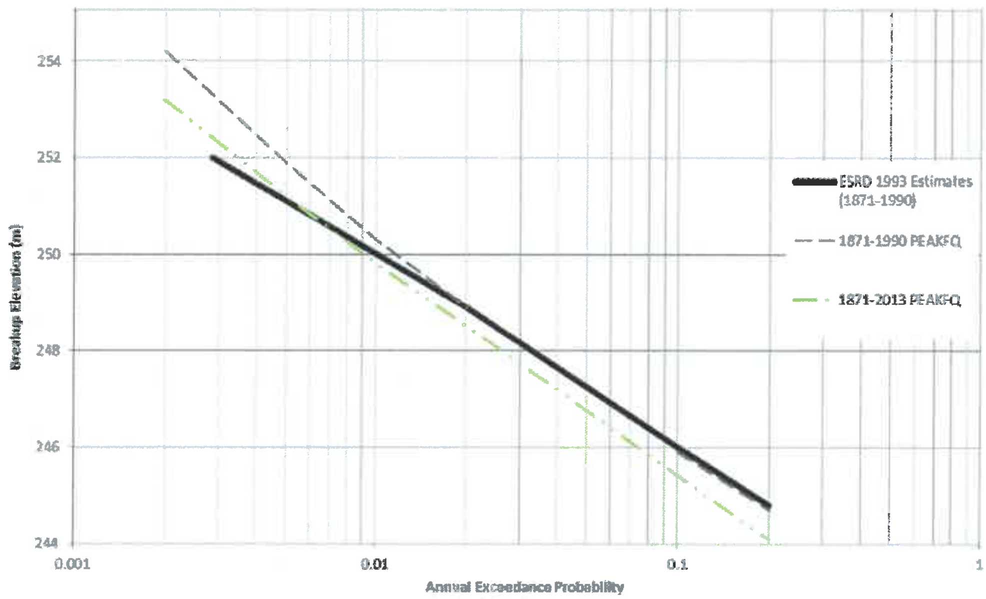
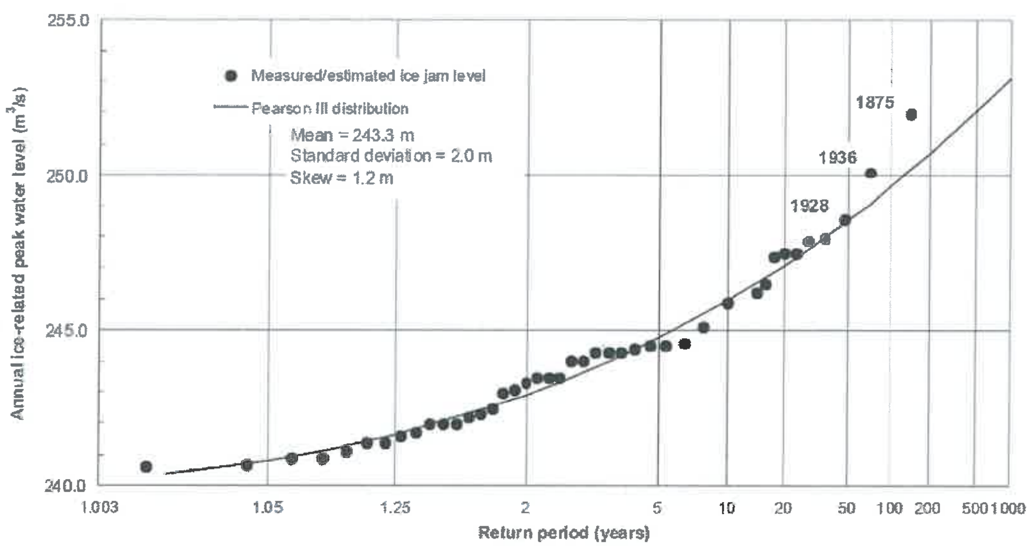


Source: Golder, 2014. Figure C- 4 of Athabasca River Basin Feasibility Study
Fort McMurray Updated Breakup Stage Frequency - LOG PEARSON TYPE III DISTRIBUTION



Source: NHC, 2014, Figure 3 of Fort McMurray Flood Protection Conceptual Design
FREQUENCY CURVE OF PEAK ICE JAM FLOOD LEVELS FOR ATHABASCA RIVER AT CLEARWATER RIVER MOUTH

LEGEND

Legend information contained within figure image

HANGINGSTONE RIVER BASIN STUDY

Ice Jam Flood Frequency Curve Athabasca River at Clearwater Mouth

TETRA TECH EBA

CLIENT: Regional Municipality of Wood Buffalo

PROJECT NO.	DWN	CKD	APVD	REV
ENVH2O03100-01	BB	MS	BR	0

OFFICE	DATE
Tt EBA-CAL	May 20, 2015

Figure 14

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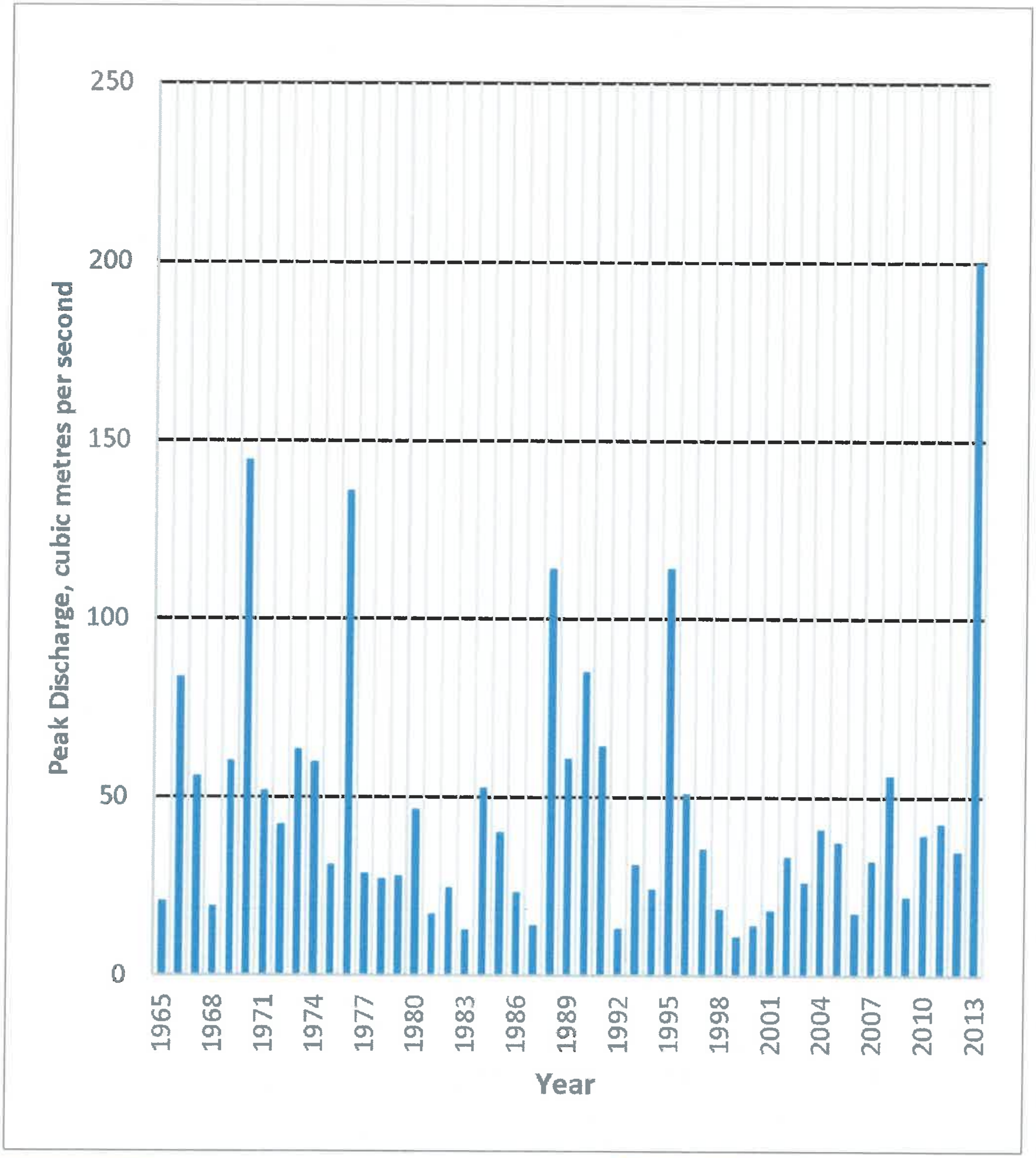

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LEGEND

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HANGINGSTONE RIVER BASIN STUDY

Historic Peak Discharges Hangingstone River at Fort McMurray

TETRA TECH EBA

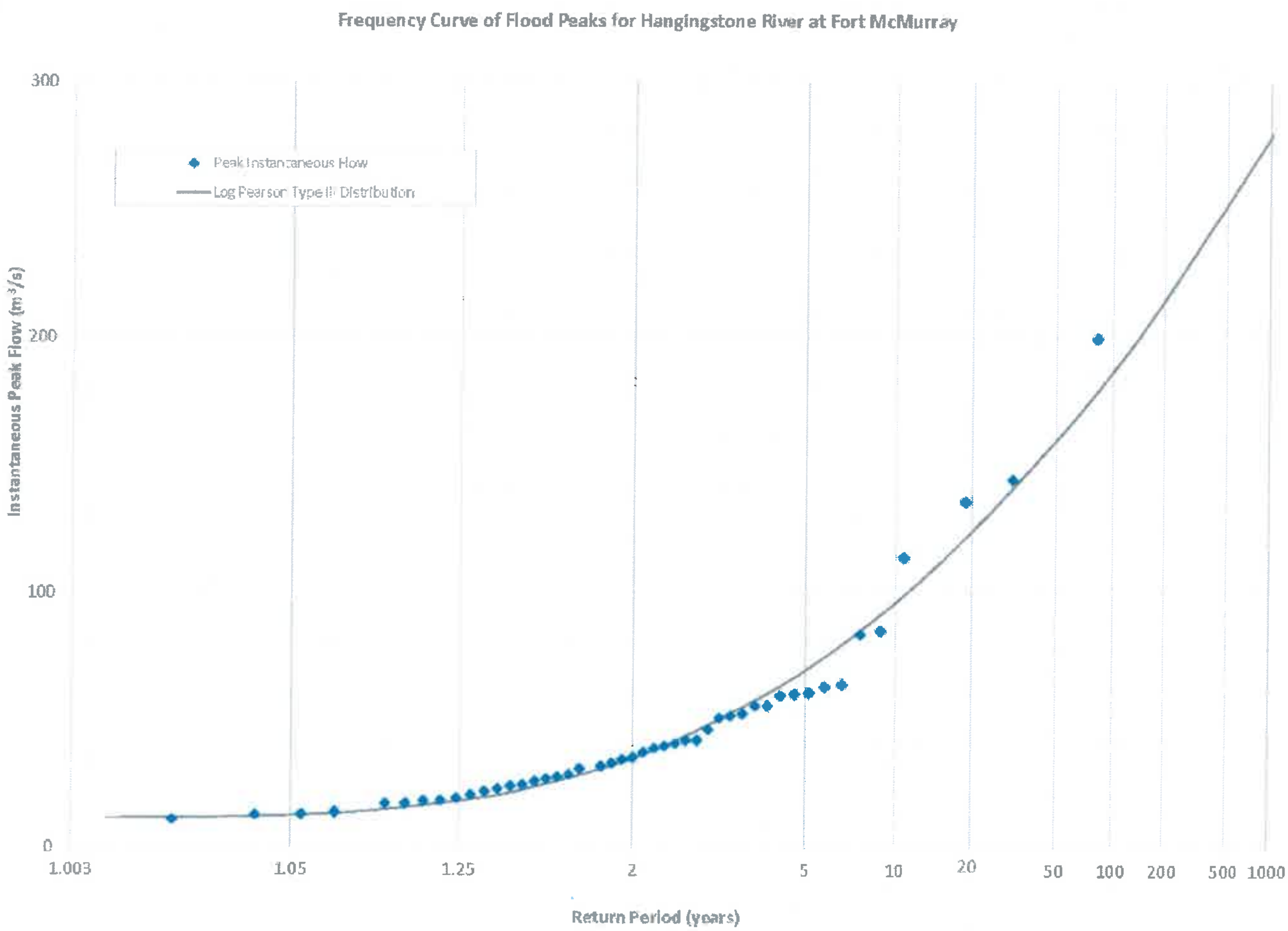
CLIENT

Regional Municipality of Wood Buffalo

PROJECT NO.	DWN	CKD	APVD	REV
ENVH2O03100-01	BB	MS	BR	0

OFFICE	DATE
Tt EBA-CAL	May 20, 2015

Figure 15



LEGEND

Legend information contained within figure image

HANGINGSTONE RIVER BASIN STUDY

Open Water Flood Frequency Curve Hangingstone River at Fort McMurray

TETRA TECH EBA

CLIENT

Regional Municipality of Wood Buffalo

PROJECT NO.	DWN	CKD	APVD	REV
ENVH2O03100-01	BB	MS	BR	0

OFFICE	DATE
Tt EBA-CAL	May 20, 2015

Figure 16

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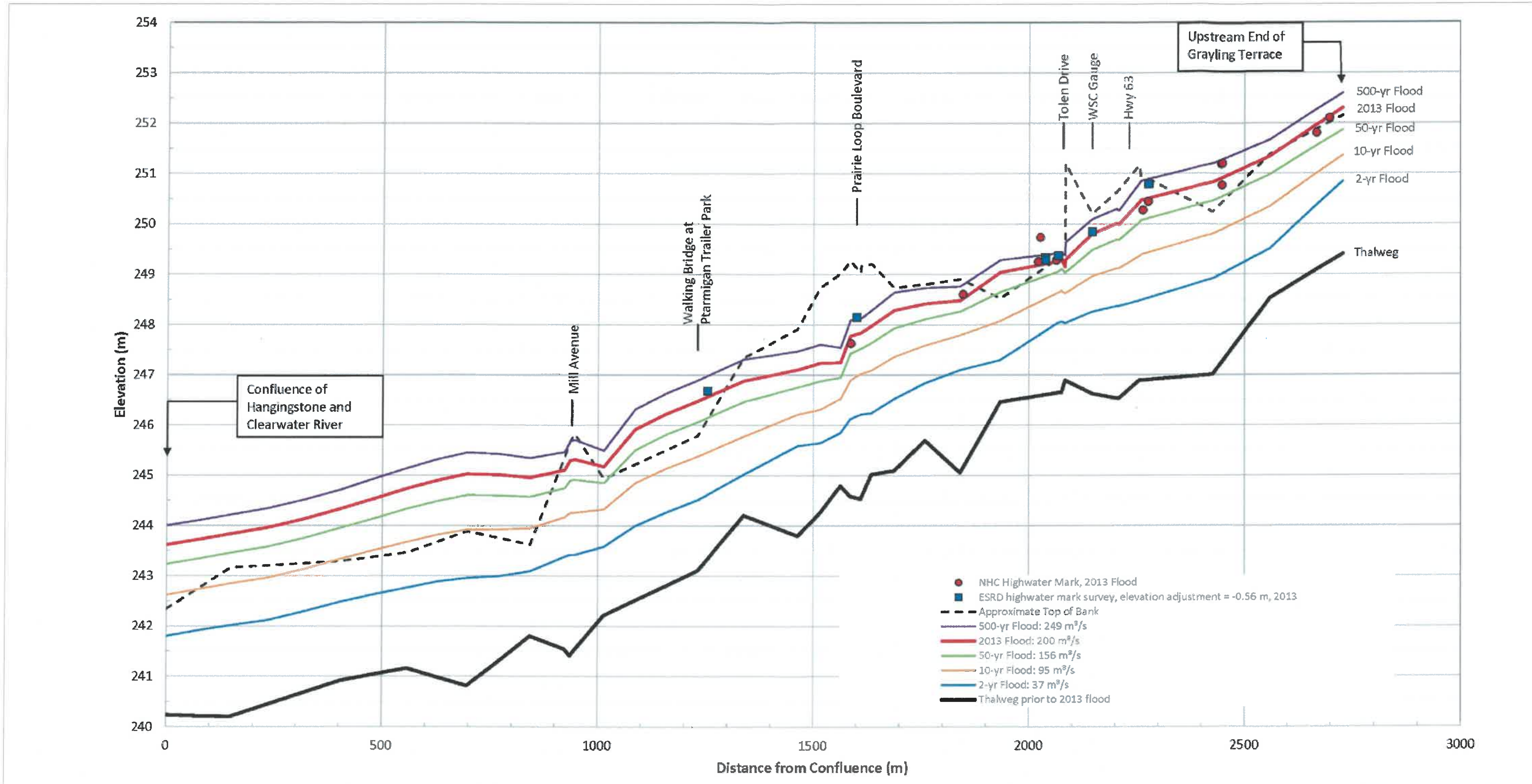

LEGEND

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HANGINGSTONE RIVER BASIN STUDY

Open Water Flood Profiles
Hangingstone River from Mouth

TETRA TECH EBA

CLIENT: Regional Municipality of Wood Buffalo

PROJECT NO.	DWN	CKD	APVD	REV
ENVH2O03100	BB	MS	BR	0

OFFICE: TtEBA-CAL
DATE: May 20, 2015

Figure 17

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LEGEND

Legend information contained within figure image

HANGINGSTONE RIVER BASIN STUDY

Combined Flood Hazard Profiles Hangingstone River from Mouth

TETRA TECH EBA

CLIENT: Regional Municipality of Wood Buffalo

PROJECT NO.	DWN	CKD	APVD	REV
ENVH2O03100	BB	MS	BR	0

OFFICE	DATE
Tt EBA-CAL	May 19, 2015

Figure 18

LEGEND

- Proposed Environmental Reserve Boundary Points from 2013 Ground Assessment
- Transition Between Riparian and Upland Forest Types
- Pre-flood Edge of Bank
- Road
- Highway

HANGINGSTONE RIVER BASIN STUDY

Field Delineation of Environmental Reserve Boundary

TETRA TECH EBA

CLIENT: Regional Municipality of Wood Buffalo

PROJECT NO.	DWN	CKD	APVD	REV
ENVH2O3100	BB	MS	BR	0

OFFICE	DATE
Tt EBA-CAL	May 13, 2015

Figure 19

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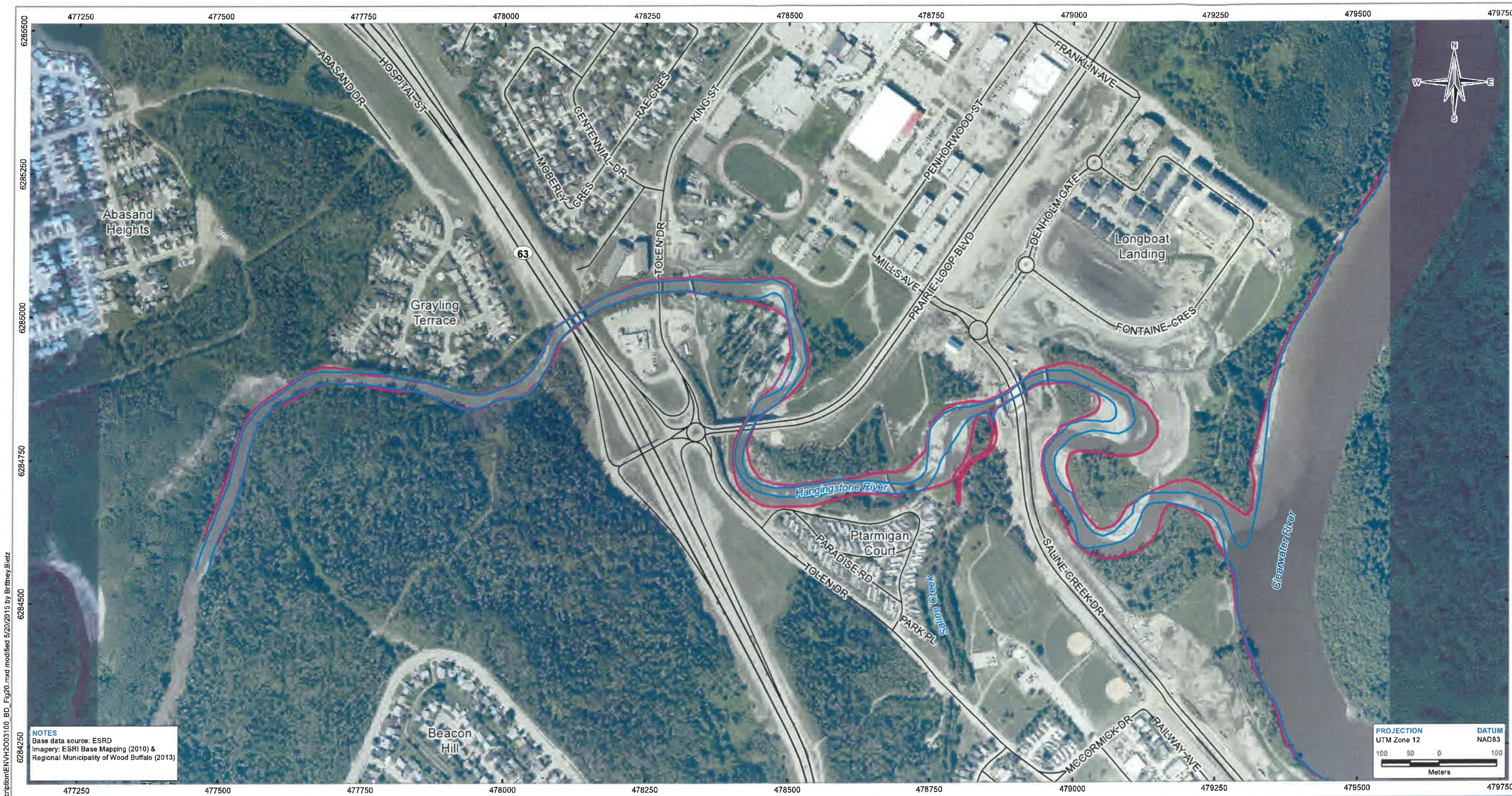

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LEGEND

- Pre-flood Edge of Bank
- Post-flood Edge of Bank
- Road
- Highway

HANGINGSTONE RIVER BASIN STUDY

Channel Shifting during 2013 Flood Hangingstone River at Fort McMurray

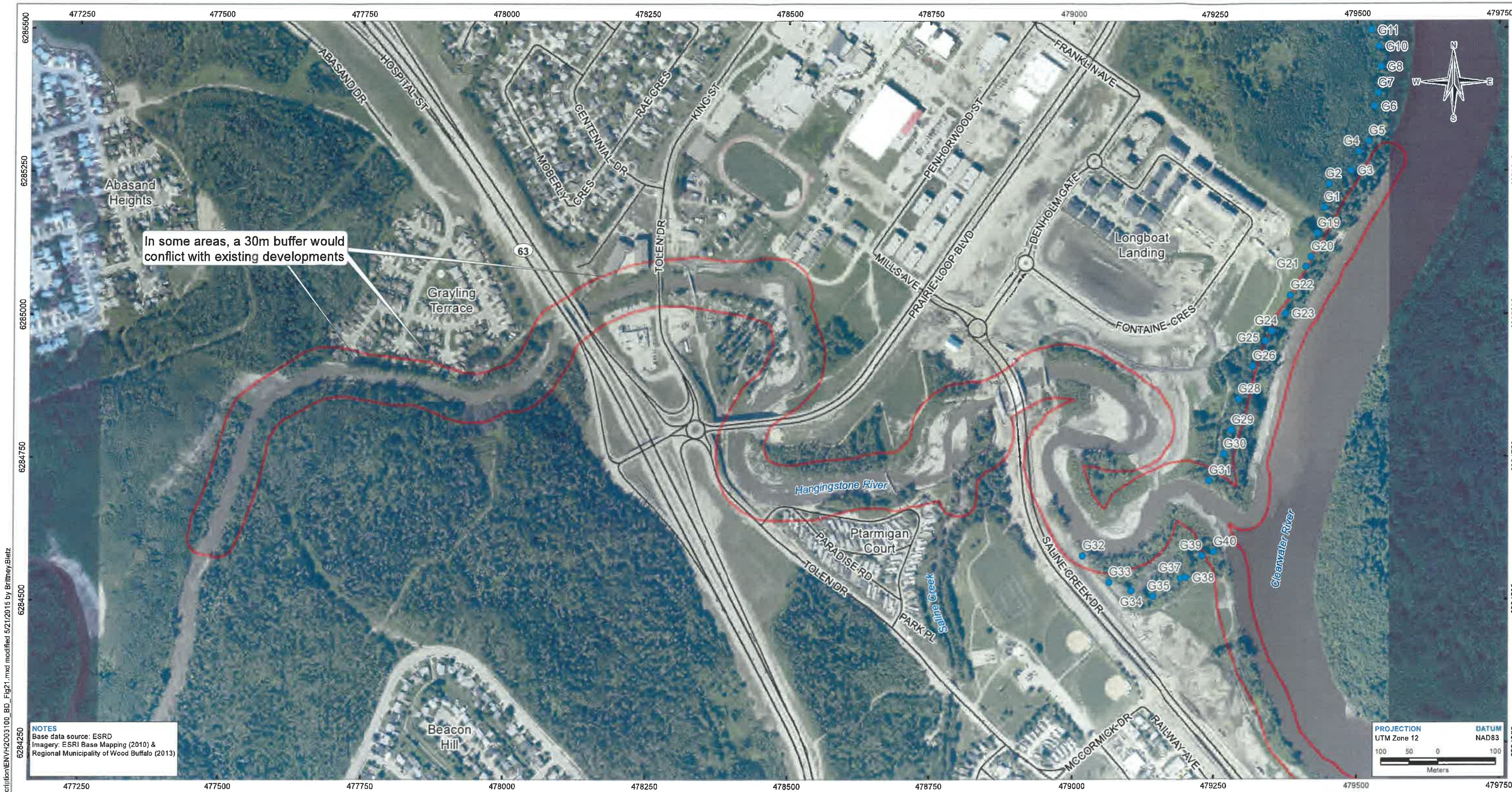
TETRA TECH EBA

CLIENT: Regional Municipality of Wood Buffalo

PROJECT NO.	DWN	CKD	APVD	REV
ENVH2O03100	BB	MS	BR	0

OFFICE	DATE
Tt EBA-CAL	May 20, 2015

Figure 20



LEGEND

- Proposed Environmental Reserve Boundary Points from 2013 Ground Assessment
- 30m Setback
- Road
- Highway

HANGINGSTONE RIVER BASIN STUDY

Buffer Lines Drawn 30 Metres from 2013 Post-flood Edge of Bank

TETRA TECH EBA

CLIENT: REGIONAL MUNICIPALITY OF WOOD BUFFALO

PROJECT NO.	DWN	CKD	APVD	REV
ENVH2O03100	BB	MS	BR	0

OFFICE	DATE
Tt EBA-CAL	May 19, 2015

Figure 21

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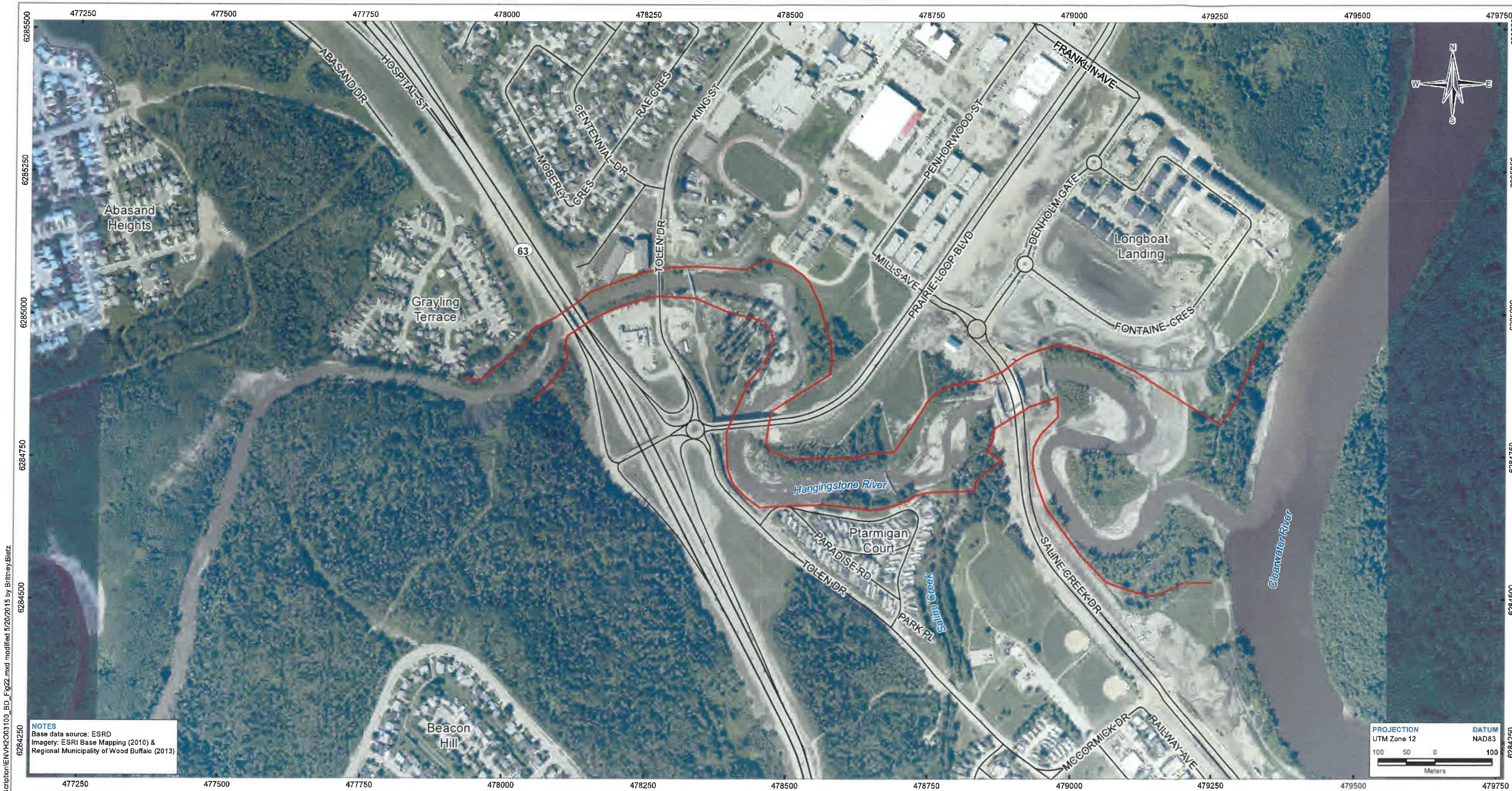

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LEGEND

- Proposed Buffer Setback Line
- Road
- Highway

HANGINGSTONE RIVER BASIN STUDY

Preliminary Proposed Setback Buffer for Hangingstone River Flood Control Works

TETRA TECH EBA

CLIENT: Regional Municipality of Wood Buffalo

PROJECT NO.	DWN	CKD	APVD	REV
ENVH2O3100	BB	MS	BR	0
OFFICE	DATE			
Tt EBA-CAL	May 19, 2015			

Figure 22

PHOTOGRAPHS

Photo 1. June 12, 2013, 9:35 a.m.

Hangingstone River viewing downstream from above Highway 63 bridge to: (1) Tolen Drive bridge, (2) pedestrian bridge, and (3) Prairie Loop Blvd bridge. RMWB Firehall No.1 is situated in the middle part of the photo adjacent to Highway 63. The grey area in the lower left of the firehall parking lot shows the flood event high water mark, and the small green structure on the opposite bank from the parking lot is the Water Survey of Canada stream gauge for the Hangingstone River at Fort McMurray. Additional grey areas (silt deposits) downstream of the Tolen Drive bridge show where overbank flooding occurred.

Photo 2. June 12, 2013, 9:35 a.m.

Hangingstone River viewing upstream, showing residual flooding at Heritage Park in middle of photo. Highway 63 is at top of photo.

Photo 3. June 12, 2013, 9:36 a.m.

Hangingstone River viewing downstream to erosion sites at Tolen Drive (at bottom of photo), Ptarmigan Court, and pedestrian bridge.

Photo 4. June 12, 2013, 9:58 a.m.

Hangingstone River viewing downstream to erosion sites at pedestrian trail parallel to Tolen Drive (at right side of photo), and Ptarmigan Court.

Photo 5. June 12, 2013, 10:13 a.m.

Viewing north to Hangingstone River flood debris lodged in deck of pedestrian bridge adjacent to Ptarmigan Court.

Photo 6. June 13, 2013, 11:58 a.m.

Hangingstone River viewing upstream at Grayling Terrace showing sandbags placed along top of bank. Area of concern for landslide hazard, and the potential to obstruct the river flow, is at the left edge of photo.

Photo 7. June 14, 2013, 12:18 a.m.

Hangingstone River viewing upstream to bank repairs works along Ptarmigan Court and Tolen Drive.

Photo 8. June 14, 2013, 12:19 p.m.

Hangingstone River viewing downstream at Saline Creek Drive bridges under construction. The proposed Longboat Landing development is under construction in the upper left portion of the photo.

Photo 9. June 14, 2013, 12:19 p.m.

Hangingstone River viewing downstream to confluence with the Clearwater River flowing right to left at top of photo.

Photo 10. June 14, 2013, 12:23 p.m.

Hangingstone River viewing upstream to localized bank erosion at outside bend downstream from Heritage Village.

Photo 11. June 15, 2013, 5:41 p.m.

Hangingstone River viewing upstream showing concrete block bank protection installed at upper end of Grayling Terrace.

Photo 12. June 15, 2013, 8:15 a.m.

Hangingstone River viewing south from Grayling Terrace to landslide area of concern on opposite bank. River flow is right to left.

Photo 13. June 15, 2013, 8:21 a.m.

Hangingstone River viewing downstream from upper end of Grayling Terrace.

Photo 14. March 12, 2015.

Hangingstone River viewing downstream from upper end of Grayling Terrace after recent (2015) construction of channel conveyance improvements, prior to landscape restoration. Work was also done in early 2015 to stabilize the landslide hazard area on the right bank.

APPENDIX A
TETRA TECH EBA'S GENERAL CONDITIONS

GENERAL CONDITIONS

GEOENVIRONMENTAL REPORT

This report incorporates and is subject to these "General Conditions".

1.0 USE OF REPORT AND OWNERSHIP

This report pertains to a specific site, a specific development, and a specific scope of work. It is not applicable to any other sites, nor should it be relied upon for types of development other than those to which it refers. Any variation from the site or proposed development would necessitate a supplementary investigation and assessment.

This report and the assessments and recommendations contained in it are intended for the sole use of Tetra Tech EBA's client. Tetra Tech EBA does not accept any responsibility for the accuracy of any of the data, the analysis or the recommendations contained or referenced in the report when the report is used or relied upon by any party other than Tetra Tech EBA's Client unless otherwise authorized in writing by Tetra Tech EBA. Any unauthorized use of the report is at the sole risk of the user.

This report is subject to copyright and shall not be reproduced either wholly or in part without the prior, written permission of Tetra Tech EBA. Additional copies of the report, if required, may be obtained upon request.

2.0 ALTERNATE REPORT FORMAT

Where Tetra Tech EBA submits both electronic file and hard copy versions of reports, drawings and other project-related documents and deliverables (collectively termed Tetra Tech EBA's instruments of professional service), only the signed and/or sealed versions shall be considered final and legally binding. The original signed and/or sealed version archived by Tetra Tech EBA shall be deemed to be the original for the Project.

Both electronic file and hard copy versions of Tetra Tech EBA's instruments of professional service shall not, under any circumstances, no matter who owns or uses them, be altered by any party except Tetra Tech EBA. The Client warrants that Tetra Tech EBA's instruments of professional service will be used only and exactly as submitted by Tetra Tech EBA.

Electronic files submitted by Tetra Tech EBA have been prepared and submitted using specific software and hardware systems. Tetra Tech EBA makes no representation about the compatibility of these files with the Client's current or future software and hardware systems.

3.0 NOTIFICATION OF AUTHORITIES

In certain instances, the discovery of hazardous substances or conditions and materials may require that regulatory agencies and other persons be informed and the client agrees that notification to such bodies or persons as required may be done by Tetra Tech EBA in its reasonably exercised discretion.

4.0 INFORMATION PROVIDED TO TETRA TECH EBA BY OTHERS

During the performance of the work and the preparation of the report, Tetra Tech EBA may rely on information provided by persons other than the Client. While Tetra Tech EBA endeavours to verify the accuracy of such information when instructed to do so by the Client, Tetra Tech EBA accepts no responsibility for the accuracy or the reliability of such information which may affect the report.

APPENDIX B
FORT MCMURRAY FLOOD STAGE FREQUENCY REPORT 1993

TETRA TECH EBA

REVIEW OF FLOOD STAGE FREQUENCY ESTIMATES FOR THE CITY OF FORT McMURRAY
FINAL REPORT

Submitted To:

TECHNICAL COMMITTEE
CANADA-ALBERTA FLOOD DAMAGE REDUCTION PROGRAM

Submitted By:

TECHNICAL SERVICES & MONITORING DIVISION
WATER RESOURCES SERVICES
ALBERTA ENVIRONMENTAL PROTECTION

NOVEMBER, 1993

EXECUTIVE SUMMARY

This study was undertaken for the Technical Committee, Canada-Alberta Flood Damage Reduction Program in response to concerns raised by the City of Fort McMurray over the validity of the elevation established in previous studies as representing the 1 in 100 year design flood level. The specific objectives were first, to examine the historic data and assess it reliability and second, to update the flood frequency analysis, incorporating additional data collected in recent years.

The main conclusions arising from the study are:

a) In spite of some limitations, the information available on the 1875 ice jam event and most other historic events is considered to be sufficiently reliable for inclusion in the flood frequency analysis,

b) the 1 in 100 year break-up stage at Fort McMurray based on the updated frequency analysis is 250.0 m, and

c) The estimated return period for the 1875 event is in the order of 350 years and corresponds to a flood stage 2.0 m above the 1 in 100 year stage.

Designation of flood risk areas based on an historical flood that has exceeded the 1 in 100 year event is an option under the Flood Damage Reduction Program. However, given the extreme magnitude of the maximum historic event at Fort McMurray, it is felt to be unreasonable and inappropriate to designate to such a level. Instead, it is recommended that the updated 1 in 100 year breakup stage of 250.0 m be adopted as the design flood level for designation under the Flood Damage Reduction Program.

ACKNOWLEDGEMENTS

This study was conducted by Terry Winhold [1] and Ron Bothe [2] of the Technical Services & Monitoring Division, Alberta Environmental Protection.

Valuable information and data obtained from numerous sources referenced throughout the report is hereby acknowledged.

---

1 River Engineer, River Engineering Branch
Co-ordinator, Hydraulic Studies,
Canada-Alberta Flood Damage Reduction Program

2 Senior Hydrologist, Hydrology Branch
Member, Technical Committee
Canada-Alberta Flood Damage Reduction Program

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1.0 INTRODUCTION

1.1 Flood Damage Reduction Program

The Canada-Alberta Flood Damage Reduction Program (FDRP) was initiated subsequent to "An Agreement Respecting Flood Damage Reduction and Flood Risk Mapping in Alberta" signed by the federal and provincial governments in April, 1989. This program supports a non-structural method of flood damage reduction by identifying urban areas subject to flood damages and by encouraging measures such as land use planning, zoning, flood proofing and flood preparedness.

The FDRP includes the following components:

1. Identify, map and designate flood risk areas in urban communities across the province;
2. Increase awareness of flood risk among the general public, industry and government agencies, through a public information program;
3. Regulate new development in flood risk areas using new federal and provincial government policies;
4. Encourage municipalities to develop bylaws recognizing the designated flood risk areas.

1.2 Flood Potential in Fort McMurray

Portions of the City of Fort McMurray (Figure 1) and Waterways situated along the Clearwater River have been subject to periodic flooding dating as far back as the 1870's when the area was first settled. Although the phenomenon is not entirely understood, it is a well documented fact that the severest flooding is associated with the occurrence of ice jams on the Athabasca River during the annual spring breakup. These jams typically form in the reach below the Clearwater River confluence causing water and ice to back up the Clearwater channel (Figure 2).

When a serious ice jam occurs, the flooding process can be dramatic, not only with respect to the depth and extent of flooding, but also in terms of the time lapse between initial jam formation and the reaching of maximum water levels. The latter can be only a matter of one or two hours, thus affording little time to implement emergency measures.

Following the last significant flood which occurred in 1977, Alberta Environment and the City of Fort McMurray have worked together to develop a breakup monitoring program, which with recent improvements can provide some advance warning of breakup on the Athabasca River. However, at the present time and for the foreseeable future, there is no reliable means of predicting or preventing the occurrence of a serious ice jam. Thus the importance of practising proper floodplain management in reducing the potential for future flood damages in Fort McMurray cannot be over stated.

1.3 Study Objective

On April 26, 1990, members of the Steering and Technical Committee's for the Canada-Alberta FDRP met with officials from the City of Fort McMurray to explore the possibility of designating flood risk areas in that community. One of the issues identified by the City Administration at that meeting concerned the validity of the elevation established in previous studies as the 1 in 100 year design flood level. This elevation (252 m) corresponds to what is generally accepted to be the maximum historic ice jam flood level reported to have occurred in 1875.

It was agreed at the April 26, 1990 meeting that the FDRP Technical Committee would undertake a review of the basis for the 1 in 100 year design flood elevation. Thus, the objective of this study is twofold; first to examine the historic data and assess its accuracy and reliability and second to update the flood frequency analysis to incorporate additional data collected in recent years. Based on the results of this investigation, a recommendation will be made with respect to the 1:100 year flood level to be adopted by the FDRP.

2.0 PREVIOUS STUDIES

2.1 Blench Report (1964)

The first serious attempt to quantify ice jam flood levels at Fort McMurray was made by T. Blench (1964) as part of an investigation into alternative flood protection measures for the city. Blench documented the history of flooding at the Fort by researching a number of sources dating back to the establishment of the first Hudson's Bay Company Post in 1870 and by carrying out interviews with long time residents of the area. From the information gathered, Blench conducted a rather crude flood stage frequency analysis by fitting the set of historic ice jam related flood levels listed in Table 2.1 to a log-normal probability distribution. This was based on the assumption that the record could be associated with the entire period dating back to 1870. A curve was fitted through the plotted points and from this the 1 in 100 year ice jam flood level was found to approximate the level of the historic 1875 event as reported by H.J. Moberly, the official in charge of the Hudson's Bay Company Post at that time.

The Blench report recommended that a dyke be constructed to close off what is known as "The Snye" (Figure 2). This recommendation was based on the theory that ice jams on the Athabasca River at Fort McMurray typically initiated or "keyed in" near the mouth of the Snye mainly due to the sudden widening and flattening of the river at this location. It was further theorized that if the Snye Channel were closed off, the "key" location would be shifted approximately 1.5 kilometres downstream to the mouth of the Clearwater River, thus resulting in a potential reduction of flood levels in the Lower Townsite by about one metre. This closure was subsequently implemented in 1966 with the construction of a dyke at the location shown in Figure 2.

TABLE 2.1

Summary of Historic Ice Jam Flood Levels At Fort McMurray

Year	Elevation [1] (m)	Location of Measurements [2]	Original Information Source
1875	251.5 - 253.0	Hudson's Bay Co. Post right bank of Athabasca River near entrance to Snye Channel	1. Hudson's Bay Co. Archives 2. Moberly H.J. and Cameron, W.R. "When Fur Was King", J.M. Dent and Sons Ltd., Toronto, 1929
1881	Undermined (less than 250)	Water levels over -topped the banks along Snye Channel-general description only.	Hudson's Bay Co. Archives
1885	249.0	Hudson's Bay Co. Post	Hudson's Bay Co. Archives
1925	247.4	Waterway's	Northern Alberta Railways Co.
1928	248.6	Waterway's	Northern Alberta Railways Co.
1936	250.1	Waterway's	Northern Alberta Railways Co.
1962	246.2	Not known-assumed to be highwater mark in Lower Townsite	Department of Northern Affairs and Natural Resources
1963	247.5	Not known-assumed to be highwater mark in Lower Townsite	Department of Northern Affairs and Natural Resources

[1] Information extracted from Blench (1964)

[2] See Figure 2

2.2 Alberta Research Council (1977)

This document presents a first hand account of a major ice jam flood which occurred at Fort McMurray in April of 1977. Detailed observations provided valuable information on ice jam formation and decay, making it possible to either substantiate or question some of the theories put forth by Blench (1964). First, it appears that the primary location for jam initiation is in the wide, multichanneled reach of the Athabasca River downstream of the Clearwater River confluence. This differs somewhat from the Blench argument that jams would typically "key in" near the Clearwater River confluence following construction of the Snye Dyke. On the other hand, longitudinal water surface profiles surveyed through the 1977 jam do indicate about a one metre drop in levels between the MacEwan Bridge located just above the Snye and the Clearwater River confluence. This later observation, therefore, tends to substantiate the second argument put forth by Blench that closure of the Snye Channel potentially results in a lowering of water levels in town by about one metre, a measure accomplished by effectively shifting control of flood levels from the entrance to the Snye to the mouth of the Clearwater River.

Figure 2 shows a profile of flood levels along the Clearwater River caused by the 1977 ice jam on the Athabasca River.

2.3 Northwest Hydraulic Consultants Report (1979)

A study of flood levels and the impact of proposed dykes along the Clearwater River at Fort McMurray was conducted for Alberta Environment by Northwest Hydraulic Consultants Ltd. (NHCL) in 1979. As with the Blench report, NHCL recommended once again that the historic 1875 event be adopted as the 1 in 100 year ice jam flood level at Fort McMurray. The consultant used a valid analytical approach to determine the statistical distribution of ice jam flood levels, however, it was felt that the results were generally inconclusive due mainly to the shortness and uncertainty of the data base. As an alternative, NHCL decided to simply accept the principle that because a given elevation had not been exceeded in over 100 years it could then be assumed to approximate the 1 in 100 year event.

The flood levels presented in Table 2.2 were used in the NHCL report as the basis for assigning return periods for various flood events. Note that all levels have been adjusted to the mouth of the Clearwater River and therefore vary in some cases from those recorded in Table 2.1. This is to account for the apparent shifting of flood level control from the Snye Channel to the Clearwater confluence as discussed in Sections 2.1 and 2.2. In other words, NHCL's analysis accepted the argument that were the historic ice jam events of 1875, 1881, and 1885 to occur today, the maximum water level reached at the site of the former Hudson's Bay Company Post (Figure 2) would be lowered by approximately one metre due to the Snye Dyke construction in 1966.

TABLE 2.2

Ice Jam Elevations and Corresponding Return Periods Determined by NHCL[1]

Year	Elevation [2] (m)	Approximate Return Period (Years)
1875	252.0	100
1836	250.2	50
1881	249.0	
1928	248.7	
1885	248.1	
1977	247.9	
1963	247.6	
1925	247.5	
1978	247.5	
1962	246.2	10
1972	244.3	

1 Table reproduced from Northwest Hydraulic Consultant Ltd. Report (1979)

2 Adjusted to mouth of Clearwater River

3.0 BREAKUP STAGE DATA REVIEW

3.1 General

As stated in section 1.3 the objectives of this study are:

1. To examine the historic ice jam flood data and assess its reliability and accuracy.
2. Update the flood frequency analysis to incorporate additional data collected in recent years.

The first objective is addressed in Section 3.2 below. The data collected in recent years is presented in Section 3.3.

3.2 Historical Data

Blench (1964) established the largest flood on record as having occurred in 1875, just five years after the establishment of a Hudson's Bay Company post at the location shown on Figure 2. This site was located on the right bank of the Athabasca River near the westend of the present day Franklin Avenue by a long time resident of the area, Mr. Joseph Shott. From a written description of the flood given by H.J. Moberly, who was the officer in charge of the Hudson's Bay Company Post in 1875, the maximum flood level was estimated to be between elevations 825 feet and 830 feet (251.5 metres and 253.0 metres).

There appears to be little doubt that the location of the former trading post site was properly identified by Mr. Shott. Hudson's Bay Company records acquired by Blench (1964) suggest the trading post existed at its original site on the right bank of the Athabasca River above the confluence with the Clearwater River from 1870 to 1899 when it was apparently closed. Mr. Shott, who's father worked for H.J. Moberly, was born in 1886, would have been 13 years old in 1899 when the post shut down and is therefore considered a reliable source of information. Furthermore the descriptions of the site found in excerpts from the Hudson's Bay Company Journals compare well with the location identified by Mr. Shott.

The probable upper limit maximum flood elevation of 830.0 feet or 253.0 metres suggested by Blench (1964) for the 1875 event (see Table 2.1) appears to be more reasonable than the probable lower limit elevation of 825.0 feet or 251.5 metres, given the natural ground elevation* at the presumed location of the original trading post and the description of the flood provided by H. J. Moberly (excerpts from various references containing Moberly's account of this flood are contained in Appendix A). Considering the amount of detail given in these accounts, there appears to be no reason to doubt their authenticity or, indeed, Moberly's credibility. The only notable discrepancy is found in references to the water having risen "about 60 feet" during the flood. It can only be assumed that this estimate was made without benefit of a survey instrument since the maximum rise in river levels based on Blench's determinations is more in the order of 40 feet.

In spite of its limitations, the information gathered on the 1875 event is still considered to be sufficiently reliable to be included in the flood frequency analysis (Section 4). Moreover, the value of including a rare event in the computations far outweighs the inaccuracy of establishing the exact stage.

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* The natural ground elevation reported by Blench (1984) was 823.0 feet (850.0 metres). The existing ground elevation at this site has since been altered by construction of the Snye Dyke in 1966.

Hudson's Bay Company records suggest another serious flood occurred in 1881, however, the description provided does not allow the maximum elevation to be determined with a reasonable degree of confidence. Indications are that the flood waters did not reach the level of the ground (approximately 850.0 metres) at the former trading post site but, perhaps came within a few feet. Because of the uncertainty of this description it is was decided that this particular event would not be included in the updated flood frequency analysis (Section 4.2).

The flood elevations quoted for the remaining historic ice jam events listed in Table 2.1 have been thoroughly reviewed and although the precise accuracy of these levels cannot be verified, the information sources in each case are considered sufficiently reliable to justify inclusion of the data in the flood frequency analysis.

3.3 Recent Systematic Record

Systematic records of maximum breakup stage at Fort McMurray are available from 1977 on with the exception of the years 1980 and 1981. This information was compiled from various sources, including; the City of Fort McMurray, the Alberta Research Council and Alberta Environmental Protection, River Engineering Branch. The data are presented in Table 3.1

The stage elevations shown in Table 3.1 were all measured at or near the mouth of the Clearwater River in order to provide a standardized data set. Water levels produced at this location as a result of a "normal" ice run * or a significant ice jam on the Athabasca River below the Clearwater confluence are, in either case, assumed to act as the control for flood levels along the lower Clearwater River and in the Lower Townsite

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* Breakup stages less than about 246.0 are generally the result of a "normal" (uneventful) ice run on the Athabasca with only minor jamming occurring.

and Waterways areas of Fort McMurray. The exception to this would be the case where local ice movement, due to partial or complete breakup of the Clearwater River resulted in higher water levels being produced in these areas than caused by the actual breakup of the Athabasca River in a particular year. The latter scenario has been documented, for example in 1983 and in 1991 when the Clearwater River broke up ahead of the Athabasca River. However, water levels associated with these events have not resulted in any significant flooding.

TABLE 3.1

Recorded Maximum Breakup Stage at the Clearwater River Confluence from 1977 to 1990

Year	Breakup Stage (m)	Source
1977	247.9	Alberta Research Council (1977)
1978	242.0	Alberta Research Council (1978)
1979	246.5	Alberta Research Council (1979)
1980	Not Available[1]	
1981	Not Available[1]	
1982	242.2	Alberta Environment (1982)
1983	242.3	Alberta Research Council (1984)
1984	243.5	Alberta Research Council (1985)
1985	243.5	Alberta Research Council (1985)
1986	244.0	Alberta Research Council (1988)
1987	245.1	Alberta Environment (1988)
1988	244.5	City of Fort McMurray [2]
1989	243.1	City of Fort McMurray
1990	243.0	City of Fort McMurray

1 "normal" ice run occurred with no significant jamming
2 City Engineering Department - Breakup Monitoring Records

4.0 FREQUENCY ANALYSIS

4.1 Re-Analysis of NHCL Data Set

A re-analysis of the NHCL data set (Table 2.2) places the 1 in 100 year breakup level (based strictly on the frequency curve) at 251.0 metres as shown in Figure 3(a). This suggests that a return period of about 1 in 500 years would have been established for the 1875 event.

Because of its magnitude, the 1875 event has a significant influence on the frequency analysis. As shown in Figure 3(a) (dotted line), removal of this event from the data set lowers the estimate of the 1 in 100 year event by about 1.0 metres. However, as stated previously the value of including a rare event in the computations far outweighs any question concerning the exact stage.

The conditional frequency curve for the NHCL data set is also plotted on Figure 3(a) for comparison. The conditional curve indicates the probability of occurrence of a certain water level given the occurrence of an ice jam.

4.2 Updated Flood Frequency Analysis

The updated breakup stage data set for Fort McMurray is listed in Table 4.1. Several significant changes have occurred to the data set (Table 2.2) which was used in the previous study by NHCL (1979). These are:

1. The 1881 stage of 249.0, which was established by NHCL, is not considered quantifiable and is therefore dropped from the data set.
2. The 1978 stage of 247.5 has been revised to 242.0 metres based on documented observations published by Alberta Research Council (1978).
3. An ice jam event with a breakup stage of 246.5 metres was recorded in April, 1979.

4. Systematic records of "normal" breakup stages for the period 1982 to 1990 have been included in the data set.

TABLE 4.1

Updated Breakup Stage Data Set for Fort McMurray

Year	Stage [1] (m)
1875	252.0
1885	248.0
1925	247.4
1928	248.6
1936	250.1
1962	246.2
1963	247.5
1972	244.3
1977	247.9
1978	242.0
1979	246.5
1982	242.2
1983	242.3
1984	243.5
1985	243.5
1986	244.0
1987	245.1
1988	244.5
1989	243.1
1990	243.0

[1] All levels have been measured near or were adjusted to the mouth of the Clearwater River.

Because of the additional data provided by the systematic record, the approach used to develop the updated frequency analysis differs from the NHCL approach. In the update analysis, the systematic data is used to define "typical" breakup stages while events above 246.0 metres* (lowest significant ice jam event) are adjusted to reflect their relative magnitude in the historical period 1871 to 1990. The results of this frequency analysis, which assumes a Pearson III distribution, are presented in Figure 3(b). Once again the conditional frequency curve is shown for comparison, as is the annual curve with the 1875 event removed from the data set.

The annual frequency curve in Figure 3(b) indicates a 1 in 100 year breakup level of 250.0 metres, whereas the 1875 event would have a return period of about 1 in 350 years. Excluding the 1875 event from the data set lowers the estimate of the 1 in 100 year event by approximately 1.0 m.

4.3 Perception Stage Method

Gerard and Karpuk (1979) have proposed an alternative method of determining the probability distribution of floods utilizing both the available historical data and the more recent systematic record. This method, which is referred to as the "perception stage" method, tends to remove the discontinuity in the probability distribution which is often found when analyzing the combined data set by conventional methods (i.e, a discontinuity often appears in the frequency curve caused by the sudden change in the number of years of record associated with the historical period and the systematic period). The problem is overcome by first establishing a stage above which a particular

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* Approximate flood threshold. Above this level flooding begins to occur along the left bank of the Clearwater River and begins to affect low lying areas in the Lower Townsite and Waterways.

source is likely to have provided information on the flood peak in any given year and then assigning an appropriate rank and record length to each reported flood peak. This procedure is illustrated in Figure 4 which shows a summary diagram of annual maximum breakup stages at Fort McMurray.

The perception stage method has been used to carry out a frequency analysis on the updated breakup stage data set listed in Table 4.1. The resulting frequency curve shown on Figure 5 places the 1 in 100 year break up stage at 250.5 metres, whereas the 1875 event is estimated to have a return period of about 250 years. Appendix B provides a further explanation of the perception stage method and documents how it was applied in this case.

4.4 Comparison of Conventional and Perception Stage Methods

Table 4.2 compares the results obtained using the "conventional" and "perception stage" methods for the updated frequency analysis.

TABLE 4.2

Comparison of Updated Flood Frequency Estimates

	Conventional Frequency Analysis	Perception Stage Method
Return Period-1875 Event	350 years	250 years
1 in 100 year Flood Stage	250.0 m	250.5 m
1 in 50 year Flood Stage	248.9 m	249.2 m
1 in 20 year Flood Stage	247.2 m	247.5 m
1 in 10 year Flood Stage	246.0 m	246.2 m
1 in 5 year Flood Stage	244.8 m	245.0 m

As can be seen from Table 4.2, the results obtained from the conventional frequency analysis and from the perception stage method are quite similar, the latter approach giving a slightly more conservative estimate of the 1 in 100 year event. Although both are considered valid methods, it is recommended that the results of the conventional frequency analysis be accepted to be consistent with the analytical approach used in other hydrologic studies conducted under the Flood Damage Reduction Program.

5.0 CONCLUSIONS AND RECOMMENDATION

Based on a review of the historical ice jam data at Fort McMurray the following conclusions are made:

1. In spite of its limitations, the information available on the 1875 ice jam event (highest known to have occurred) is still considered to be sufficiently reliable to be included in the flood frequency analysis.
2. With the exception of the 1881 event, all of the historic ice jam events documented by Blench (1964) and listed in Table 2.1 are believed to be quantified with sufficient accuracy to be included in the flood frequency analysis.
3. The 1 in 100 year break up stage at Fort McMurray based on the updated frequency analysis is 250.0 metres.
4. The estimated return period for the 1875 event based on the updated frequency analysis is in the order of 350 years.

Recommendation:

Updated frequency estimates place the 1875 event at Fort McMurray as a 1 in 350 year event, corresponding to a flood stage 2.0 metres above the 1 in 100 year stage. Designating flood risk areas to an historical flood that has exceeded the 1 in 100 year event is an option under the Flood Damage Reduction Program, however, given the extreme magnitude of this event, it is not considered reasonable or appropriate to designate to this level. It is therefore recommended that the updated 1 in 100 year breakup stage of 250.0 m be adopted as the design flood level for designation under the Flood Damage Reduction Program.

REFERENCES

1. Blench, T. & Associates Ltd., "Flood Protection Proposals for Fort McMurray", (Prepared for Alberta Provincial Planning Board) Edmonton, May, 1964.

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3. Northwest Hydraulic Consultants Ltd, "A Study of Flood Levels and The Impact of Dikes Along the Clearwater River at Fort McMurray", (Prepared for Alberta Environment, Technical Services Division), Edmonton, January, 1979.

4. Doyle, P.F. & Andres, D.D., "1978 Breakup in the Vicinity of Fort McMurray and Investigation of Two Athabasca River Ice Jams", Alberta Research Council Report No. SWE-78/05, Edmonton, December, 1978.

5. Doyle, P.F. & Andres, D.D., "1979 Spring Breakup and Ice Jamming on the Athabasca River Near Fort McMurray", Alberta Research Council Report No. SWE-79/05, Edmonton, October, 1979.

6. Rickert, H., "1982 Spring Breakup and Monitoring Report Athabasca and Clearwater Rivers at Fort McMurray", River Engineering Branch, Alberta Environment, Edmonton, December, 1982.

7. Andres, D.D. & Rickert, H.A., "Observations of the 1983 Breakup in the Athabasca River Basin Upstream of Fort McMurray, Alberta", Alberta Research Council Report No. SWE-84/01, Edmonton, August, 1984.

8. Andres, D.D. & Rickert, H.A., "Observations of Breakup in the Athabasca River Basin Upstream of Fort McMurray, Alberta, 1984", Alberta Research Council Report No. SWE-85/09, Edmonton, November, 1985.

9. Andres, D.D. & Rickert, H.A., "Observations of the 1985 Breakup In the Athabasca River Basin Upstream of Fort McMurray, Alberta", Alberta Research Council Report No. SWE-85/10, Edmonton, December, 1985.

10. Malcovish, C.D. et al, "Observations of Breakup on the Athabasca River Near Fort McMurray, 1980 and 1987", Alberta Research Council Report No. SWE-88/12, Edmonton, November, 1988.

11. Winhold, T.H., "Fort McMurray Ice Studies 1987 Breakup Observation Report", Alberta Environment, River Engineering Branch, Edmonton, January, 1988.

FIGURES

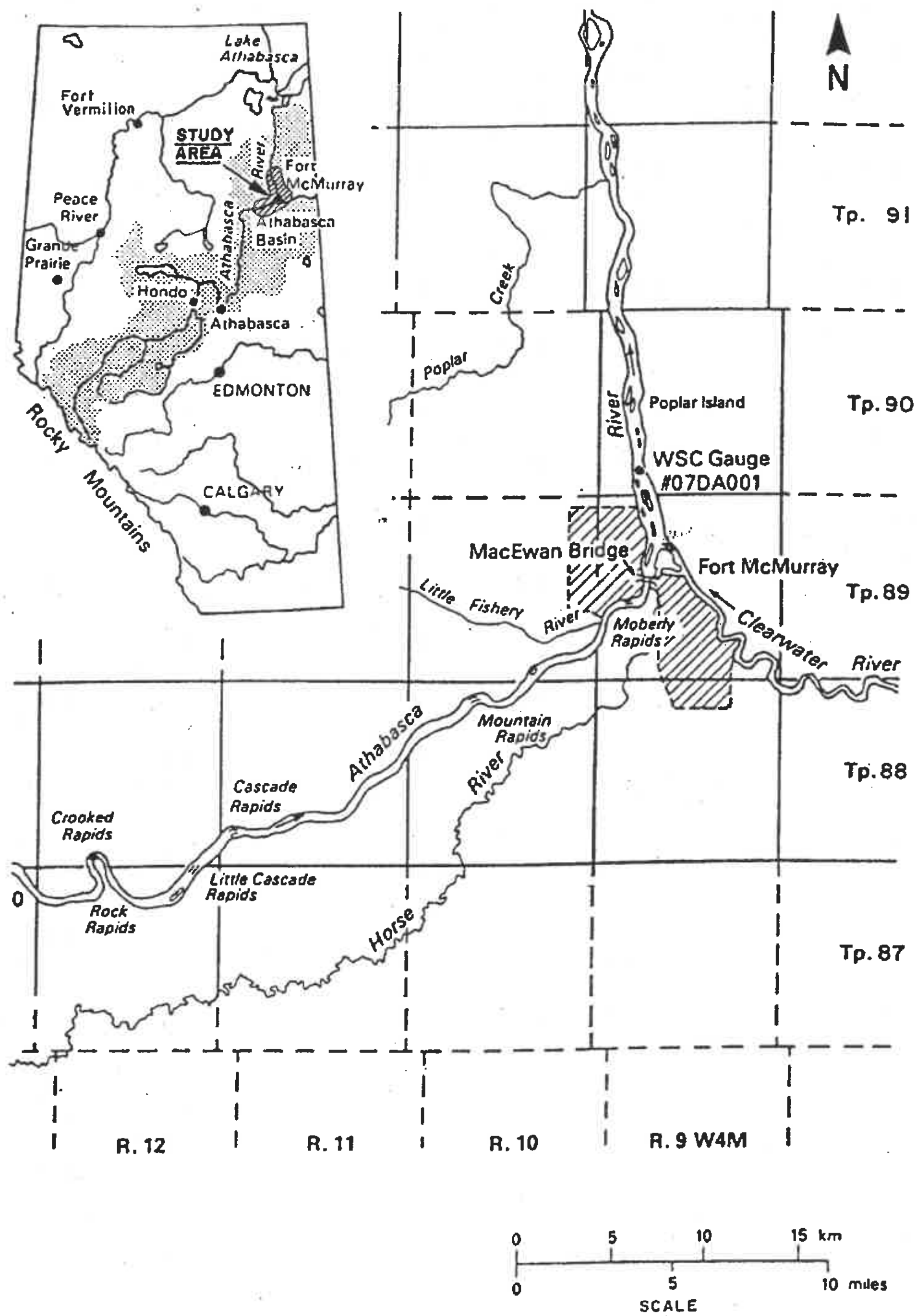
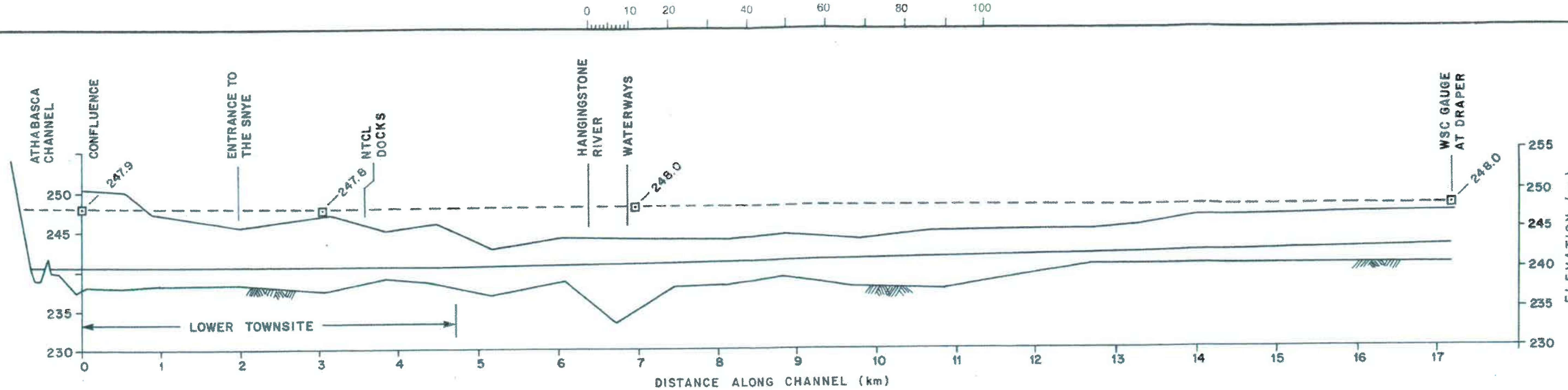
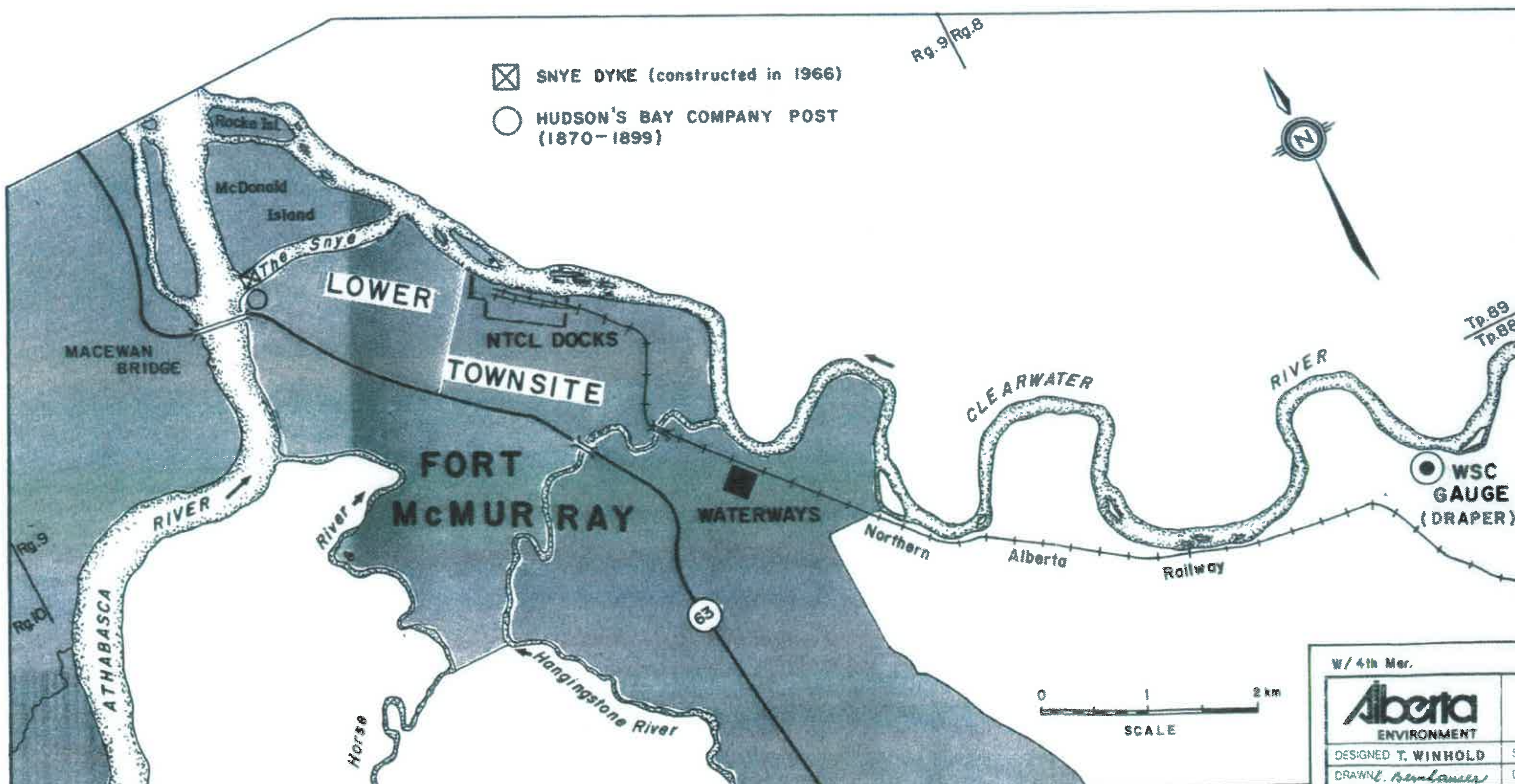


FIGURE 1. LOCATION PLAN



CHANNEL LONGITUDINAL PROFILE



LEGEND:

- 1977 ICE JAM FLOOD
- BANKFULL STAGE
- LOW WATER PROFILE*
- CHANNEL THALWEG*
- 1977 HIGHWATER MARK

*SURVEYED BY ALBERTA ENVIRONMENT AUGUST 1978.

W/ 4th Mer.

Alberta ENVIRONMENT	RIVER ENGINEERING BRANCH	CLEARWATER RIVER PLAN AND PROFILES
DESIGNED T. WINHOLD	SCALE AS SHOWN	
DRAWN [signature]	DATE APRIL, 1987	
CHECKED	SHEET OF	FIGURE No. 2

MICROFILM DATE

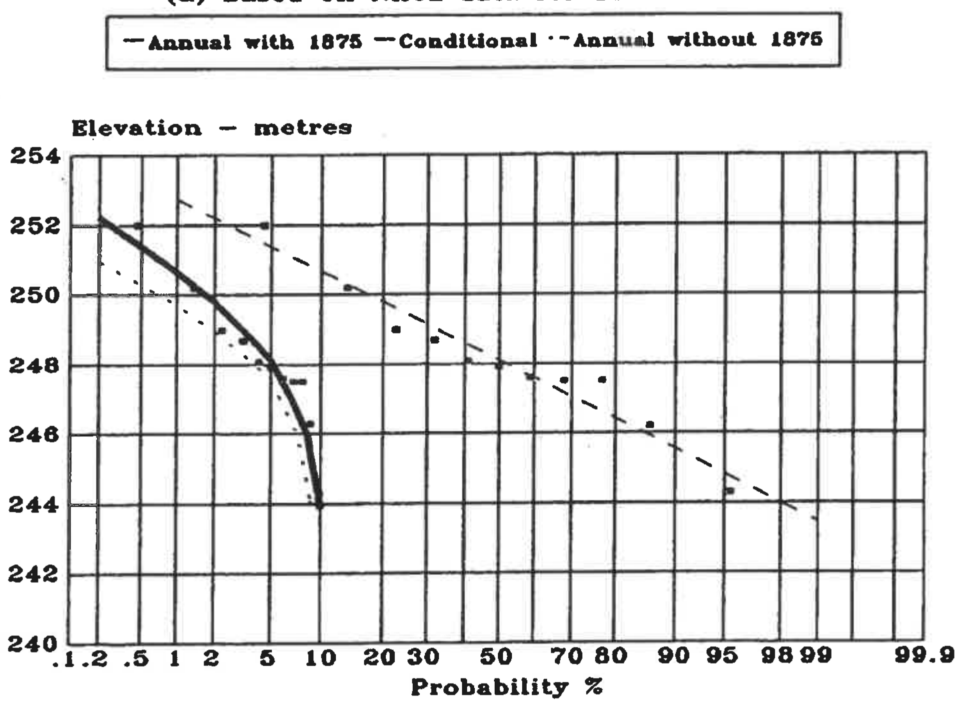
DRAWING FILE No.

CENTRAL FILE No.

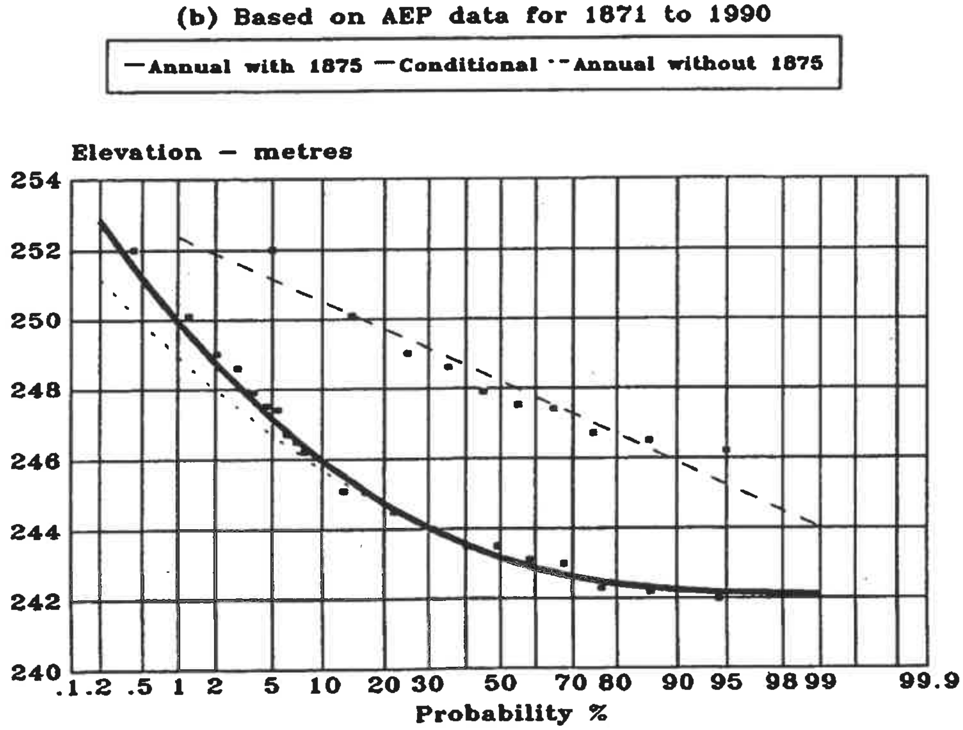
AEOR 7C 2B #60

P3-280 x 430

(a) Based on NHCL data for 1871 to 1978

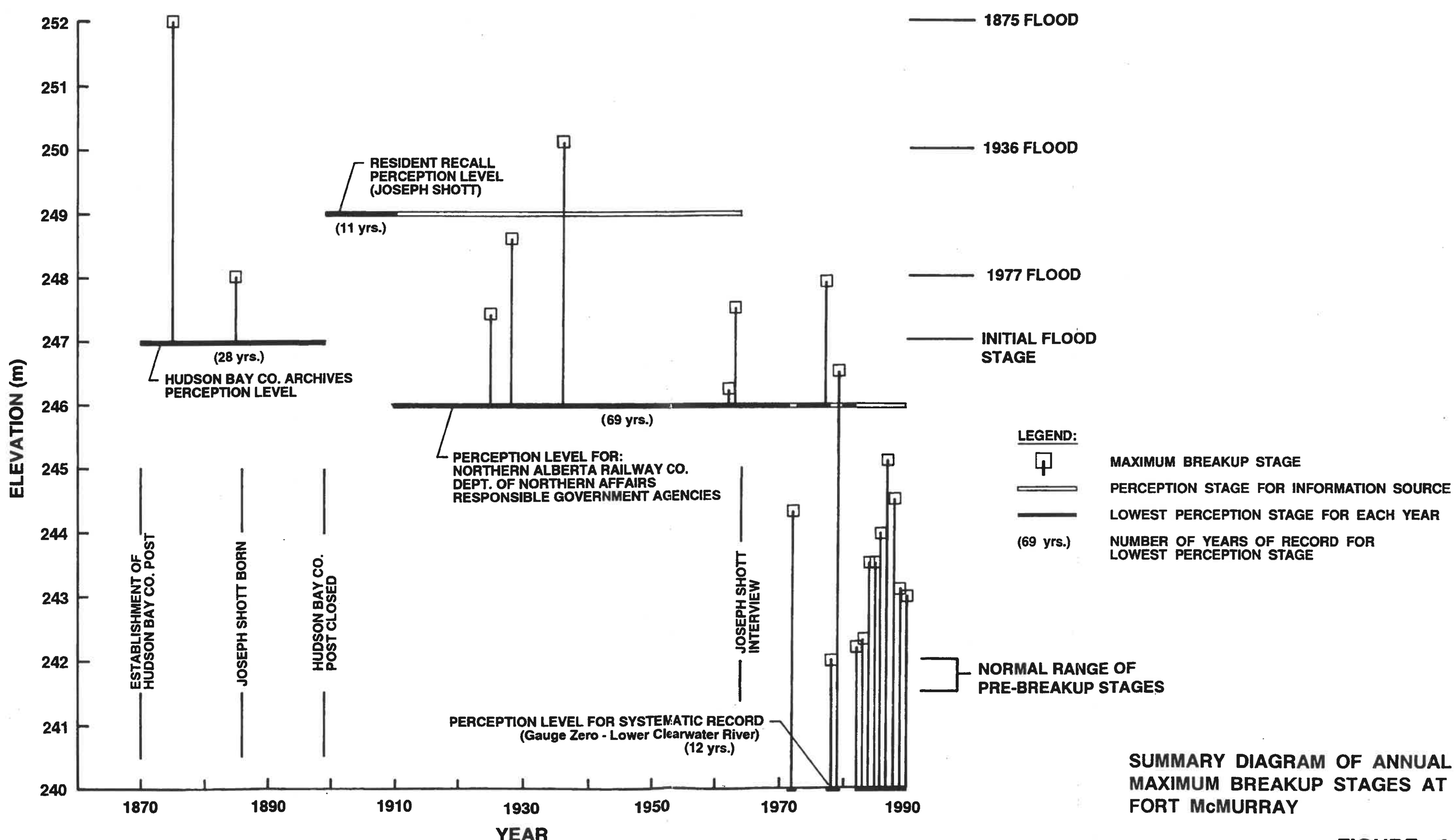


(b) Based on AEP data for 1871 to 1990



Alberta ENVIRONMENT	Technical Services Division HYDROLOGY BRANCH	Frequency of Athabasca River Breakup Stage at Fort McMurray
SUBMITTED R.A. Bothe, P. Eng. DATE October 1990	DESIGNED R.A. Bothe, P. Eng. DATE October 1990	SCALE
APPROVED A.M. Mustapha, P. Eng. DATE October 1990	DRAWN CHECKED	DATE October 1990 — FIGURE No. 3

FOR 3B #60



SUMMARY DIAGRAM OF ANNUAL MAXIMUM BREAKUP STAGES AT FORT McMURRAY

FIGURE 4

AEOR T.C. 48 #60

[redacted]
SB#60

Breakup Stage Frequency Analysis - Perception Stage Method

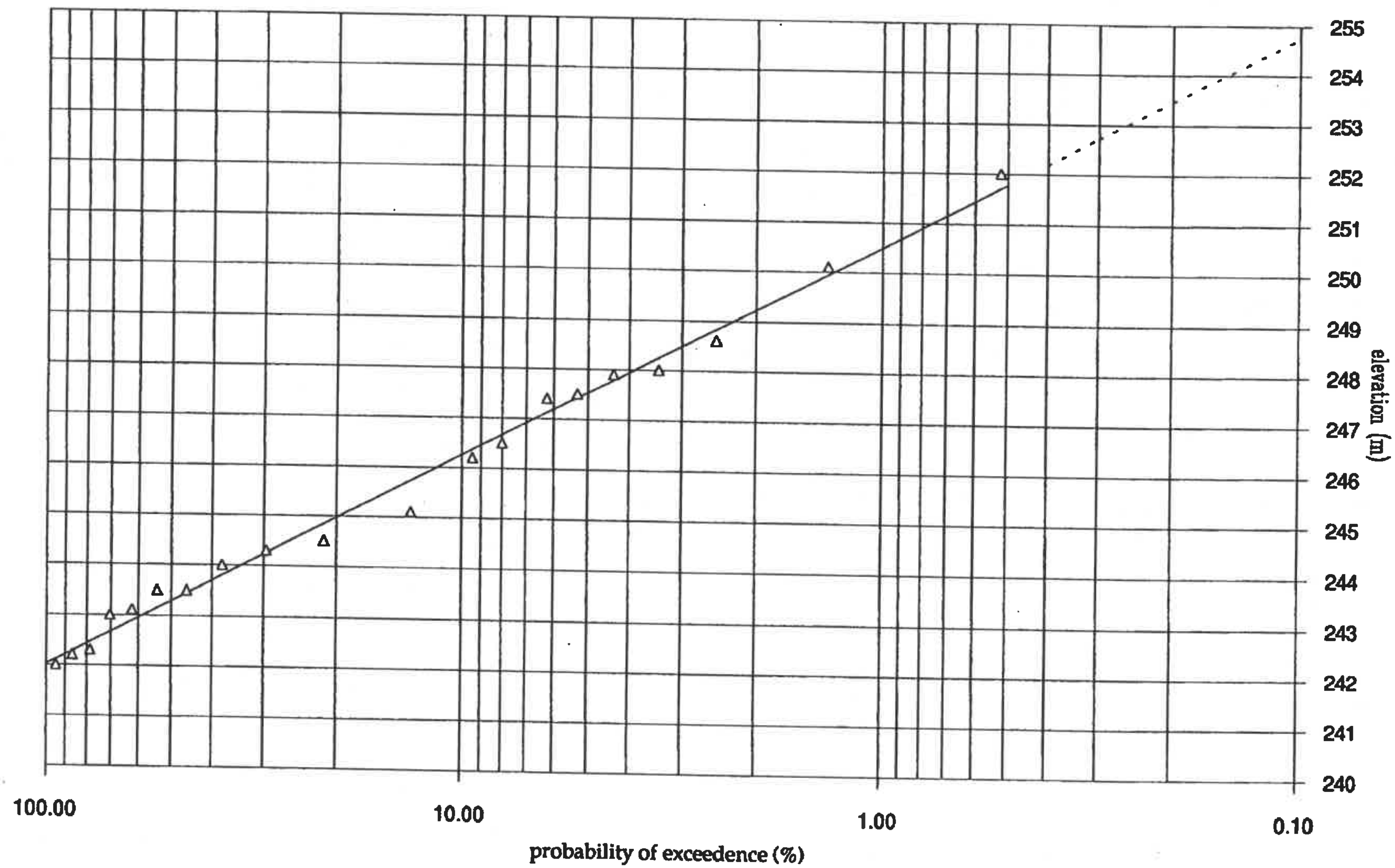


FIGURE 5

APPENDIX A

ACCOUNTS OF THE 1875 ICE JAM FLOOD AT FORT MCMURRAY

ACCOUNTS OF THE 1875 ICE JAM FLOOD AT FORT MCMURRAY

This appendix includes selected exerpts from H.J. Moberly's accounts of the 1875 ice jam flood at Fort McMurray. The exerpts are reproduced from Blench (1964) with the original sources noted as follows.

Exerpts No.	Original Source
1	Moberly H.J. and Cameron, W.B. "When Fur Was King", J.M. Dent and Sons, Ltd., Toronto, 1929, pp. 141-2, pp. 151-2.
2	Hudson's Bay Co. Archives [1]
3	Hudson's Bay Co. Archives [1]

1 A statement of the rules and regulations governing information obtained from the Hudson's Bay Company Archives is included as Attachment No. 1.

ENCLOSURE NO. 1

Extract from copy of letter from Chief Trader Roderick MacFarlane to Chief Commissioner James A. Grahame at Fort Garry, dated 'En Route Clear Water River', 14 June 1875.

"I beg to transmit to you herewith copy of Mr H.J. Moberly's Report to me dated 25 April 1875*...

Fort McMurray is situated on the left bank of the Athabasca River at its confluence with the 'Clear Water' - the buildings are upwards of 50 feet above the winter level of the water. A beautiful Prairie extends for 2 miles to the rear of the post along the clear water river. On the East it is bounded by a hummock of tall pines and poplars and on the South by a high ridge of land. A supply of excellent hay for 60 head of Cattle can be obtained on this Prairie. For the sake of shelter and convenience of watering the Animals during Winter, the Byres were erected in the midst of said timber, also their keeper's house.

On the morning of 20 April last James Daniel (a) the man in charge on becoming aware that the river was breaking up, immediately liberated the Oxen and began to drive them to the highlands beyond the Woods, but before he could get them through, the water rose so suddenly that he barely escaped with his own life and had to leave the poor animals to their fate. Had the Ice, however, not completely surrounded, as it did, the said woods, all of them would have escaped by swimming; but as the water and ice continued high for 5 or 6 days, it was impossible to render them any assistance from the Fort, and the poor brutes after swimming about and making the most strenuous efforts to escape, at length perished one by one, their bodies being since found scattered at intervals in all directions ... The Athabasca broke up very suddenly and quite unexpected while the water rose higher than was ever before known; and after making full and particular enquiries on the spot, I feel satisfied that no blame can justly attach to any one for this unfortunate and much to be regretted occurrence...

A Flood similar to that of 1875 has probably never before happened, and is not likely to occur again so soon; At all events, after this spring's experience, I think I may safely venture to state that with the precautionary measures to be taken in future, no danger need be apprehended that we shall again lose any Animals or property from this cause ...'.

EXERPT NO. 1

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* See Enclosure No. 2.

ENCLOSURE NO. 2

Extract from copy of letter from Henry J. Moberly, clerk in charge of Fort McMurray, to Chief Trader Roderick MacFarlane, officer in charge of Athabasca District at Fort Chipewyan, dated Fort McMurray, 25 April 1875.

'I have now the painful duty to perform of letting you know that we have had a very sudden Inundation here, a few days ago, accompanied by serious loss to the Hudson's Bay Company.

On the 20 Instant about 2 hours after daylight, the river suddenly gave signs of breaking up and in half an hour from that time the water had risen about 60 feet, and the whole place was flooded - the water and ice passing with fearful rapidity and carrying off everything before them. We had just time to escape to the hill, in our immediate vicinity, with the families, bedding and a little Provisions and Ammunition, and to throw up stairs the Furs and most of the valuable property, when the water was already rushing through the Fort. From the time the river first gave signs of starting hardly half an hour elapsed before there was 5 feet of water in the highest building in the Fort, and the Interpreter's house was carried bodily away and dashed to pieces in the Woods; the Workshop and Men's houses have been almost destroyed.

As soon as the river appeared bad, I gave immediate orders to have the Cattle driven to the high lands; and altho' their Keeper James Daniel did all that could be done and even risked his life to save them, still there was no time, as the water rose so suddenly, and I regret to say they all perished ... I had been expecting high water this spring, altho' nothing like what has happened: But the Weather was still very cold - the snow had hardly melted any, and the Ice on the river to all appearance as solid as in Winter - and no one expected the river to break up for 10 days, and then only if the Weather changed and got warm ...

The Ice and Water swept clean over the Prairie up the Clear Water River, which accounts for all the Cattle being drowned as they could not hold against such a torrent ... It may take 2 weeks before the Ice, which is now piled up at least 80 or 100 feet in the Athabasca and Clear Water Rivers, clears off ...'.

(H.B.C. Arch. B.39/c/2)

EXERPT NO. 2

EXERPT NO. 3

"The winter of 1874-75 was a bitter one, with deep snow and never a thaw until April. On the 2nd or 3rd of that month, however, a further heavy fall of snow was followed by a sudden rise in temperature. The change of weather and weight of the melting snow caused the ice for the eighty-five-mile stretch of rapids above the fort to break up, and it came down the Athabasca with terrific force. On striking the turn in the stream at the post it blocked the river and drove the ice two miles up the Clearwater in piles forty or fifty feet high. In less than an hour the water rose fifty-seven feet, flooding the whole flat and mowing down trees, some three feet in diameter, like grass.

Fortunately, the spur of the hill just above the fort sloped to the river, forming an eddy. The flood caught only one of the houses, but this was at once swept away. When the water had mounted almost to the bank I ordered everyone back to the high ground, but fearing that if the rise reached the house its contents would be damaged, I stayed behind and, shutting the doors, commenced to carry what articles I could to the upper rooms.

Presently I noticed water trickling in under the doors. I was too much occupied, however, to take the time to look out, until a large tree dashed in at the window. I knew now that I was in for a cold bath. After I had with great difficulty got out of the trap a hundred yards of water five to ten feet deep still separated me from dry land. When, at times wading and again swimming, I at length reach it and safety no one with ague ever shook harder than did I after my ducking.

We cleared away the snow and made a comfortable camp, and here we remained for five days before we could re-occupy the houses. Out of thirty-seven oxen for the transport service one only escaped. The rest were drowned".

ATTACHMENT NO. 1

HUDSON'S BAY COMPANY

RULES AND REGULATIONS CONCERNING
INFORMATION FROM THE ARCHIVES

1. None of the information supplied by the Company, or extracts therefrom, shall be transmitted to third parties or deposited in University or other Libraries, without the Company's prior permission.

2. Enquirers are reminded that information from the Archives is supplied by courtesy of the Hudson's Bay Company and that the Company itself has undertaken the duty of making its records public. The Company, therefore, discourages the publication of documents, or excerpts, except by itself and in this matter expects the co-operation of all concerned.

3. Information from the Company's Archives is supplied on the express condition that no publication thereof is made without the prior approval of the Company. Where the Company approves publication, acknowledgment shall be made in the following terms:

'Published by permission of the Governor and Committee of the Hudson's Bay Company'.

By order of the Governor and Committee
of the Hudson's Bay Company,

signed (R.A. Reynolds)
Secretary

Revised 27 September 1962.

APPENDIX B

PERCEPTION STAGE FREQUENCY ANALYSIS

PERCEPTION STAGE FREQUENCY ANALYSIS

General

Since the crux of the problem of analyzing historical data is in the assigning of an appropriate rank and record length to each reported flood peak, Gerard and Karpuk (1979) introduced the concept of "Perception Stage" which they defined as the stage above which it is estimated that a particular source would have provided information on the flood peak in any given year. For instance, the perception stage for a resident is the level below which the maximum stage in a given year is likely to have gone unnoticed, or not be recalled by the resident. Obviously this stage would depend on such factors as how far back from the river the resident lived and the residents memory capability (i.e, the perception stage for a 70 year old resident living 100 metres from the river bank is likely to be lower than for a 90 year old resident living 1.0 kilometres from the river bank). The perception stage for archival sources such as journals and newspapers is the minimum flood level that would have warranted a special comment or report. Because the information is normally recorded immediately after the event, the perception stage for such sources will not require modification for failing recollection as may be the case for a long time resident. For hydrometric records the perception stage would be the minimum gage reading for that station. Similar assessments can be made for other sources, and a perception stage allocated to each source for each year of record.

The perception stage allocated to each source for each year of record provides the means whereby the data can be merged to estimate the probability distribution. The advantage of the perception stage concept over conventional methods "follows from the fact that if the source was in a position to notice and recall if this perception stage was exceeded, but didn't report it, it can be presumed the maximum water level was below the perception stage for that year. This simple property of the perception stage allows for the systematic analysis of historical data and although the determination of these perception stages will generally be quite subjective, it is felt that this subjectivity is more than compensated for by the objective analysis of the historical data it affords".

Procedure Followed

Step 1:

A perception stage was assigned for each information source associated with the updated breakup stage data set (Table 4.1 Main Report). The rational for this selection is given in Table B-1.

TABLE B-1

Determination of Perception Stage

Information Source [1]	Perception Level (m)	Rational
Hudson's Bay Co. Archives	247.0	approximate initial flood stage for "prairie" lands east of trading post site
Joseph Shott	249.0	has no recollection of a significant flood prior to 1936 - it is assumed that he would have some recollection of a flood larger than the 1928 event which reached a peak stage of 248.6 m
Northern Alberta Railway Co.	246.0	railway line is close to being overtopped at Waterways at this level
Department of Northern Affairs/Responsible Government Agencies	246.0	approaching initial flood stage in Fort McMurray
Systematic Record	240.0	assumed gauge zero for Clearwater River above confluence with Athabasca River

[1] Refer to Table 2.1 and 3.1 (Main Report)

Step 2:

The breakup stages from the updated data set were plotted on a summary diagram (Figure 4 Main Report) along with their corresponding perception stages as determined in Step 1. The length of time the information source was able to observe or record breakup stages equal to or higher than the perception stage is indicated by a horizontal bar on the summary diagram. The "lowest" perception stage for each year is denoted by the solid portion of the horizontal bars on the summary diagram.

Step 3:

The number of years of record associated with each breakup stage was determined by summing all of the years having a "lowest" perception level at or below that stage (ie., sum of all years marked with a solid bar on Figure 4 at or below a given stage).

Step 4:

The rank of each breakup stage shown on Figure 4 was determined by ordering (based on magnitude) all of the events in the group having a perception stage equal to or lower than the breakup stage for that event.

Step 5:

Probability estimates for each breakup stage were calculated using the formula

$$(m - 0.375) / (N + 0.250)$$

which defines the plotting positions for the log-normal frequency distribution. These calculations are summarized in Table B-2.

Step 6:

The results of the frequency analysis were than presented graphically on Figure 4 (Main Report). A linear regression was used to produce the "best fit" line through the calculated plotting positions.

Table B2 - Calculations for Breakup Stage Frequency Analysis using Perception Stage Method

frequency analysis of known peak breakup stages

gauge zero = 240 m geodetic

year	breakup stage (m)	elevation (m)	perception stage (m)	years of record	rank	exceedence probability	exceedence probability (%)	return period (years)
1875	12	252	7	120	1	0.0052	0.52	192
1936	10.1	250.1	5	120	2	0.0135	1.35	74
1928	8.6	248.6	5	106	3	0.0247	2.47	40
1885	8	248	7	106	4	0.0341	3.41	29
1977	7.9	247.9	0	106	5	0.0435	4.35	23
1963	7.5	247.5	5	106	6	0.0529	5.29	19
1925	7.4	247.4	5	106	7	0.0624	6.24	16
1979	6.5	246.5	0	70	6	0.0801	8.01	12
1962	6.2	246.2	5	70	7	0.0943	9.43	11
1987	5.1	245.1	0	12	2	0.1327	13.27	7.5
1988	4.5	244.5	0	12	3	0.2143	21.43	4.7
1972	4.3	244.3	0	12	4	0.2959	29.59	3.4
1986	4	244	0	12	5	0.3776	37.76	2.6
1984	3.5	243.5	0	12	6	0.4592	45.92	2.2
1985	3.5	243.5	0	12	7	0.5408	54.08	1.8
1989	3.1	243.1	0	12	8	0.6224	62.24	1.6
1990	3	243	0	12	9	0.7041	70.41	1.4
1983	2.3	242.3	0	12	10	0.7857	78.57	1.3
1982	2.2	242.2	0	12	11	0.8673	86.73	1.2
1978	2	242	0	12	12	0.9490	94.90	1.1

APPENDIX C
FLOOD DAMAGE REDUCTION AGREEMENT 1989

Flood Hazard Identification Program Guidelines

Appendix A

An Agreement Respecting Flood Damage Reduction and Flood Risk Mapping in Alberta

AN AGREEMENT RESPECTING

FLOOD DAMAGE REDUCTION

AND

FLOOD RISK MAPPING

IN ALBERTA

THIS AGREEMENT made this 3rd day of April , 1989

BETWEEN:

THE GOVERNMENT OF CANADA
represented by the Minister of the Environment for Canada
(hereinafter referred to as "Canada")

OF THE FIRST PART

AND

THE GOVERNMENT OF THE PROVINCE OF ALBERTA
represented by the Minister of the Environment for Alberta
(hereinafter referred to as "Alberta")

OF THE SECOND PART.

WHEREAS:

(1) Floodplains are land areas adjacent to lakes and watercourses which are subject to natural inundation by floodwaters and the use of which by man invites risk to life and inevitable damage to property in the event of a flood;

(2) In Alberta, many communities, large and small, are situated in otherwise attractive river valley locations for both historical and municipal water supply reasons;

(3) The increase in potential and actual flood damage through greater utilization of flood risk areas has resulted in public pressure on Alberta to construct or provide financial assistance towards the construction of protective works;

(4) These works, which include dams, diversions, dykes and modifications to channels, are costly to construct, operate and maintain, do not generally provide complete protection against all possible flood

damage and tend to attract additional investment in, and use of, areas prone to flooding with the result that the potential for loss of life and property damage is further increased;

(5) Canada and Alberta, through their disaster assistance programs, and the public at large, through contributions, have been called upon to assist in fighting flood emergencies and to extend disaster relief to those affected by the floods;

(6) The potential for flood damage and the costs to Canada, Alberta and the public for such damage can be reduced by control of the uses made of areas prone to flooding;

(7) Alberta has maintained a program of floodplain mapping since the mid-sixties in support of its floodplain management policy of discouraging development of flood prone lands;

(8) Canada and Alberta desire to take full advantage of existing flood risk information generated by Alberta by designating, or designating on an interim basis, a number of flood prone communities in the province;

(9) Canada and Alberta desire to jointly remap and designate an additional group of flood prone communities in the province;

(10) Wide public awareness of the risks and costs involved in occupying areas prone to flooding is likely to result in support for the control of the uses made of such areas;

(11) In special circumstances, structural measures are the most appropriate means of reducing flood damage potential to existing development and therefore may be eligible for cost sharing by Alberta and Canada;

(12) By Order in Council no. P.C. 1988-5/2588 made the seventeenth day of November, 1988 the Governor General in Council has authorized the Minister of the Environment to enter into this Agreement on behalf of Canada; and

(13) By Order in Council no. 754/88 made the fifteenth day of December, 1988 the Lieutenant Governor in Council has authorized the Minister of the Environment to enter into this Agreement on behalf of Alberta.

IT IS THEREFORE AGREED BETWEEN THE PARTIES HERETO AS FOLLOWS:

DEFINITIONS

1. In this Agreement

(a) "design flood" means a flood, which may occur in any given year, of such magnitude as to at least equal a flood having a 100 year recurrence interval, based on a frequency analysis of unregulated historic flood records.

(b) "designation" means formal acceptance by the Ministers of a Steering Committee recommendation as described in Clause 10 to adopt the measures described in Clauses 11 and 12 of the Agreement, to the geographical extent of the flood risk area shown on the maps referred to, having been satisfied that the information provided is adequate and complies with the procedures set out in Schedules B and C of the Agreement.

(c) "flood fringe area" means the portion of any flood risk area that is not in the floodway to which floodproofing constraints upon any undertaking as set out in this Agreement shall apply.

(d) "flood proofing", for the purpose of preventing damage by floods of a specified magnitude, means

i) with respect to an existing structure or other undertaking, the modifications or alteration thereof;

ii) with respect to a new structure or other undertaking, a design, manner of construction, or the siting thereof;

iii) with respect to any structure or other undertaking, the construction of a protective work or alterations, designed for that particular structure or undertaking; and

iv) with respect to protected areas, adequately designed, constructed and maintained flood control works.

(e) "flood risk area" means the area that would be inundated by the design flood.

(f) "flood risk map" means a topographic or other map, upon which the extent of the flooded area for the design or other specified flood, is plotted.

(g) "floodway" means the area within which the entire design flood could be conveyed if the water surface elevation at any point were allowed to increase by an amount as specified by the Technical Committee. Other criteria such as depth or velocity may be used for determining the floodway with the approval of the Technical Committee.

(h) "interim designation" means a designation that may not fully comply with the procedures set out in Schedules B and C of the Agreement.

(i) "Ministers" means the Minister of the Environment for Canada and the Minister of the Environment for Alberta.

(j) "undertaking" means

i) the construction, erection, extension or alteration of any structure, other than

(A) a temporary structure for agricultural use, or

(B) an open air building for recreational use, or

(C) any structure, other than a building, for recreational use, or

(D) structures or works associated with flood control measures;

ii) the use of land, whether surface or subterranean use, for any purpose other than for agriculture, or recreation, or use related to flood control measures.

(k) "zoning authority" means a federal, provincial, regional or municipal planning authority or any other body or agency which has the authority to impose restrictions on land use.

AGREEMENTS

2. It is agreed in principle that the following programs may be undertaken jointly by Alberta and Canada, through appropriate specific agreements between the parties. These programs will be undertaken on the basis of sharing the costs thereof, with the parties paying such percentage as may be agreed upon by the parties, and include, but are not restricted to:

(a) research, studies and surveys, and mapping for the purpose of identifying flood risk and reducing potential flood damage,

(b) the development and installation of flood forecasting and flood warning systems,

(c) the planning of flood proofing measures or flood control works,

(d) the construction of flood proofing measures or flood control works,

(e) the acquisition of land for the purpose of reducing flood damage, including, but not being limited to, the acquisition of property or easements for accommodation of flood warning systems, for flood proofing measures, for flood control works, and as a preventative measure against loss of life and property damage arising from floods.

FLOOD RISK MAPPING AND PUBLICATION

3. Canada and Alberta agree to undertake jointly a program which will ensure the provision of adequate information on the extent of flood risk areas within Alberta through,

(a) the preparation of maps delineating flood risk areas in Alberta, and the indication thereon of the areal extent of the design flood,

(b) the preparation of information maps and such other forms as are pertinent, and

(c) the dissemination of such information to interested agencies or individuals.

4. The program shall include, as hereinafter provided,

(a) the determination of the location and extent of the flood risk area at selected areas identified in Schedule A,

(b) the preparation and dissemination of information about the flood risk area through flood risk maps, public information maps and such other forms as are pertinent, to zoning authorities and to persons, including governments and agencies thereof, who may be considering at any time an undertaking at or near a place named in Schedule A,

(c) the review, if necessary, and acceptance, as appropriate, by the Steering Committee, of flood risk mapping previously prepared by Alberta as identified in Schedule A,

(d) the designation or interim designation of the flood risk area by the Ministers,

(e) a commitment by Canada and Alberta to apply the measures described in Clauses 11 and 12,

(f) a commitment, at the discretion of Alberta, to encourage the participation of local authorities, including sharing the costs with Alberta of new or revised engineering scale mapping and new public information mapping undertaken pursuant to this agreement.

5. (1) The hydrologic and hydraulic procedures set out in Schedule B and the surveying and mapping procedures set out in Schedule C shall be complied with in:

(a) carrying out all new studies and surveys necessary to determine the location and extent of the flood risk area referred to in Clause 4 (a);

(b) preparing and printing the maps referred to in Clause 4 (b); and

(c) the assessment by the Technical Committee of the adequacy of completed studies.

(2) A Party may, with the approval of the Steering Committee, enter into a contract to have any work referred to in Clause 5(1) done by a third party.

6. Any map, or other form of information made available under the Program as set out in Clause 4 (b), shall bear identification as a joint publication of both Parties.

7. With the exceptions of Clause 13 and Clause 18, this Agreement may be reviewed by the Steering Committee from time to time and may be amended, and any amendments thereof shall be confirmed by an exchange of letters between the Ministers.

STEERING COMMITTEE

8. (1) A Steering Committee shall be established, consisting of two members appointed by the Minister of the Environment for Canada and two members appointed by the Minister of the Environment for Alberta.

(2) The appointment of a member as chairperson shall be for a one year term and shall alternate between the Canada members and the Alberta members beginning with an Alberta member.

(3) The Steering Committee shall:

(a) be responsible for the general administration of this Agreement;

(b) establish the financial procedures referred to in Clause 15;

(c) keep minutes of its meetings;

(d) review and, if satisfactory, approve any proposals which would require that a contract or contracts be entered into by either Party pursuant to Clause 5 (2);

(e) within three months after receiving a map compiled under this Agreement at a selected area listed in Schedule A, or remapped pursuant to Clause 8 (3) (e) (ii) or 8 (3) (f) (ii), review the map and material relevant thereto, and:

i) if satisfied that the information contained therein is adequate and that the procedures set out in Schedules B and C are complied with, recommend to the Ministers that the flood risk area shown on the map be so designated; or

ii) if not so satisfied, ensure the remapping of the areas prone to flooding at the place or places shown on the map; or

iii) recommend to the Ministers that the flood risk area shown on the map be interim designated.

(f) following completion of further work in accordance with the procedures set out in Schedules B and C as commissioned by the Technical Committee, review interim maps already published as listed in Schedule A.2 showing the location and extent of any area or areas within Alberta that are prone to flooding; and

i) if satisfied that the new information contained thereon is adequate and that the procedures set out in Schedules B and C are complied with, recommend to the Ministers that the flood risk area shown on the map be so designated; or

ii) if not so satisfied, ensure the remapping of the areas prone to flooding at the place or places shown on the map; or

iii) recommend to the Ministers that the flood risk area shown on the map continue to be interim designated;

(g) upon the Ministers making the designation, publish or cause to be published the map showing such designated flood risk areas and where applicable, designated floodways;

(h) be responsible for the preparation of all material, other than maps, in which information is to be made available pursuant to Clause 3 (b);

(i) be responsible for carrying out the public information program referred to in Clause 3 (c);

(j) establish a Technical Committee and any other committees as necessary;

(k) prepare an annual program of work, an annual budget and an annual report to the Ministers;

(l) where the Parties have agreed or agree to a comprehensive river basin planning and management program or other agreement under which measures to reduce potential flood damage are, or are to be, carried out, maintain such coordination with the committee or board responsible for the implementation of that program as is necessary to ensure adequate exchange of information and to avoid duplication under this Agreement; and

(m) carry out such related duties as the Ministers may request.

TECHNICAL COMMITTEE

9. (1) The Technical Committee shall report to the Steering Committee.

(2) The Technical Committee shall

(a) recommend to the Steering Committee the sequence in which the areas listed in Schedule A shall be mapped, remapped, published, republished or accepted as they currently exist;

(b) where a contract is to be entered into by a Party pursuant to Clause 5 (2), review the contract proposals received and, if satisfactory, recommend a contract to the Party;

(c) ensure that the specifications set out in Schedules B and C are complied with in each study or survey undertaken and each map prepared pursuant to Clause 5;

(d) ensure the timely transfer of information between the Parties, including any changes in policies;

(e) review maps already prepared by either Party showing the location and extent of any area or areas within the Province that are prone to flooding;

(f) recommend to the Steering Committee a survey and mapping inspector pursuant to Schedule C for assisting, as required, the Technical Committee in the evaluation of completed flood risk maps;

(g) upon determining that a map reviewed pursuant to paragraph (e) or prepared pursuant to Clause 5 (1) (b) for publication complies with the specifications set out in Schedules B and C, recommend to the Steering Committee that the flood risk areas and floodways shown therein be designated;

(h) upon determining that a map referred to in paragraph (e) does not comply with the specifications set out in Schedules B and C, advise the Steering Committee whether

i) an interim designation, pursuant to Clause 10 (1), of the flood risk areas shown therein should be made, or

ii) remapping of the areas prone to flooding at the place or places shown in the map should be carried out; and

(i) carry out such related duties as the Steering Committee may request.

DESIGNATION

10. (1) The Ministers shall, upon receipt of a recommendation pursuant to Clause 8 (3) (e) or 8 (3) (f), determine whether such recommendation shall be accepted, and upon acceptance, designate or interim designate the flood risk areas and the same shall have effect until otherwise changed by the Ministers.

(2) Where the Ministers fail to make a designation within six months after receiving a recommendation that a flood risk area be designated, after full consultation either Party may unilaterally implement the policies described in Clauses 11 and 12 and the same shall have effect until otherwise changed by the Party concerned.

11. (1) Upon designation or interim designation of a flood risk area pursuant to Clause 10:

(a) Canada shall ensure that its departments and agencies do not engage in any further undertakings that are vulnerable to flood damage and are to be located in the designated or interim designated area; and

(b) Canada shall ensure that its programs of financial assistance to third parties are administered so that no assistance is given to any further undertakings in a designated or interim designated area that are vulnerable to flood damage and, without limiting the generality of the foregoing:

i) The Department of Regional Industrial Expansion and the Western Diversification Office shall provide no loan, grant or any other form of financial assistance for such undertakings, and

ii) The Canada Mortgage and Housing Corporation shall award no financial assistance, in the form of loans, grants, guarantees and insurance or, in any other form, for such undertakings;

(c) Canada shall encourage the appropriate authorities under its jurisdiction to impose land use restrictions that will prohibit further undertakings in a designated area or interim designated area that are vulnerable to flood damage, or where appropriate, make such undertakings subject to requirements for adequate floodproofing; and

(d) paragraphs (a) and (b) shall not apply for locations in the flood fringe area with respect to:

i) Any undertaking that is adequately floodproofed,

ii) Any assistance to a third party with respect to an undertaking that is adequately floodproofed and is to be located in the flood fringe area.

(2) Upon designation or interim designation of a flood risk area pursuant to Clause 10:

(a) Alberta shall ensure that its departments and agencies do not engage in any further undertakings that are vulnerable to flood damage and are to be located in the designated or interim designated area; and

(b) Alberta shall ensure that its programs of financial assistance to third parties are administered so that no assistance is given to any further undertakings in a designated or interim designated area that are vulnerable to flood damage; and

(c) Alberta shall encourage the zoning authorities under its jurisdiction to impose land use restrictions that will prohibit further undertakings in a designated or interim designated area that are vulnerable to flood damage, or where appropriate, make such undertakings subject to requirements for adequate floodproofing; and

(d) paragraphs (a) and (b) shall not apply for locations in the flood fringe area with respect to:

i) Any undertaking that is adequately floodproofed.

ii) Any assistance to a third party with respect to an undertaking that is adequately floodproofed.

(3) Indian reserve lands and other lands set aside or held for Indians shall be excluded from designation.

12\. (1) Subject to sub-clauses (2) and (3), assistance under any Alberta or Canada disaster assistance program shall not extend to costs and losses incurred as the result of a flood, with respect to any undertaking commenced, or moveable placed, within any area after its designation or interim designation as a flood risk area.

(2) Sub-clause (1) does not affect the application of any disaster assistance program by either Alberta or Canada in those circumstances where the prerequisities for assistance are met, to costs and losses incurred:

(a) with respect to any structure including any undertaking commenced, or any moveable placed, within any area prior to its designation or interim designation as a flood risk area;

(b) with respect to any structure, including an undertaking or moveable located outside the designated or interim designated flood risk area;

(c) with respect to any structure, including any undertaking commenced, or moveable placed, within an area outside the floodway subsequent to its designation or interim designation as a flood risk area, which is adequately floodproofed;

(d) as a result of a disaster other than flood or a flood exceeding the design flood.

(3) Where extraordinary circumstances in a particular situation warrant such action, Alberta or Canada may provide assistance in accordance with the terms of any disaster assistance program with respect to costs or losses described in sub-clause (1).

ADMINISTRATION

13. (1) Subject to sub-clause (2),

(a) the total sum for the carrying out of this agreement shall not exceed $5,500,000.00 which sum shall be contributed to equally by the parties and shall be paid in the manner referred to in Clauses 14 and 15.

(b) paragraph (a) shall not include any costs incurred by either Party for the mapping of any flood risk area prior to April 1, 1988.

(2) Each Party shall bear the entire costs of the salary, including employee benefits and travelling and related expenses of:

(a) each of its members of the Steering and Technical Committees;

(b) any other employee who, although engaged in an activity hereunder, does not have a specified portion of his work day, week, month or year assigned exclusively to the carrying out of this Agreement; and

(c) such costs are not shareable and shall not count against the limit stipulated in sub-clause (1).

14. Where a Party supplies, for the purpose of carrying out this Agreement:

(a) material, equipment or other property;

(b) services, other than the services referred to in Clause 13 (2), the same shall be supplied at cost, including the cost of salaries and employee benefits. Acceptable employee benefit costs are to be determined by the Steering Committee annually.

15. (1) Alberta shall:

(a) pay such costs as they come due; and

(b) where the cost is incurred by Canada, reimburse Canada upon submission of the claim in accordance with procedures to be established by the Steering Committee for such purpose.

(2) Canada shall, upon receipt of claims from Alberta, pay at least upon a quarterly basis, its share of the costs paid by Alberta pursuant to sub-clause (1).

16. (1) Each Party shall maintain adequate documentation and records of the costs that are to be shared by the Parties and which are incurred by it and shall, upon request, make available such documentation and records for examination by auditors of the other Party.

(2) Any discrepancy disclosed by audit shall be promptly adjusted between the Parties.

17. The provisions of this agreement are subject to the appropriation of funds by the Parliament of Canada and the Legislative Assembly of Alberta.

18. Subject to paragraphs (a) and (b), this Agreement shall terminate on the 31st day of March, 1998, unless before that date the Agreement is amended in respect to its termination date.

(a) The provisions of the Agreement respecting the payment of the costs of the flood risk area mapping program shall be in effect until the 31st day of March, 1994; and

(b) Canada and Alberta recognize the need to continue to meet the provisions of Clauses 11 and 12.

19. No member of the Parliament of Canada or of the Legislative Assembly of Alberta shall hold, enjoy or be admitted to any share, part or benefit from this Agreement or any agreement, contract or benefit arising therefrom.

IN WITNESS WHEREOF the Minister of the Environment for Canada has hereunto set his hand on behalf of Canada and the Minister of the Environment for Alberta has hereunto set his hand on behalf of Alberta.

Signed on behalf of Canada by the Minister of the Environment in the presence of

Signed on behalf of Alberta by the Minister of the Environment in the presence of

Signed by the ~~Minister of Public Works for Canada and~~ Minister responsible for the Canada Mortgage and Housing Corporation in the presence of

Signed by the Minister responsible for Western Diversification in the presence of

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Signed by the Minister of
Regional Industrial Expansion
for Canada in the presence of

M. Houlton
____

Approved Pursuant to the Alberta
Department of Federal and
Intergovernmental Affairs Act

____
Minister of Federal and
Intergovernmental Affairs

SCHEDULE A

This schedule lists in three parts urban communities in Alberta that:

1. have been mapped by the province and can be used for final designation;
2. have been mapped by the province and have been chosen for interim designation. The mapping for these communities will require updating before final designation will occur.
3. may or may not have been mapped but need new or additional mapping.

A.1: Final Designation

Communities which can be designated with the use of existing maps:

Community	River	Legal Limits of Study Area
Calgary	Bow Elbow Nose Creek	SW 3-23-2-W5 to NE 25-22-1-W5 SE 32-23-1-W5 to NW 14-24-1-W5 SW 13-24-1-W5 to NE 36-26-1-W5
Cochrane	Bow	NW 4-26-4-W5 to SW 1-26-4-W5
Drumheller	Red Deer	NW 8-29-20-W4 to NW 29-27-18-W4
Fort McMurray	Athabasca Clearwater	E1/2 20-89-9-W4 SE 28-89-9-W4 to NW 2-89-9-W4
Medicine Hat	South Saskatchewan	NE 35-12-6-W4 to SE 5-13-5-W4
Okotoks	Sheep	NW 29-20-29-W4 to NW 22-20-29-W4
St. Albert	Sturgeon	SW 32-53-25-W4 to NW 10-54-25-W4

A.2: Interim Designation

Communities which may be interim designated:

Community	River	Legal Limits of Study Area
Airdrie	Nose Creek	SE 35-27-1-W5 to SE 1-27-1-W5
Black Diamond/ Turner Valley	Sheep	SW 1-20-3-W5 to NW 21-20-2-W5
Bragg Creek	Bow	NE 11-23-5-W5 to SE 13-23-5-W5
Edmonton	North Saskatchewan	NE 29-51-25-W4 to NE 29-53-23-W4
Fort MacLeod	Oldman	SE 9-9-26-W4 to NW 20-9-24-W4
High River	Highwood	NE 25-18-30-W4 to NW 17-19-28-W4
Lethbridge	Oldman	NW 22-8-22-W5 to NE 20-9-22-W5
Pincher Creek/ Kettles Creek	Pincher Creek Kettles Creek	SE 22-30-6-W5 to SE 25-30-6-W5 NE 14-30-6-W5 to SE 25-30-6-W5

Community	River	Legal Limits of Study Area
Ponoka	Battle	SE 36-42-26-W4 to NW 10-43-25-W4
Red Deer	Waskasoo Creek	NE 8-38-27-W4 to SW 21-38-27-W4
Vegreville	Vermilion	SW 15-52-14-W4 to NE 32-52-14-W4
Whitecourt	McLeod Athabasca	SE 22-59-12-W5 to NW 35-59-12-W5 NE 33-59-12-W5 to NW 30-60-11-W5

A.3: New Mapping Required

Community	River	Legal Limits of Study Area
Athabasca	Athabasca	NE 19-66-22-W4 to SW 28-66-22-W4
Barrhead	Paddle	NW 18-59-3-W5 to SW 14-59-3-W5
Camrose	Camrose Creek	NW 11-47-20-W4 to NE 21-46-20-W4
Canmore	Bow	SE 13-25-11-W5 to NE 18-24-9-W5
Carbon	Kneehills Creek	NW 15-29-23-W4 to SW 14-29-23-W4
Cardston	Lee Creek	SW 36-2-26-W5 to SW 15-3-25-W5
Coleman/ Blairmore/Frank	Crowsnest	SE 12-8-5-W5 to SE 30-7-3-W5
Didsbury	Rosebud	SW 30-31-1-W5 to NW 9-31-1-W5
Drayton Valley	West Creek	SW 5-49-7-W5 to NE 18-49-7-W5
Edmonton	North Saskatchewan	SW 35-50-27-W4 to SW 7-56-21-W4
Exshaw	Canyon Creek	SW 23-24-9-W5 to SE 27-24-9-W5
Fort Vermilion	Peace	SW 29-108-13-W5 to NE 32-108-12-W5
Hinton	Hardisty Creek	NE 23-51-25-W5 to SW 13-51-25-W5
Lacombe	Wolf Creek	SE 19-40-26-W4 to SE 32-40-26-W4
Lamont	Lamont Creek	NW 20-55-19-W4 to NE 16-55-19-W4
Manning	Notikewin	NE 21-91-23-W4 to NW 27-91-23-W4
Milk River	Milk	NW 20-2-16-W4 to SE 22-2-16-W4
Millet	Pipestone Creek	SW 29-47-24-W4 to NW 32-47-24-W4
Paddle Prairie	Boyer	NW 18-103-21-W5 to SE 30-103-21-W5
Penhold	Waskasoo Creek	SW 24-36-28-W4 to NW 6-37-27-W4
Radway	Namepi Creek	NE 31-58-20-W4 to SE 32-58-20-W4
Red Deer	Red Deer	NE 13-38-28-W4 to SE 2-39-27-W4
Rochester	Tawatinaw	SW 30-62-23-W4 to NE 13-62-24-W4
Rocky Mountain House	North Saskatchewan	NE 21-39-7-W5 to SW 4-40-7-W5
Rosebud	Rosebud	NE 12-27-22-W4 to SW 18-27-21-W4

Community	River	Legal Limits of Study Area
Rycroft	Spirit	SW 16-78-5-W6 to SE 21-78-5-W6
Sangudo	Pembina	SE 36-56-7-W5 to SE 1-57-7-W5
Slave Lake	Sawridge Creek	SW 5-73-5-W5 to NW 25-72-6-W5
Stettler	Redwillow Creek	SW 7-39-19-W4 to SE 31-38-19-W4
Sundre	Red Deer Bearberry Creek	NW 28-32-5-W5 to SE 22-33-5-W5 SW 12-33-6-W5 to SW 6-33-5-W5
Two Hills	Vermilion	NE 25-54-13-W4 to NW 28-54-12-W4
Watino	Smoky	NW 27-77-24-W5 to SW 2-78-24-W5
Writing-On-Stone Park	Milk	SE 3-2-13-W4 to NE 31-1-12-W4