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Year 1 Summary Report
Surface Water & Integration

Integrated Assessment of Water Resources for Unconventional Oil and Gas Plays, West-Central Alberta

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Prepared by:
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EXECUTIVE SUMMARY

The Integrated Assessment of Water Resources for Unconventional Oil and Gas Plays, West-Central Alberta Project is a multi-stakeholder project that is building a regional understanding of surface water, groundwater and deep saline water resources and disposal zone is a large portion of west-central Alberta.

There are three main areas of focus for the project, surface water, non-saline and saline groundwater resources. The project is compiling existing data and research results, interpreting key factors controlling water availability, and integrating the results from surface to deep subsurface zones.

This report summarizes activities completed and results from the first year of the project for the surface water and data integration components. First year deliverables for surface water include this report, regional analyses of several components of the water cycle and an extensive GIS database of foundational and related information. Integral data sets compiled as part of the project, and analysis results are also presented on the internet through the NOLA framework - a web-mapping tool available to partners for the duration of the project. NOLA also provides the key integrative functionality, presenting research results from the surface water, shallow groundwater and deep saline groundwater components in a cohesive framework that allows for direct comparison across the study area.

Separate reports have been produced for the non-saline and saline groundwater components. While groundwater components are discussed on occasion within this report, the summary reports for the shallow, non-saline and deep saline groundwater components provide more detailed and complete information.

The Project is a joint initiative of Petrel Robertson Consulting, Foundry Spatial, and Strategic West Energy, and is supported by the Petroleum Technology Alliance of Canada, the Canadian Association of Petroleum Producers, Canadian Natural Resources, Cequence Energy, Chevron, ConocoPhillips, Encana, Husky Energy, Shell and Talisman Energy.

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OBJECTIVES

Philosophy

Exploration and development of the unconventional hydrocarbon resources within the study area is at an early stage, and a broad understanding of the water availability from surface water, saline and non-saline groundwater will provide useful information in development planning, complementing other information such as access to infrastructure, locations of sensitive habitat, and land use.

Freshwater alternatives are desirable, but viable options may not be available at all locations within the study area. When freshwater is used, consideration of other existing users and the needs of the environment is essential. In order to understand the spatial and temporal dynamics of water availability, data for surface water, saline and non-saline groundwater has been compiled and analysed.

The Canadian Association of Petroleum Producers (CAPP) has developed several operating practices relating to hydraulic fracturing (CAPP 2012). The water sourcing, measurement and reuse practice outlines industry commitments relating to water acquisition. One commitment is to ensure the sustainability and safeguarding of surface water and groundwater quantity, and to make use of freshwater alternatives where appropriate. The project is well aligned with the operating practice, as the key underlying objective, is to produce a regional understanding of the potential availability of surface water, saline and non-saline groundwater. Project results will allow industry to evaluate options across the plays, and use the information generated through the project in the development of water management plans. Furthermore, as project results will be public, industry will be able to engage with decision makers in regulating bodies and with public stakeholders, to explore available options and communicate the rationale behind their water sourcing decisions.

Study area overview

The study area covers a large portion of western Alberta, stretching from the Peace River in the north across the Athabasca and North Saskatchewan River watersheds to the headwaters of the Red Deer River near Sylvan Lake. Internally within the project, there are two study areas instructing detailed work. Deep saline aquifer work covers the combined fairways of the Montney and Duvernay plays, limited towards the Rocky Mountains by the edge of the deformed belt, and up dip by the inferred hydrocarbon potential type within the plays. The surface study area covers the entire subsurface study area, and extends to the headwaters of the drainages that pass through it as those areas influence water availability downstream (Figure 1).

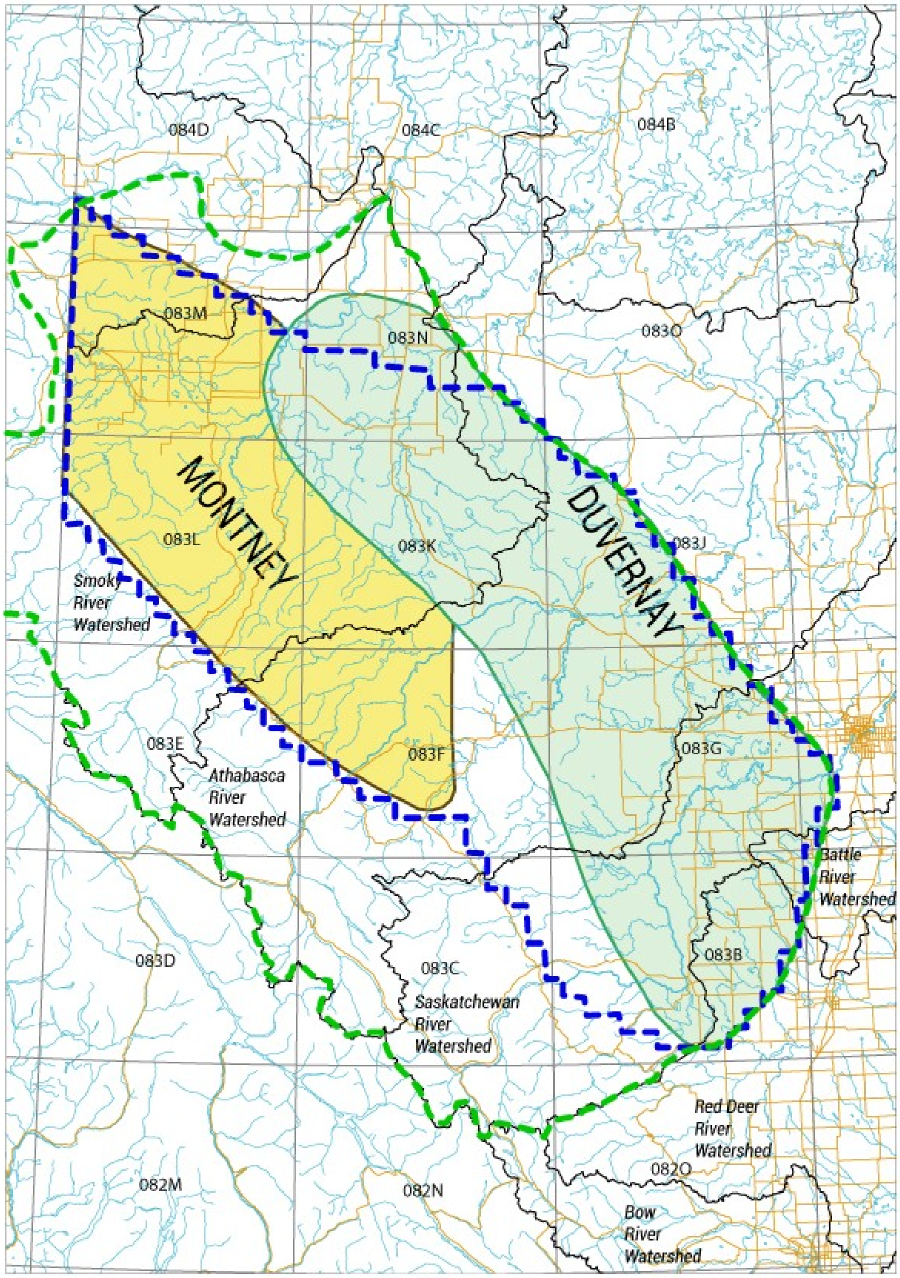

Figure 1. Integrated Assessment of Water Resources for Unconventional Oil and Gas Plays, West-Central Alberta, surface (green, 142,000 km^2) and subsurface (blue, 91,000 km^2) study areas.

A small portion of the study area extends into British Columbia, to include the Pouce Coupe River, which flows west from Alberta, through the town of Dawson Creek in BC, and then back into Alberta before joining the Peace River. The approximate area of the surface study area is 142,000 km^2. The approximate area of the subsurface study area is 91,000 km^2, and covers nearly 1200 townships.

Geographic profile and settlements

From the significant peaks in the Rockies, several of which remain glaciated, elevations decrease moving northeast across the study area. The Swan Hills and the area between Fox Creek and Edson are higher in elevation than the portions of the study area to the north and southeast from there (Figure 2).

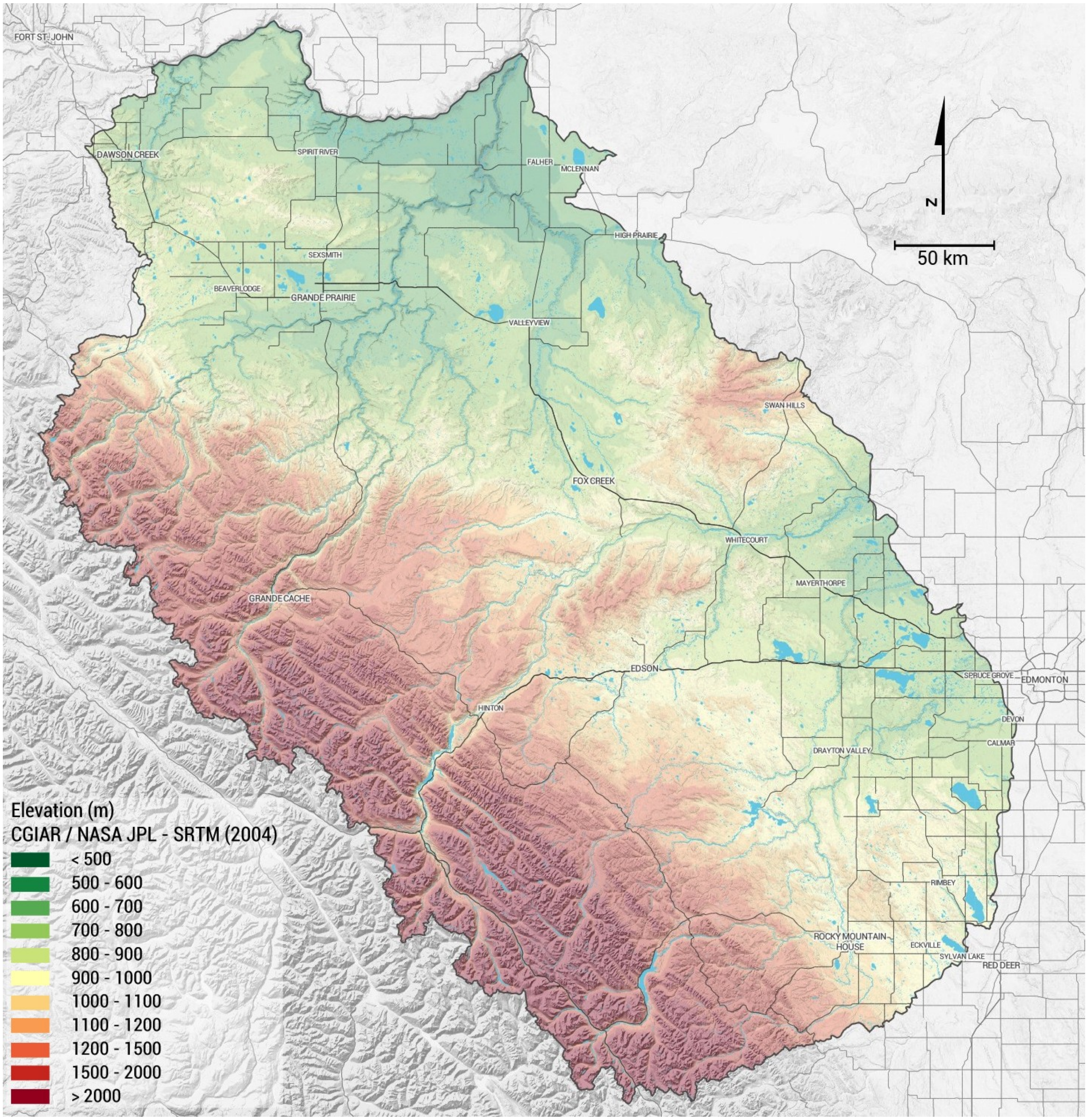

Figure 2. Ground surface elevation, masl (CGIAR 2004).

The project area includes parts of several of the natural regions of Alberta, including the Rocky Mountains, Foothills, Boreal Forest and Parkland. The majority of the project area is within the Upper and Lower Foothills natural sub regions, with central and dry mixedwood sub regions along the eastern and northern limits (Natural Regions Committee 2006). The majority of the project area is forested, with wetlands interspersed throughout and agricultural and rangeland within the mixedwood sub regions.

The major rivers flowing through the study area include the Peace, Athabasca and North Saskatchewan Rivers (Figure 3). Major tributaries of these include the Smoky, Wapiti, McLeod, and Pembina Rivers.

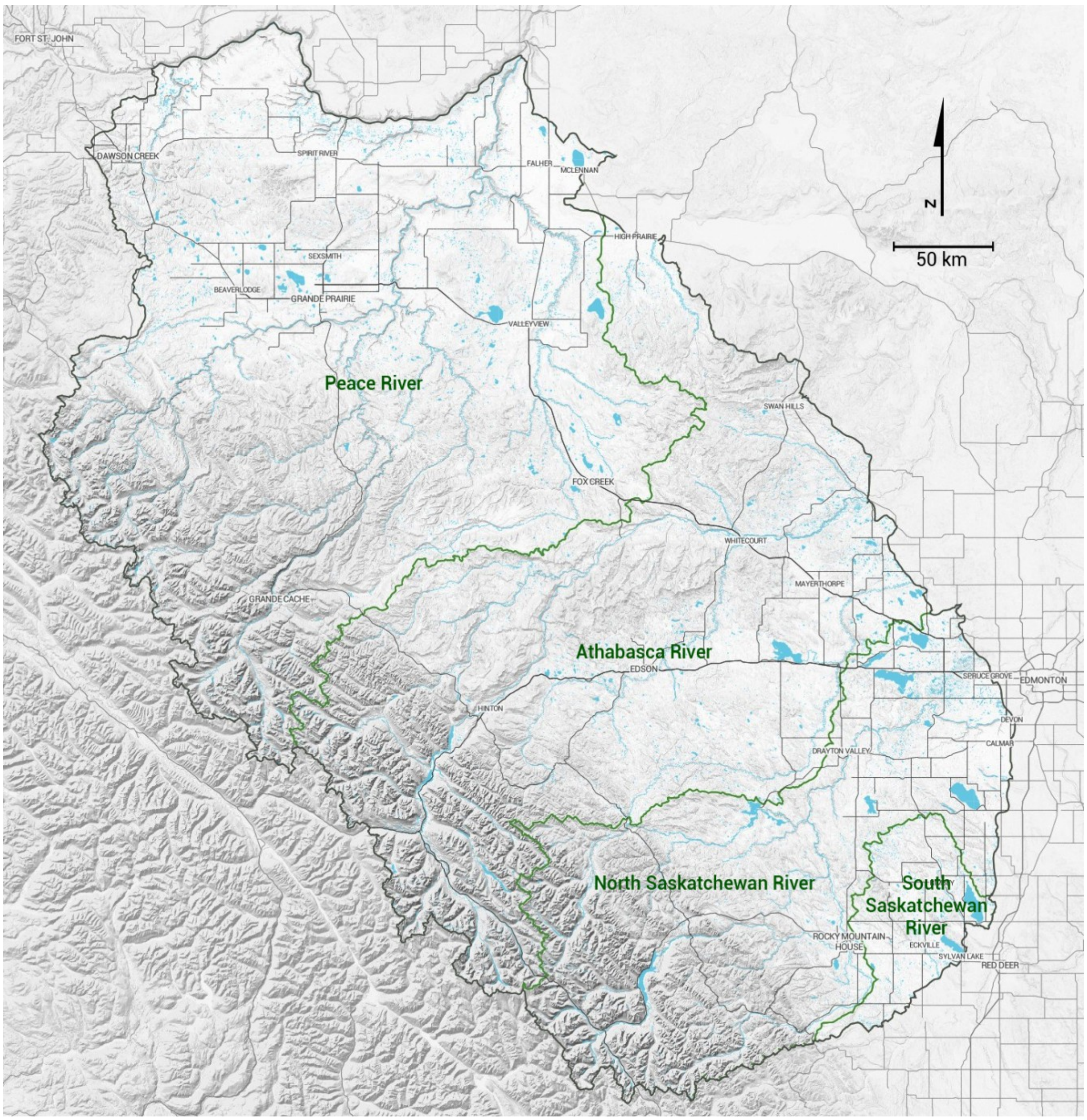

Figure 3. Major drainage basins.

The drainage divide between the Athabasca and North Saskatchewan Rivers is also a continental drainage divide, with northern drainages flowing through the Mackenzie River to the Arctic Ocean, and southern drainages flowing through the Nelson-Churchill River system to Hudson Bay. From the southeast of the study area, the headwaters of the Red Deer River flow to the South Saskatchewan River.

Grande Prairie is the largest settlement in the northern portion of the study area. It is connected by Highway 40 which travels south through Grande Cache and the foothills to junction with Highway 16, and by Highway 43 which extends west to Dawson Creek and east to Valleyview. Highway 43 continues south and eastward from Valleyview through Fox Creek and Whitecourt, ultimately ending in Edmonton 20 km outside of the eastern extent of the study area. Highway 16 crosses from BC through the Rockies, passing through Jasper, Hinton and Edson which are the major settlements within the central portion of the study area, en route to Edmonton. Rocky Mountain House and Drayton Valley are located within the southern portion of the study area, with Sylvan Lake and Red Deer just outside the southeast boundary. The populations within these major settlements and also within First Nations reserves located within the study are provided in Table 1.

Table 1. Population of Settlements and First Nations Reserves within the study area (Statistics Canada 2013).

Settlement	Population (2011)
Dawson Creek (BC)	11,583
Drayton Valley	7,049
Edmonton	812,201
Edson	8,475
Fox Creek	1,969
Grande Cache	4,319
Grande Prairie	55,032
Hinton	9,640
Jasper	4,051
Red Deer	90,564
Rocky Mountain House	6,933
Sylvan Lake	12,327
Valleyview	1,761
Whitecourt	9,605

First Nation Reserves	Population (2011)
Horse Lakes 152B	402
Sturgeon Lake 154,A,B	1,186
East Prairie Metis	366
Alexander 134A	1,027
Alexis 133	817
Stony Plain 135	987
Pigeon Lake 138A	485
Wabamun 133A, 133B	1,086
O'Chiese 203	751
Sunchild 202	677

Integration

Each component of the project has been designed in consideration of the others. Data compilation and analysis is a critical step in the evaluation of each potential water source, and all data is being integrated in a spatially enabled relational database. This ensures that data products are compatible in scale and content for analysis, and can be easily integrated into partners' corporate systems upon completion. At the surface water / groundwater interface, areas of recharge and discharge are relevant to both baseflow conditions in rivers and streams, and replenishment of groundwater aquifers. While the speed at which water moves differs by orders of magnitude, surface water and fresh, shallow groundwater resources are intimately linked.

In Alberta, the Base of Groundwater Protection (BGWP) distinguishes saline and non-saline groundwater aquifers. Saline groundwater is defined based on a threshold of 4000 mg/L of total dissolved solids (TDS). The bottom of the lowermost geologic formation bearing water with TDS less than 4000 mg/L, as assessed by the Alberta Geological Survey, acts as the base of groundwater protection. In some portions of Alberta, where the Paskapoo Formation is present, for example, the depth of the BGWP reaches several hundred meters. Characterization of non-saline groundwater resources is typically performed drawing heavily on water well drilling records. Very few water wells exist where the Paskapoo reaches these depths, and characterization of the groundwater resource must be done using petroleum borehole methods. Where the Paskapoo Formation, at shallower depths, can be described using similar methods to other shallow non-saline sources, at deeper depths its description is an example of overlap in methods between deep saline aquifer characterization and non-saline groundwater work.

Moving beyond integration in the context of methods and processes in water source assessment, it is critical in the communication of results. This is one of the key benefits in pursuing an integrated approach. The compiled database and results of project analyses are displayed in an interactive mapping framework, NOLA. The system allows for users to visually explore and interpret the data using overlay analysis, and also to interact with spatial, temporal, hydrologic and other analyses describing characteristics of several different themes related to water availability in 34 sub-basins within the study area (Figure 4). In doing so, the spatial context of water availability from each component is exposed, both in relative terms and absolutely in relation to the watersheds, socio-geography, and developed infrastructure in a local area.

The sub-basins used correspond to the Fundamental Drainage Areas from the Atlas of Canada and sub-sub-component basins used by the Water Survey of Canada. The code for each sub-basin match with the first four characters of hydrometric stations located within the sub-basin.

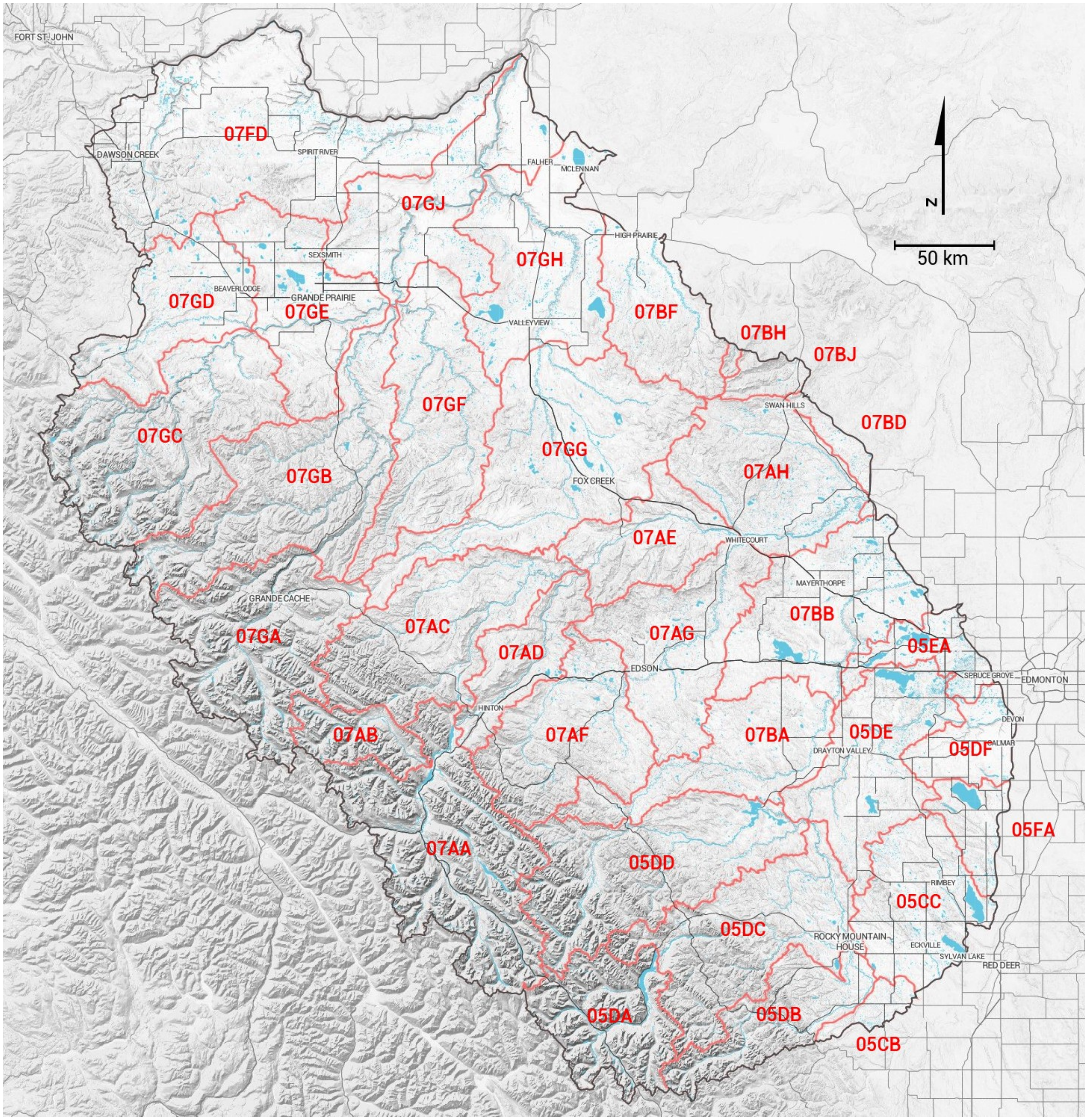

Figure 4. Sub-basins within the study area.

METHODS

GIS and Database Framework

The characteristics of the study area and data identified for compilation put several criteria on the type of data framework needed. Fast, responsive access to very large datasets was required for display and analysis. Robust database administration software was required to define and maintain complex relations between spatial and tabular data sources. Process automation was desired to update individual data sources as required. As this project is a collaborative effort between multiple groups, the relational database framework allows for secure multi-user access to the data without creating branching versions of the data. All of these features make the relational database a robust environment to store and access the data for analysis.

The PostgreSQL, PostGIS, Quantum GIS, gvSIG, Mapnik, PROJ.4, GDAL, Leaflet, OpenLayers, HTML, CSS, Bootstrap, PHP, JavaScript, jQuery and amCharts technologies were used to organize, manipulate, analyze and present data within the project. Using a web interface for analysis meant that a functional high-speed, multi-user environment is used for consistency of data and clarity in communications in the development of this report. Much of the initial data processing was completed on an in house server for the storage of large datasets, running the analysis and managing data backups. Products from the analysis were held on a secure webserver for map assembly and analysis during the project. The NOLA mapping framework, discussed in the 'Integration' section of this report, was used for the purpose of data analysis and display. Metadata has been maintained in the database and will be included with deliverables to project partners.

Data and Analysis

The primary Year 1 objective for the project was to compile data and information on the key components of the water cycle that influence, and can be used to characterize, surface water availability across the study area. Project activities were designed to provide immediate, useful information to project partners to be used in building knowledge about water resources, and also to prepare data and analyses to be used in Year 2 activities which centre around fully distributed modeling of surface water resources.

Themes

Climate

Climate in the context of the project refers to several processes or components of the hydrologic, or water cycle. As opposed to weather, which is an instantaneous measurement of conditions, climate is a more general characterization of longer term average conditions. Precipitation, both as rain and snow, is the sole input to the water cycle. The timing and amount of precipitation during the ice-free season, and over-winter accumulations of precipitation as snow influence the timing and amount of runoff in streams. Temperature influences the form of precipitation as it falls, and also whether it is stored as snow, infiltrates or runs off. Temperature variations during the spring related to elevation changes control the rate of snow melt. Evaporation, where water turns to vapor as a result of combined solar radiation, wind and temperature, moves significant amounts of precipitation back to the atmosphere from wet ground and water bodies. Transpiration, or the respiration of water by plants, is also a significant transfer of water back to the atmosphere from surface and ground water stores. Transpiration is often lumped with evaporation as a process called evapotranspiration. Actual evapotranspiration is influenced by available atmospheric energy, available moisture, and land cover characteristics. It is thus a significantly more complex process to quantify than precipitation and temperature, especially at large spatial scales. Similar to precipitation and temperature, rates of evapotranspiration vary substantially over the course of a year (Figure 5).

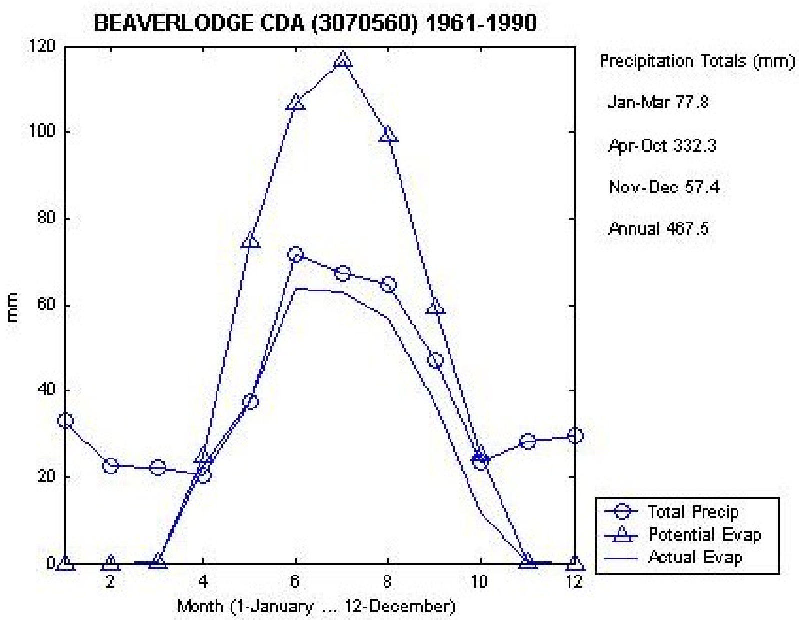

Figure 5. Precipitation and Evapotranspiration, 1961-90, Beaverlodge AB (CICS 2005).

As part of the surface water data compilation process, several sources of gridded precipitation and temperature data were collected and assessed. These include products from the Climatic Research Unit, University of East Anglia (New 2002), University of Alberta (Mbogga 2010), University of British Columbia (Wang 2012) and University of California (Hijmans 2005). These products are similar in that they each provide the ability to represent long term climate normals, typically over a 30 or 50 year period. The global scale products (New 2002, Hijmans 2005) are provided at a defined spatial resolution, whereas the western Canada focused products (Mbogga 2010, Wang 2012) provide climate information in a scale-free format, allowing researchers to generate climate data at spatial resolution appropriate for their analysis from the climate models contained within the programs. The University of British Columbia product (ClimateWNA) was ultimately selected for use within this project as it allowed for the generation of climate data for the entire study area, including the portions of watersheds located in British Columbia. The climate normal period of 1961-90, and a spatial resolution of 400m was used to generate monthly and annual gridded products for temperature and precipitation. Annual precipitation for the climate normal period is shown in Figure 6.

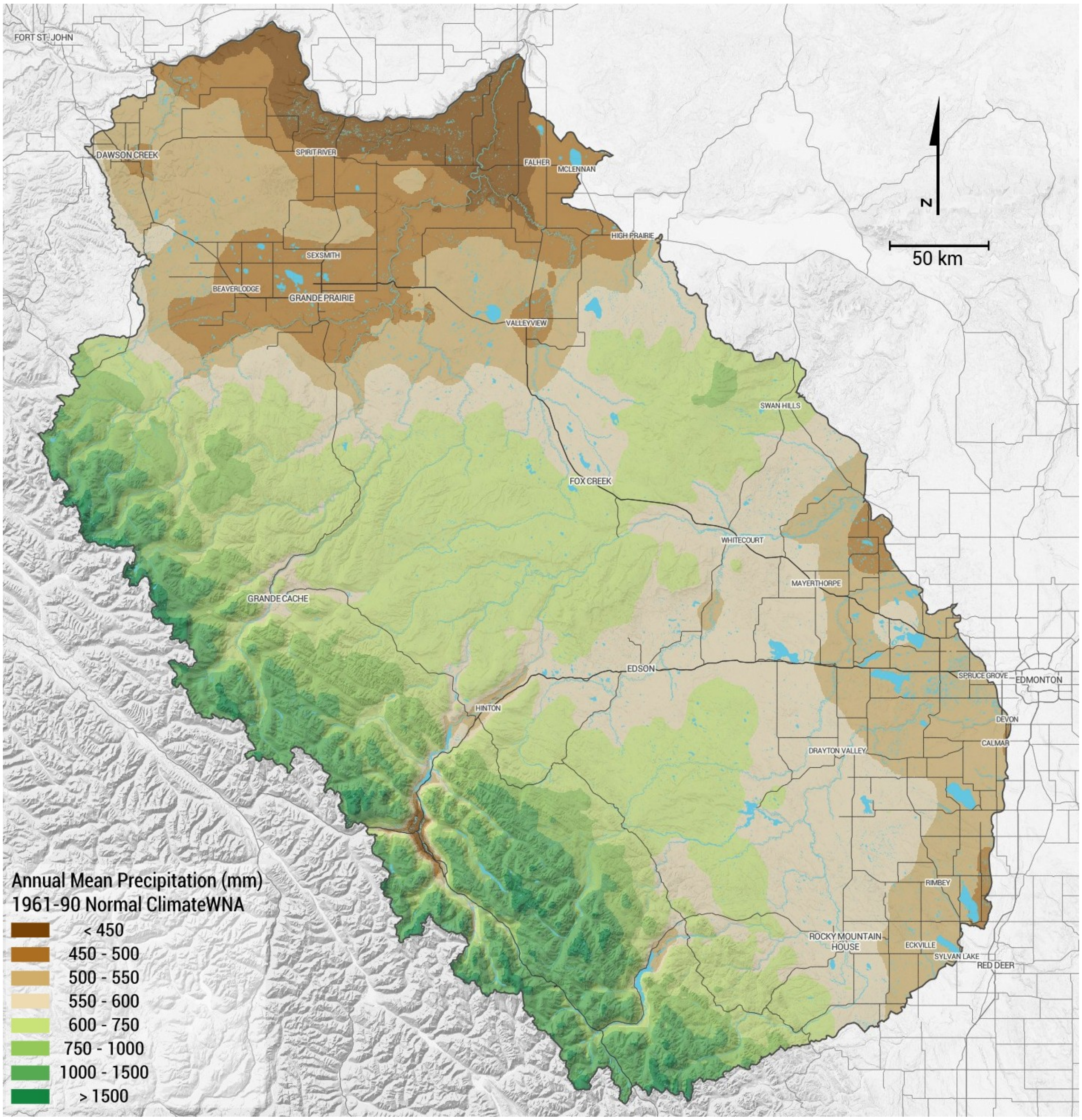

Figure 6. Annual Mean Precipitation, 1961-90 (Wang 2012).

Actual evapotranspiration (AET), which is influenced by climatic, hydrologic and land use characteristics is included in this section on climate due to the methodology used to produce the data source collected. A global, gridded product is provided by the Consultative Group on International Agricultural Research (CGIAR), and uses a modified Hargreaves method to determine AET (Trabucco 2010). Climate data is used to represent the moisture availability component of the equation, but land cover is assumed to be uniform and results are thus explicit only to climatic conditions. The climate period represented in this data set is 1950-2000 and the spatial resolution is approximately 500m within the study area. The CGIAR estimated AET data is shown in Figure 7.

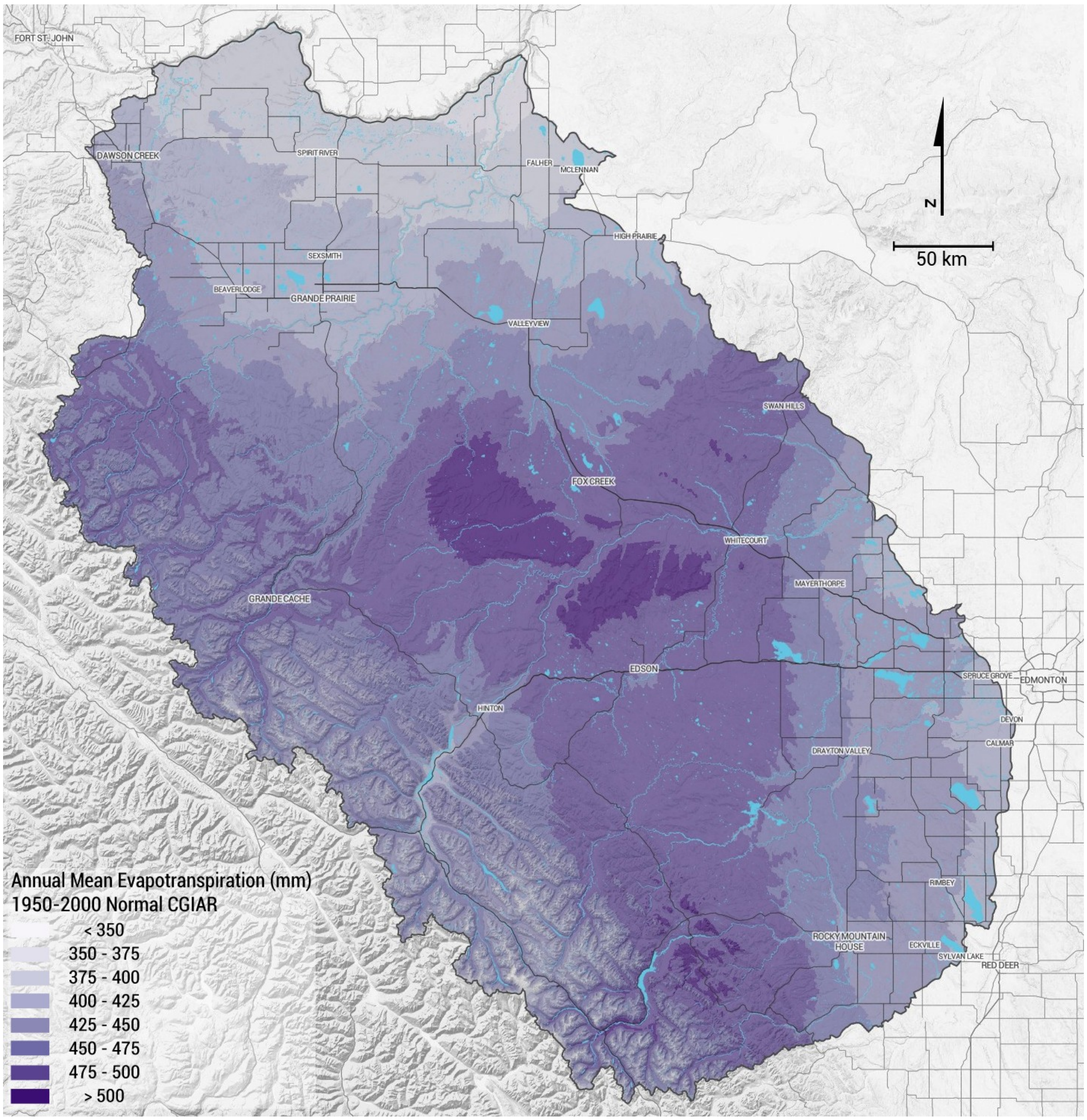

Figure 7. Annual Mean Actual Evapotranspiration (Trabucco 2010).

Within each sub-basin in the study area, analysis was performed on the monthly precipitation and temperature data. Charts were created displaying monthly mean values for precipitation and temperature and are available within Appendix A. For the precipitation charts, colors were used to distinguish the magnitude of values for each month in comparison to other sub-basins within the study area. Monthly bars colored brown have lower precipitation than the mean for the study area, and bars colored green have higher precipitation for the month than the mean in the study area.

Over 60 weather stations exist within the study area. The location of these stations is shown in Figure 8 and also provided in the project database, along with direct links for each station to the Agro-Climatic Information Service provided by the Government of Alberta (ACIS 2013).

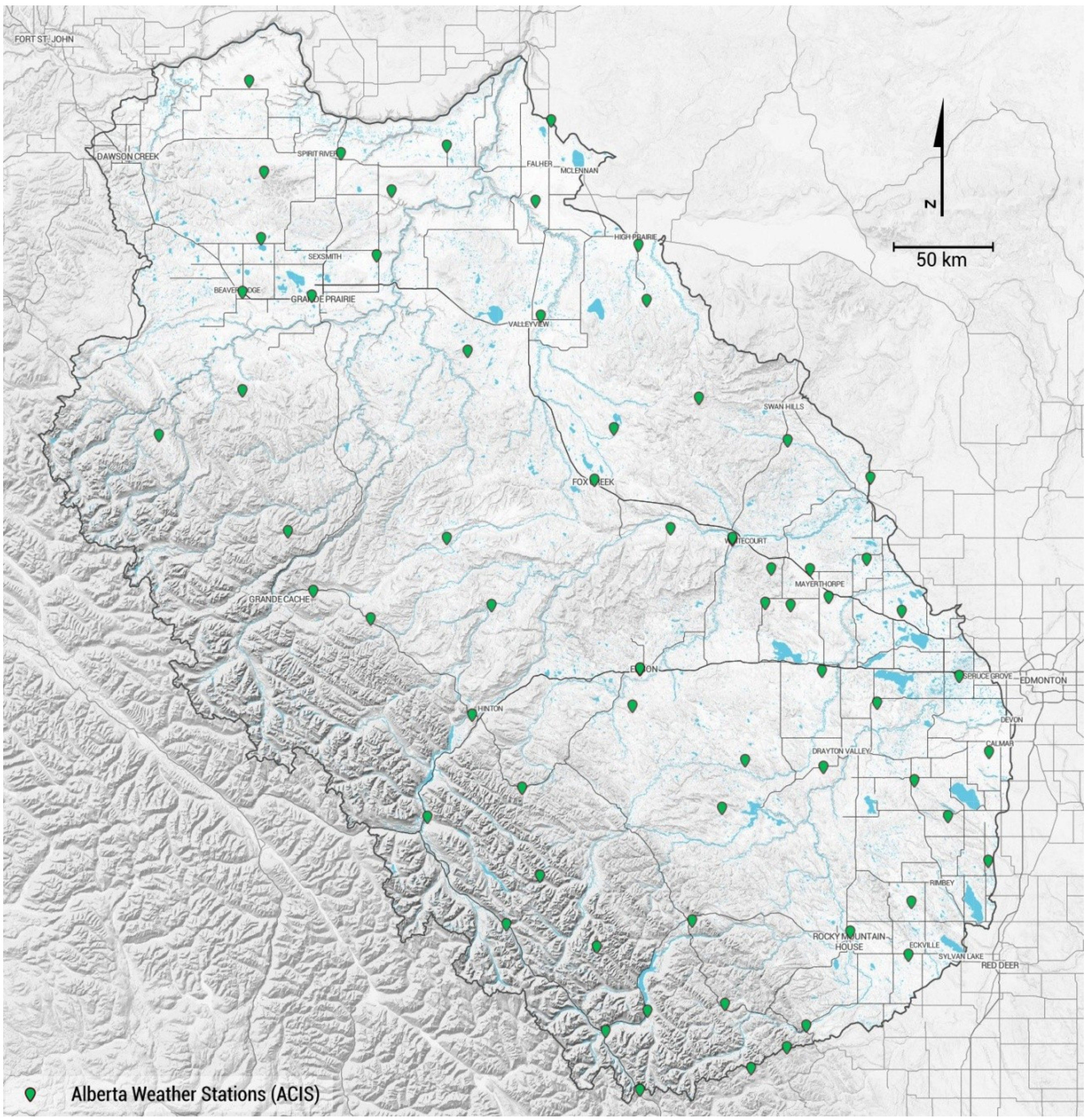

Figure 8. Alberta Climatic Information System Weather Stations (ACIS 2013).

Hydrology

Hydrometric data has been collected and catalogued by the Water Survey of Canada since 1908. Within the project study area, the earliest water quantity data available is from 1909 on Pigeon Lake Creek, in the southeast portion of the study area between Edmonton and Red Deer. A station on the North Saskatchewan River near Rocky Mountain House is the longest running currently active station, with data dating back to 1913 with the exception of a 12 year gap between 1931 and 1944. There are 248 stations with the study area in the Water Survey of Canada database. Based on a review of data availability and quality for these stations, 183 stream gauges were selected for further review and analysis, which are shown in Figure 9.

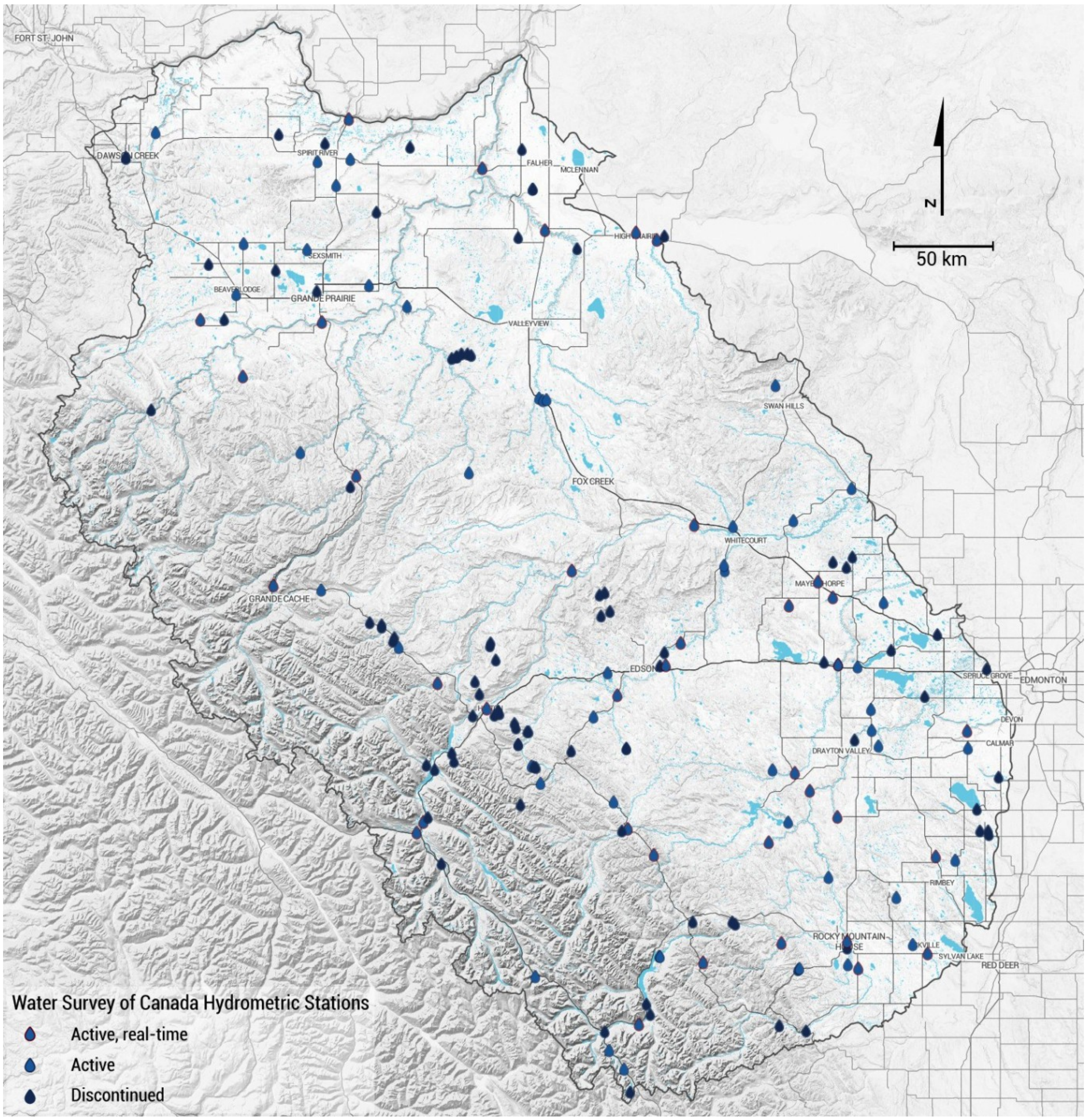

Figure 9. Hydrometric Stations.

Analysis of unit and annual runoff, flow duration, flood frequency, and low flows were performed on these 183 stations. Methods and results for these analyses are discussed in the Hydrologic Analysis section which follows. Monthly stream flow data, flow duration curves, flood frequency and monthly flow characteristics are also provided in Appendix B.

Reports were reviewed and data was compiled from three studies describing the regional unit runoff characteristics across the Canadian Prairies (Bell 1994), Alberta (AENV 2008), and Canada (AAFC 2013). These reports provided interpretations of areas with similar hydrologic conditions or annual runoff quantities per unit area. Data from these studies were used in a spatial analysis for each sub-basin, to quantify the estimated unit runoff with the sub-basin. Results of these analysis are provided for each sub-basin within Appendix A, and include seven probability based assessments of unit runoff for the 1994 and 2013 studies. The median estimated annual runoff within the study area is shown in Figure 10.

Data for water features was compiled for lakes, rivers and streams within the study area from Natural Resources Canada. Additional information on lakes, including bathymetry, was collected from the Alberta Geological Survey and other agencies.

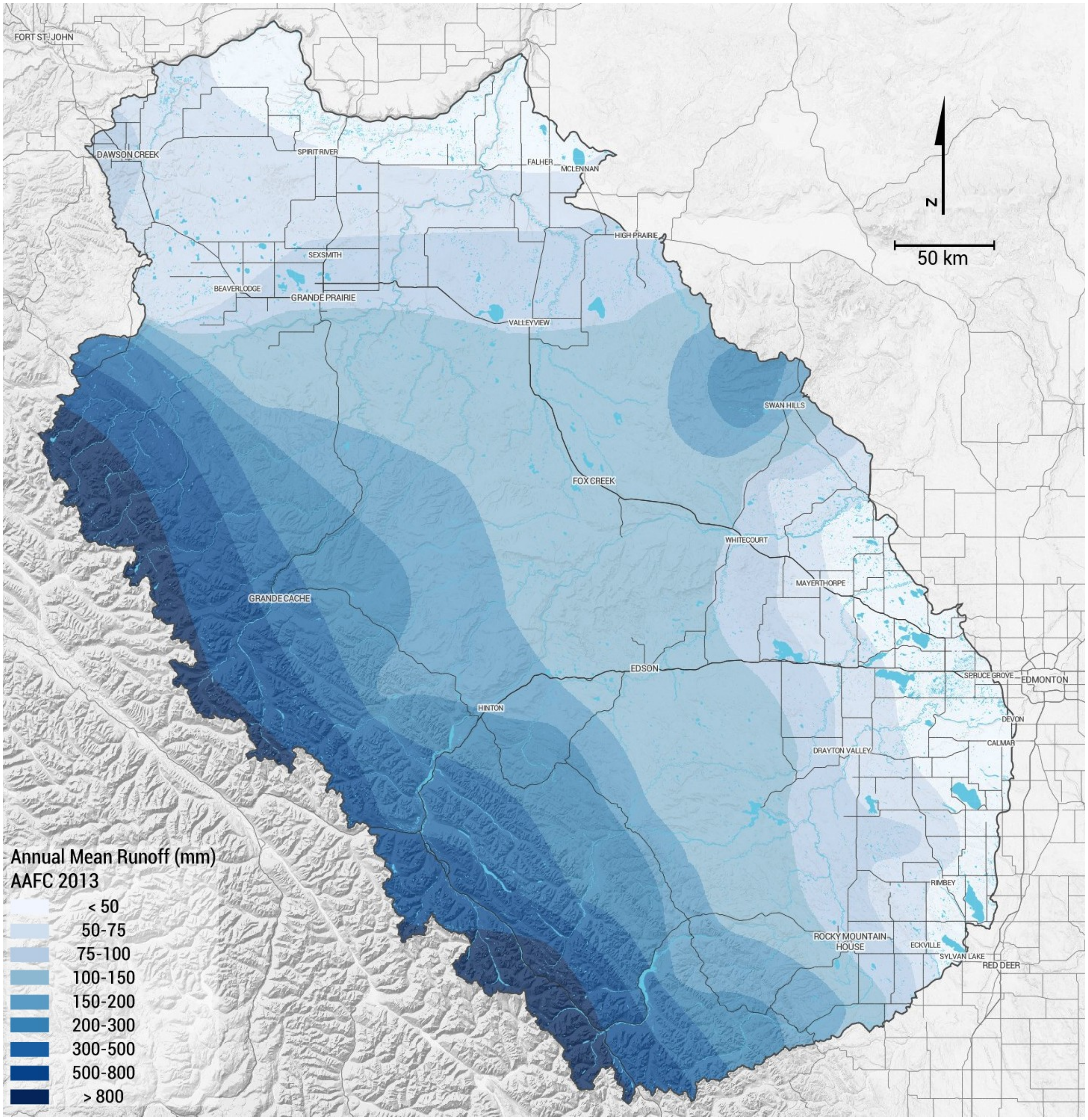

Figure 10. Estimated Annual Runoff, P50 (AAFC 2013).

Land Cover

Land Cover is used to describe characteristics of the surface of the earth. In natural or vegetated areas, land cover information specifies forest type, wetland type, or other type of landscape. In non-vegetated areas, land cover classifications revert to a usage based classification, and include category types such as barren, snow/ice, rock/rubble, exposed or developed. The primary source for land cover data in the project is the *Land Cover, circa 2000-Vector* product, produced and distributed by Natural Resources Canada (Geobase 2009). The product combines individual projects completed by the National Land and Water Information Service of Agriculture and Agri-Food Canada for agricultural areas, the Earth Observation for Sustainable Development project of the Canadian Forest Service for forested areas, and the Canadian Centre of Remote Sensing for northern territories.

The land cover data product was generated by the vectorization of raster imagery collected by the Landsat 5 and Landsat 7 satellites, around the year 2000. The spatial scale of the resultant vectors is controlled by the resolution of the original imagery, which is 30m, with areas of several contiguous pixels of the same type being distinguished as uniform areas. An example of the land cover detail is shown in Figure 11.

Figure 11. Land cover mapping near Whitecourt, AB. (Geobase 2009).

Land cover has an important influence on the behaviour of water within the water cycle. Vegetation type influences interception, the process whereby precipitation rests on vegetation rather than falling to the ground. Water is used as part of the carbon cycle, and the availability of water and the efficiency with which different types of vegetation can use the water to fix carbon relates to the rate of actual evapotranspiration for each plant or tree, stand, or vegetation type in general. A component of the literature review that was performed as part of the project involved cataloguing measured evapotranspiration rates for characteristic vegetation types found within the project area, to be used in Year 2 modeling work (Figure 12).

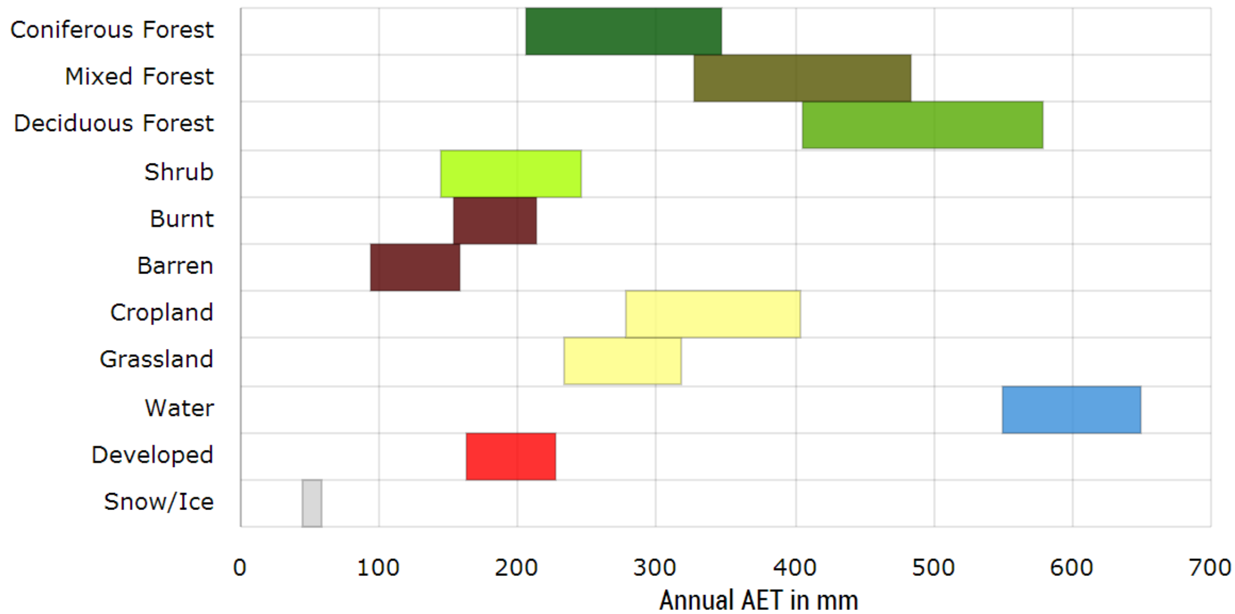

Figure 12. Approximate Annual Actual Evapotranspiration by land cover class (Liu 2003, Morton 1983).

Spatial analysis of the land cover data that was compiled for the project was conducted for the sub-basins within the study area. The percentage of each basin covered by each land cover type, and the gross area of each land cover type is presented in Appendix A.

Surficial Geology and Soils

Surficial geology data recently released by the Alberta Geological Survey (Fenton 2013) was collected as part of the project. This is the culmination of several years of work, which led to the production of a 1:1,000,000 scale product available for all of Alberta. Previous to the release of this product, the only data available for all of Alberta was a 1:10,000,000 national product from the Geological Survey of Canada. The compilation of the AGS 601 map involved a significant effort in edge-matching, translating different definitions used by different geologists across map boundaries, and in-filling holes in the previous available mapping with new work. The data from this compilation map is shown in the context of the study area in Figure 13.

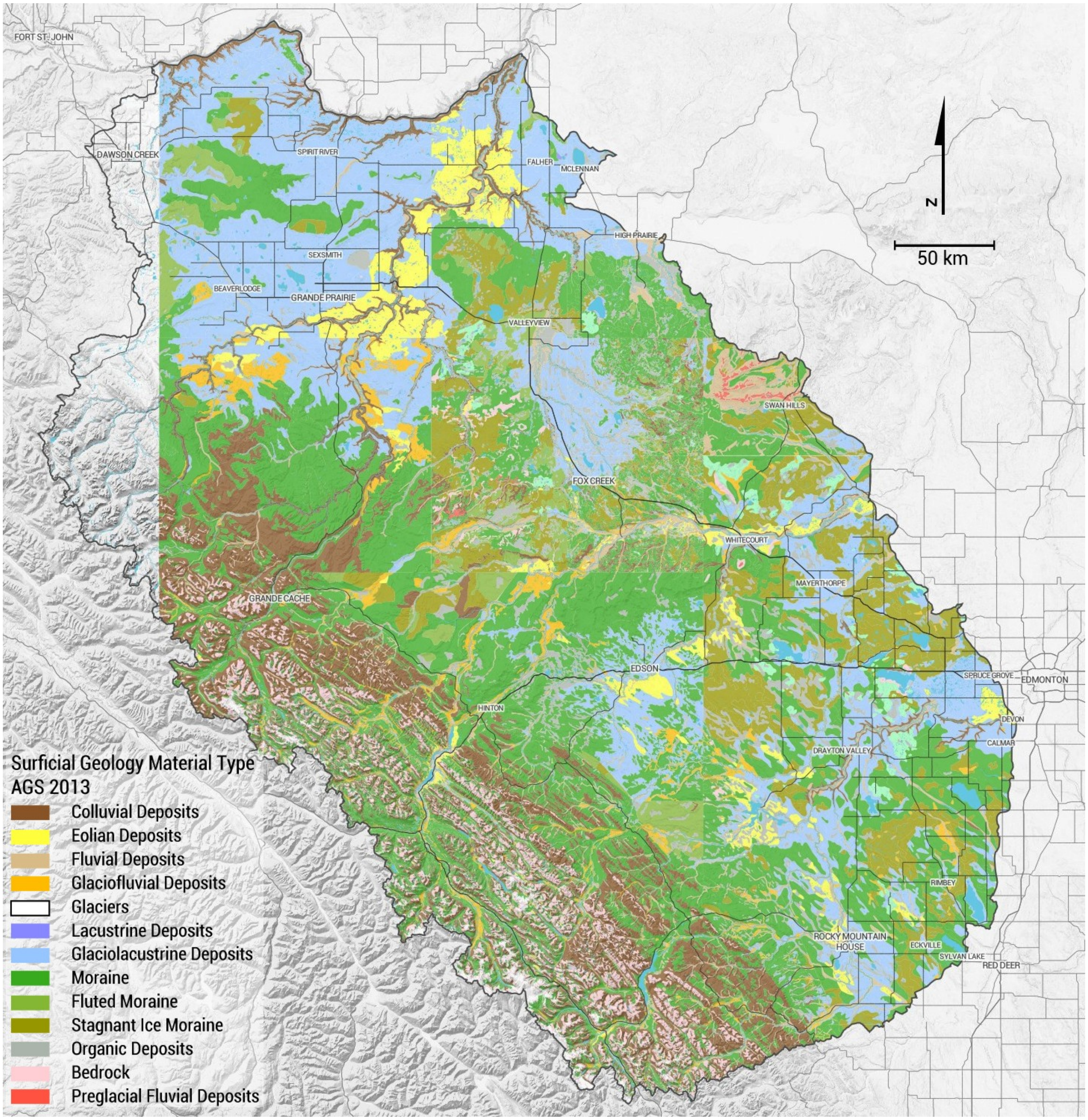

Figure 13. Surficial geology (Fenton 2013).

The surficial geology data represents the characteristics of the sediments lying between the ground surface and the underlying bedrock, and are typically described using process based terms, distinguishing sediments based on the forces that deposited them there. The physical properties of the sediments can then be inferred based on understanding of the typical grain size distribution, sorting, and depositional characteristics associated with the different processes (Table 2).

Table 2. Surficial Material Types (after AGS 2013).

Deposit Type	Description
Colluvial Deposits	Slope and slump deposits of bedrock and surficial materials on valley sides and floors.
Eolian Deposits	Wind-deposited sediments comprising well-sorted, medium- to fine-grained sand and minor silt.
Fluvial Deposits	Sand, gravel, silt, clay and organic sediments deposited by streams and rivers in channel and overbank deposits.
Glaciofluvial Deposits	Variable grain size, poor to well sorted, massive to stratified sediments deposited by glacial meltwater in subaerial, subaqueous and subglacial environments.
Glaciers	Permanent snow and ice circa 1994, including icefields, valley and cirque glaciers.
Lacustrine Deposits	Lake deposits, offshore sand, silt, clay and minor organics. May also include minor nearshore beaches and bars composed of sand, silt, and minor gravel.
Glaciolacustrine Deposits	Glacial lake deposits, offshore sand silt and clay, nearshore sand, pebbly sand and minor gravel.
Moraine	Glacial ice deposited till, composed of clay, silt, sand, minor pebbles, cobbles and boulders. Lack of distinctive topography.
Fluted Moraine	Glacially streamlined sediments, mainly till; terrain varies from alternating furrows and ridges to elongated smoothed hills which parallel the inferred local ice-flow direction.
Stagnant Ice Moraine	Collapsed and slumped englacial and supraglacial debris associated with buried ice melting. Primarily till, hummocky topography.
Ice-thrust moraine	Glaciotectonic displaced blocks or rafts of syngenetic till and masses of pre-existing sediments/bedrock.
Organic Deposits	Undifferentiated peat occurring in wetlands; commonly underlain by fine-grained, poorly drained glaciolacustrine or lacustrine deposits; in some places underlain by till.
Bedrock	Conglomerate, sandstone, siltstone, and shale in the foothills, limestone and dolostone in the mountains.
Preglacial Fluvial Deposits	Well sorted quartzite and chert gravel and cobbles with minor sand, deposited by streams and rivers prior to glaciation. Erosional remnants capping isolated upland and midland peneplains.

Sand and gravel deposits with the potential to host aggregates have been delineated by the Alberta Geological Survey (Edwards 2009) and are provided within the project database. These areas important with regards to water resources as the permeability of the sediments allows for increased movement of water between the surface and groundwater. These are notable for the consideration of groundwater recharge and discharge areas and also for evaluating surface areas for sensitivity to groundwater contamination. Data resulting from a more detailed assessment of natural suitability of geological settings for waste management (Andriashek 2005) has also been collected and compiled for the project area. This data provides a qualitative assessment of the suitability of all areas in the province for the siting of waste management facilities, and is based on several additional factors including buried channels and drift aquifers, drift thickness and bedrock geology. This product has been used previously as a proxy for determining surface water / groundwater interactions (AENV 2008).

Data from the Soil Landscapes of Canada has been collected and compiled within the project area. This national scale product provides the major attributes of soil characteristics and is mapped at 1:1,000,000 scale. More detailed soil surveys have been completed in the agricultural regions in the north and southeast of the study area and are also provided in the project database.

Spatial analysis for the surficial geology theme was performed, and the composition by percentage and gross area for each material type is provided for each sub-basin in Appendix A. The presence of buried valleys previously identified by either the Prairie Farm Rehabilitation Administration (Lemay, 2009) or the Alberta Geological Survey (Pawlowicz, 2007) is also indicated within the sub-basin analysis results in Appendix A.

Shallow Hydrogeology

Shallow hydrogeologic potential was characterized for each sub-basin, using the estimated groundwater yield product compiled by the Alberta Geological Survey (Lemay 2009), and water well drilling records provided by the Groundwater Information Centre. The results of these analyses are available in Appendix A. More detailed information on these and other data sources relating to shallow hydrogeologic potential is available in the complementary shallow groundwater report for Year 1 of the project.

Deep Hydrogeology

Information on deep saline aquifer potential is provided in detail within the deep saline Year 1 summary report. Regional aquifers identified in the deep saline aquifer component have been related to the sub-basins used for classification in previously mentioned themes. Within each sub-basin, potential aquifers are identified and listed with brief summaries. Results are provided in Appendix A.

Hydrologic Analysis

Using daily and monthly data from the 183 hydrometric stations, analyses were performed to determine the flow characteristics of the river or creek at each station. The methodology and objective for the unit and annual runoff, flow duration and flood frequency assessments is provided here, with results of the analyses provided in Appendix B along with metadata and monthly mean runoff values for the period of record. Within the study area, 30 of the 183 stations are currently or have been monitored throughout all seasons. The remainder are classified as seasonal gauges.

Annual runoff

Whereas streamflow measurements are typically provided as volume based rates, in cubic metres per second, annual runoff presents the integral of the series of flow measurements over the course of a year, as a pure volume. Annual runoff volumes for individual years were calculated and plotted using vertical bar charts. Visually, this provides the ability to assess the range in magnitude of annual discharge over the period of record, and also the variability between years. For each station, quality assessment of the data for each individual year was performed. Based on an assessment of the completeness of the monitoring period for the individual year, data was flagged as complete or incomplete for inclusion in further annual analyses. For some seasonal gauges, this was a subjective process as the monthly availability of data fluctuated between years. For annual runoff calculations, monthly mean values as provided by the Water Survey of Canada were used.

Unit runoff

Unit runoff is an assessment made using the mean of the annual runoff calculations, and the drainage basin areas. The average annual runoff is divided into the basin area, to produce a unit runoff value presented in mm. The unit runoff can be considered as the average runoff generated across the entire watershed, or the average for the runoff component in a traditional mass balanced water balance equation. The unit runoff calculations for individual hydrometric stations can be compared with the estimated runoff probabilities provided in the Hydrology sections of Appendix A for the individual sub-basins. For unit runoff calculations, results from the annual runoff calculations were used, which are based on monthly mean values as provided by the Water Survey of Canada.

Flow duration

Flow duration curves present the magnitudes of measured discharges, in a probability of exceedance context. Discharge magnitudes are provided on the vertical axis, with exceedance probabilities on the horizontal axis. The shape of the curve plotted provides multiple insights into the hydrologic characteristics of the gauged drainage. Flow duration curves for each hydrometric station are provided in Appendix B. They are based on daily streamflow values as provided by the Water Survey of Canada. For continuously operated stations, the flow duration curves represent the full year, whereas for seasonal stations the flow duration curves only represent the flow characteristics for the seasons during which the station is operated.

Flood frequency

Flood frequency analysis was conducted to determine the peak flows associated with a 2, 5, 10, 25, 50, 100 and 200 year recurrence interval. Frequency analysis was performed using a Log-Pearson Type III distribution, and based on daily mean streamflow values as provided by the Water Survey of Canada. The results of the analysis therefore represent the peak flow values for an individual day rather than an instantaneous measurement of a peak. Some quality assurance was performed on the data, to remove years from the analyses where only partial years were recorded and the partial year measurements did not cover the typical period of peak discharge. Results of the flood frequency analysis are provided for each hydrometric station in Appendix B.

Drought flows

Recurrence based assessment of low flow periods provides a complementary review of low flow conditions to that of the flow duration curve. By applying a recurrence based assessment, discharge associated with droughts can be characterized. Three temporal analyses were conducted on the daily mean streamflow values as provided by the Water Survey of Canada for each hydrometric station. Summer (May 1 - October 31), Winter (November 1 - April 30), and full year. The analyses were set up to determine the discharge associated with the seven day low flow, with a 10 year recurrence interval (7Q10). Analysis was conducted using the DFLOW program (EPA 2006).

Geographic regression

Watershed size is a primary variable influencing hydrologic characteristics in streams and rivers. Results from individual hydrometric stations for the annual runoff, flood frequency, and drought flow analyses were plotted against basin size and statistically regressed to determine predictors for analysis results, based solely on watershed size.

COMMUNICATION

Project Website

To communicate objectives and goals a website was developed, with a secure access section for partners to access project materials. The website is available at the address www.integratedwaterresources.ca. The primary purpose of the website during Year 1 of the project has been to serve as a repository for project documents such as meeting presentations, minutes, project updates and draft maps and reports. The password protected section also provides access to NOLA, the framework used for the communication of spatial and analytical results.

INTEGRATION

Technology

Project datasets mentioned previously as well as other related datasets and base mapping such as roads, rivers and administrative boundaries are maintained in a spatially enabled relational database. The PostGIS extension for Postgresql was used to manage all data and metadata. Project data is managed in a standard transverse mercator projection for Alberta, referenced as EPSG:3400 (Spatial Reference 2013). This projection allows for suitably accurate calculations of distance and area to be made during analysis. The standardized projection also allows for analysis on multiple datasets to be performed quickly and easily. Layer level metadata is maintained in the database, and directly linked to tables within the database. The database framework allows for the integration of disparate data sets representing all three components of the project; surface water, non-saline and saline groundwater. Raster data, which requires specification of spatial resolution during production, has primarily been standardized at a 400m cell size. This cell size provides a suitable level of detail across the study area.

NOLA

Results of data compilation and analysis for the Year 1 surface water component are contained within this report and appendices. With the large amount of data and analysis resulting from the consideration of 183 hydrometric stations, multiple spatial analyses within 34 sub-basins, and several hundred individual data layers, this report and appendices provide a substantial volume of information, which is challenging to deal with in a traditional report format.

Foundry Spatial has developed a web-based framework, NOLA, to support the communication and integration of analysis results generated within the project. NOLA provides a map based interface to visually interact with key map layers compiled and symbolized. Furthermore, NOLA allows interaction with the sub-basin query analysis results described in the Data and Analysis section of this report. By combining visual information on individual data themes with analysis results for each component of the project, users can quickly and easily compare and contrast water availability options within each sub-basin from surface water, non-saline and saline groundwater sources. A snapshot of the NOLA framework is shown in Figure 14.

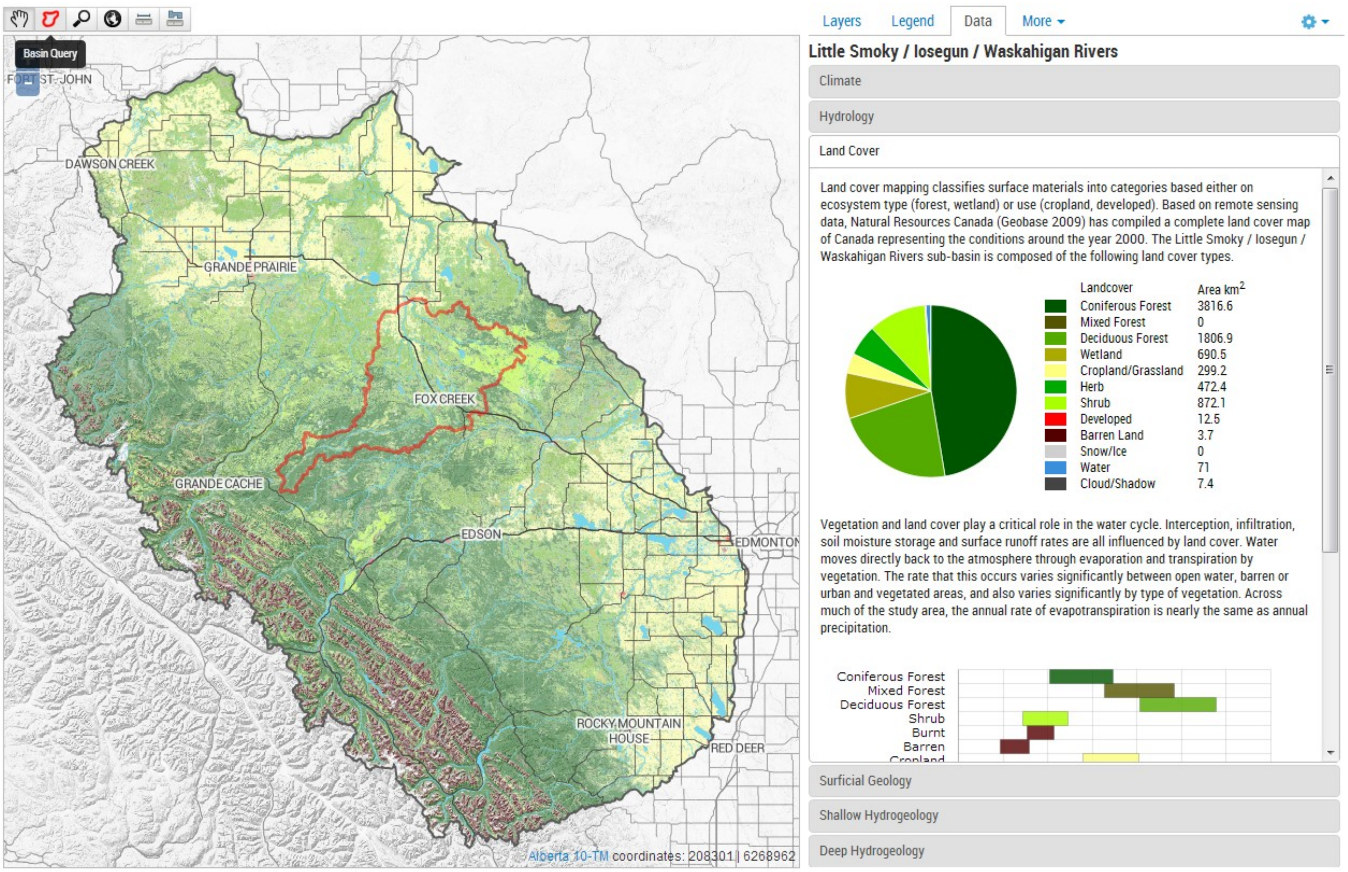

Figure 14. NOLA framework.

RESULTS

Analysis

The previous section, Data and Analysis, summarized methods and described key data sources compiled for thematic and hydrologic analyses performed. This section of the report will regionally describe the results of the analyses and provide interpretive highlights for selected basins, demonstrating the variability in themes across the study area and how the variability influences surface water resources.

Climate

The Koppen climate classification system categorizes the majority of the project study area as continental / microthermal (Kriticos 2012). In the northern portion of the study area, near the Peace River, and in the southeast near Edmonton, summer mean temperatures are lower than in the majority of the study area. At higher elevations in the Rocky Mountains, the climate is classified as Tundra, as the warmest monthly mean temperature is between 0 and 10 °C.

Precipitation varies across the study area substantially, ranging from less than 450 mm per year in the Peace River Valley to more than 1500 mm per year in the Rocky Mountains. Within the fairways of the Montney and Duvernay plays, significant variation also exists, with over 750 mm of precipitation per year occurring in the Swan Hills region. Climatically the Swan Hills and Peace River Valley areas are similar for much of the year (Figure 15).

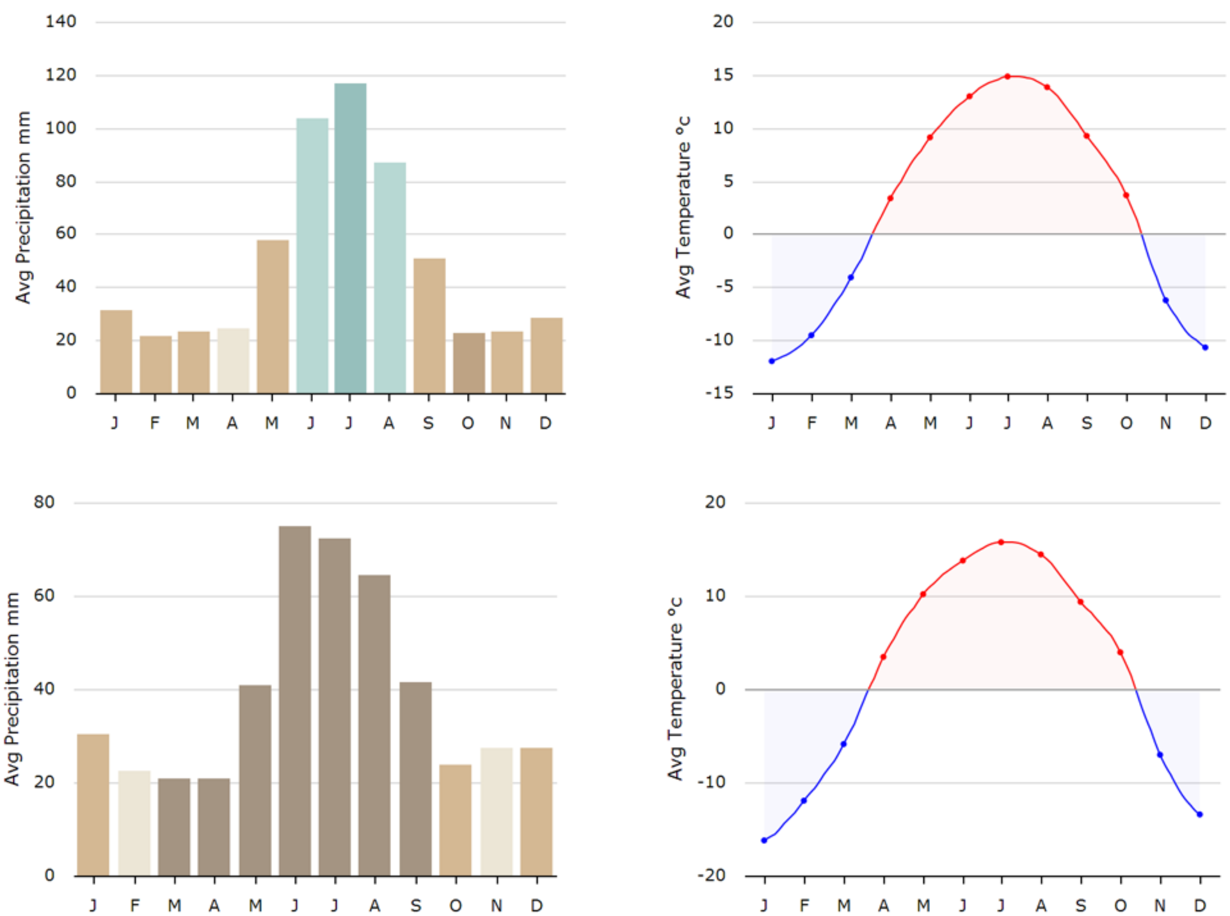

Figure 15. Monthly mean precipitation (left) and temperature (right), 1961-1990. Freeman / Sakwatamau Rivers sub-basin 07AH (top) and Lower Smoky River sub-basin 07GJ (bottom). Data from ClimateWNA.

Both areas receive 20-30 mm of precipitation through the fall and winter, and monthly mean temperatures are approximately the same over the course of the year. Over the summer however, the Swan Hills receives significantly more rain from convective storm events. As a result, hydrologic characteristics of each region are significantly different. Hydrometric station 07BJ003 gauges a 155 km^2 watershed, on the Swan River near Swan Hills, and produces gross unit runoff over 300mm per year on average, which is well distributed throughout the open water season. Hydrometric station 07GJ005 gauged a 160 km^2 watershed, on Lalby Creek near Girouxville. The 160 km^2 watershed produces less than 30mm per year on average, which primarily occurs during April. The gauge was monitored for 18 years, from March to October each year, and 50% of the time the river was dry.

The timing and amount of precipitation over the year exerts a significant influence on the runoff characteristics for watersheds in the region, and consideration of these patterns in evaluating potential runoff in ungauged basins is instructive.

General characteristics of monthly temperatures throughout the study area are similar. In April, mean temperatures move above 0°C with the exception of the Rocky Mountains. July is typically the warmest month, with mean temperatures above 15°C for most of the lower elevation regions. In October, mean temperatures drop below zero in the Rocky Mountains again, and mean temperatures move below -5°C for the majority of the study area in November with the exception of a band of warmer temperatures along the foothills front ranges.

The results of the spatial analysis of monthly precipitation and temperature based on the ClimateWNA data, as provided in Appendix A, provides information on historical average temperatures and precipitation for each individual sub-basin in the study, as shown in Figure 4.

Yearly evapotranspiration estimates were not analysed in detail during Year 1 of the project, as limitations in the methodology restrict the usefulness of the data to only describing the results of climate controls on actual evapotranspiration. In Year 2, vegetation characteristics will be integrated with the climate controlled evapotranspiration data to provide a more representative estimate of actual evapotranspiration across the study area.

Hydrology

Analysis of the regional hydrology draws heavily on previous research conducted by Agriculture and Agri-Food Canada (Bell 1994, AAFC 2013) and Alberta Environment (2008). The map results from these projects were integrated with the sub-basin boundaries and used to generate estimates of unit runoff for each sub-basin. While differences exist locally in the estimates from each source, each provides a useful estimate of the estimated average unit runoff across the study area. In the case of the AAFC products, insight into the expected variability of runoff on a probability basis is also very useful.

The Prairie Farm Rehabilitation Administration has mapped non-contributing areas across the Canadian prairies. Non-contributing areas are defined as areas that would not contribute surface runoff to a stream for a flood event with a recurrence interval of 2 years. These non-contributing areas can thus be excluded from the calculation of drainage area size in determining unit runoff. An important caveat, is that in ungauged basins, these non-contributing areas must also be considered, and not used in any area based calculations for expected runoff. Annual unit runoff for Lower Smoky River sub-basin and gauged stations within is provided in Table 4.

Table 4. Calculated unit runoff from the gauged hydrometric stations within the sub-basin, and three assessments of unit runoff characteristics in the Lower Smoky River sub-basin (07GJ) - 2013 (AAFC 2013), 2008 (Alberta Environment 2008), 1994 (Bell 1994).

Annual Unit Runoff (mm)

Project	P10	P25	P50	P70	P75	P80	P90
2013	153.6	111.6	65	46.7	40.7	35.1	25.3
2008			98.1				
1994	129.2	74.7	53.3	34.7	30.2	28.5	17.5

Gauged Unit Runoff (mm)

Station	Gross Drainage Area	Effective Drainage Area
07GJ001	212	215
07GJ004	68.5	68.5
07GJ005	28.6	60.6

Station 07GJ001 is on the Smoky River, and gauged unit runoff is significantly higher than the two other stations located within the sub-basin. The Smoky River has headwaters in the Rocky Mountains which generated much greater runoff per unit area than stations 07GJ004 and 07GJ005, which have discharge generated within the prairies. Station 07GJ005 illustrates the impact that non-contributing areas can have in hydrologic characterization of an area with the difference between the gauged unit runoff calculated using the gross and effective drainage areas.

In the Upper Pembina River sub-basin (07BA), annual unit runoff is higher, and non-contributing areas are fewer, with less impact on unit runoff calculations. Table 5 shows annual unit runoff for the sub-basin as a whole and for the individual gauged stations within the sub-basin.

Table 5. Calculated unit runoff from the gauged hydrometric stations within the sub-basin, and three assessments of unit runoff characteristics in the Upper Pembina River sub-basin (07BA) - 2013 (AAFC 2013), 2008 (Alberta Environment 2008), 1994 (Bell 1994).

Annual Unit Runoff (mm)

Project	P10	P25	P50	P70	P75	P80	P90
2013	257	192.6	131.3	110.4	104.6	96.9	86.6
2008			160.7				
1994	271.7	187.1	137.4	107.2	102.1	87.8	73.2

Gauged Unit Runoff (mm)

Station	Gross Drainage Area	Effective Drainage Area
07BA001	161.7	165.5
07BA002	116.5	121.3
07BA003	233.9	233.9

The three gauged stations listed in Table 5 are all fully contained within the sub-basin. The probability assessments are representative of the sub-basin as a whole, but runoff varies substantially still within the sub-basin. Station 07BA003 which is located in the western portion in the foothills, has substantially greater unit runoff due to greater precipitation in that area. Analysis results for each sub-basin in the study area are provided in Appendix A.

While analysis of previous regional hydrologic analysis projects is useful in characterization regional differences in surface water runoff across the study area, the scale of the mapping for these projects was at a provincial, or larger scale, and in order to understand local hydrology with the appropriate level of detail reference must be made to the individual gauged records for stations in the vicinity of the immediate area of interest. In the subsequent Hydrologic Analysis results section a more thorough discussion of seasonal runoff and other hydrologic characteristics will be provided.

Land Cover

Land cover characteristics of the study area vary substantially, both moving northeast away from, and parallel in a northwest /southeast direction to the Rocky Mountains. Substantial glaciers exist in the higher elevations of the Rocky Mountain headwaters of the Smoky, Athabasca, and North Saskatchewan Rivers. Below the treeline, coniferous forests dominate the landscape and are interspersed with areas of wetland and shrub, either natural or the result of recent forestry activity. Typical species types in these regions include white spruce *(Picea glauca)*, black spruce *(Picea mariana)*, and lodgepole pine *(Pinus contorta)*. A similar mix of land cover types extends northeast along the drainage divide between the Smoky and Athabasca Rivers, extending to the Swan Hills. Locally interspersed in this area, and becoming more dominant to the northwest and southeast are stands of deciduous trees, typically trembling aspen *(Populus tremuloides).* North of Grande Prairie, and east of Drayton Valley and Rocky Mountain House, land cover shifts rapidly to predominantly grassland and cropland. Regional land cover characteristics are shown in Figure 16.

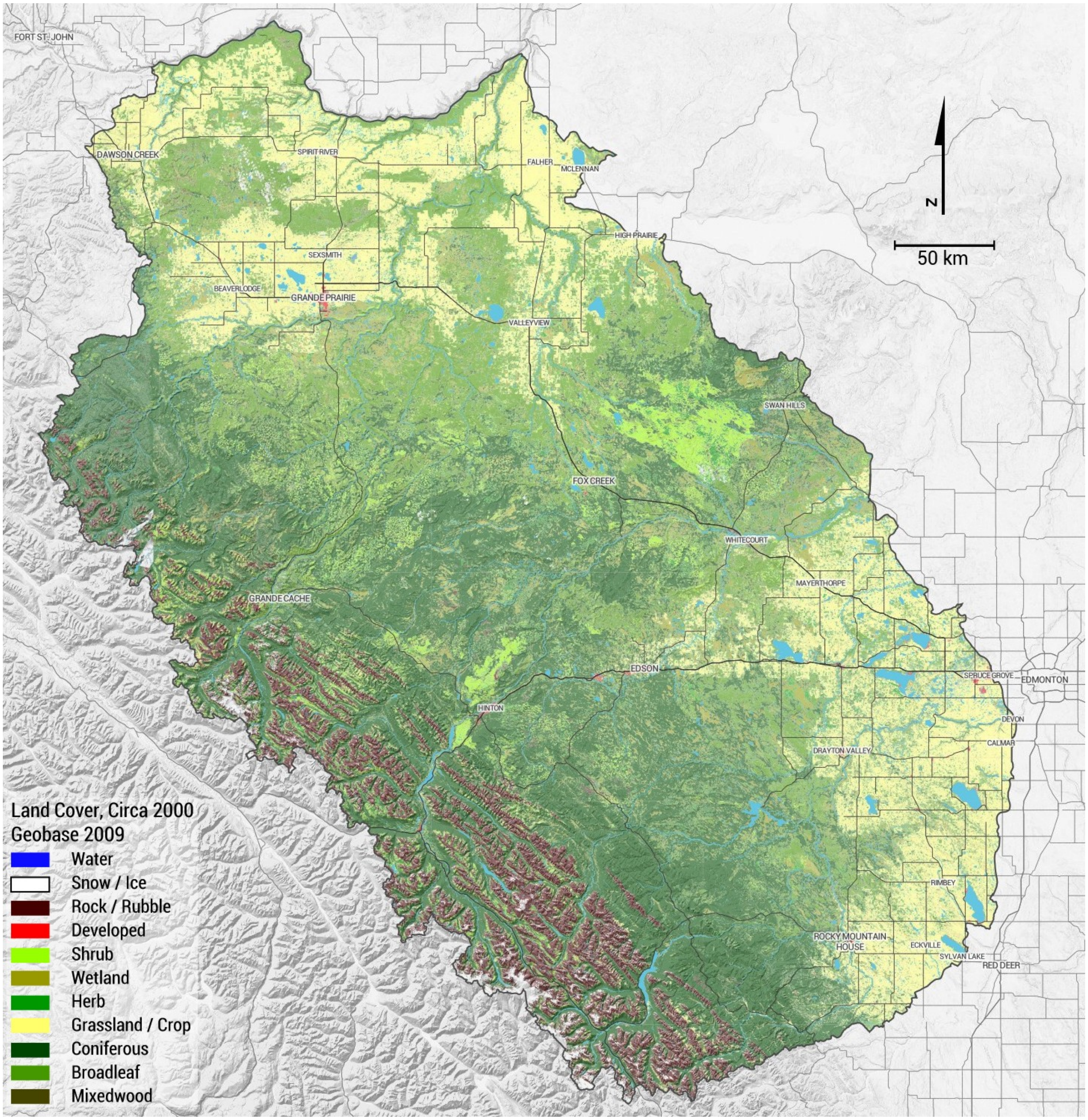

Figure 16. Land Cover (Geobase 2009).

Evapotranspiration is a significant component of the water cycle in the study area, and land cover types play a strong influence in the rate at which evapotranspiration occurs. Specific vegetation types, including trembling aspen, are very proficient in finding water and moving it back to the atmosphere (Devito 2012). The net makeup of land cover in a watershed can be considered as representative of the actual evapotranspirative capacity of the watershed.

Results of the spatial analysis for each sub-basin is provided in Appendix A. A sample land cover class breakdown for the Little Smoky / Iosegun / Waskahigan Rivers sub-basin (07GG) is shown in Figure 17.

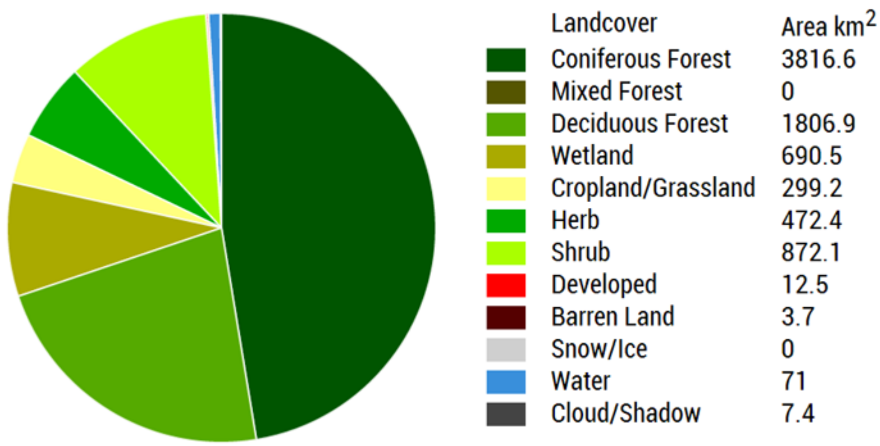

Figure 17. Land cover types in the Little Smoky / Iosegun / Waskahigan Rivers sub-basin (07GG).

Surficial Geology

The description of surficial geology in the study area relates to the unconsolidated sediments laying between the ground surface and uppermost bedrock unit. Analysis performed on surficial geology data in the study area characterized deposit types across the region and identified areas where buried valleys may be present (Figure 18).

Fine grained, impervious sediments restrict the rate at which water can infiltrate and percolate through the soil and sediments to reach groundwater aquifers. Impervious sediments also restrict the ability of water to pass back to the surface and wells drilled into such confined aquifers may have artesian flow. Land cover and surficial geology interact in the determination of groundwater recharge and discharge zones. Black spruce swamps may indicate areas of groundwater discharge, or they may be underlain by impervious sediments impounding precipitation and surface runoff. Consideration of both land cover and surficial geology is thus critical.

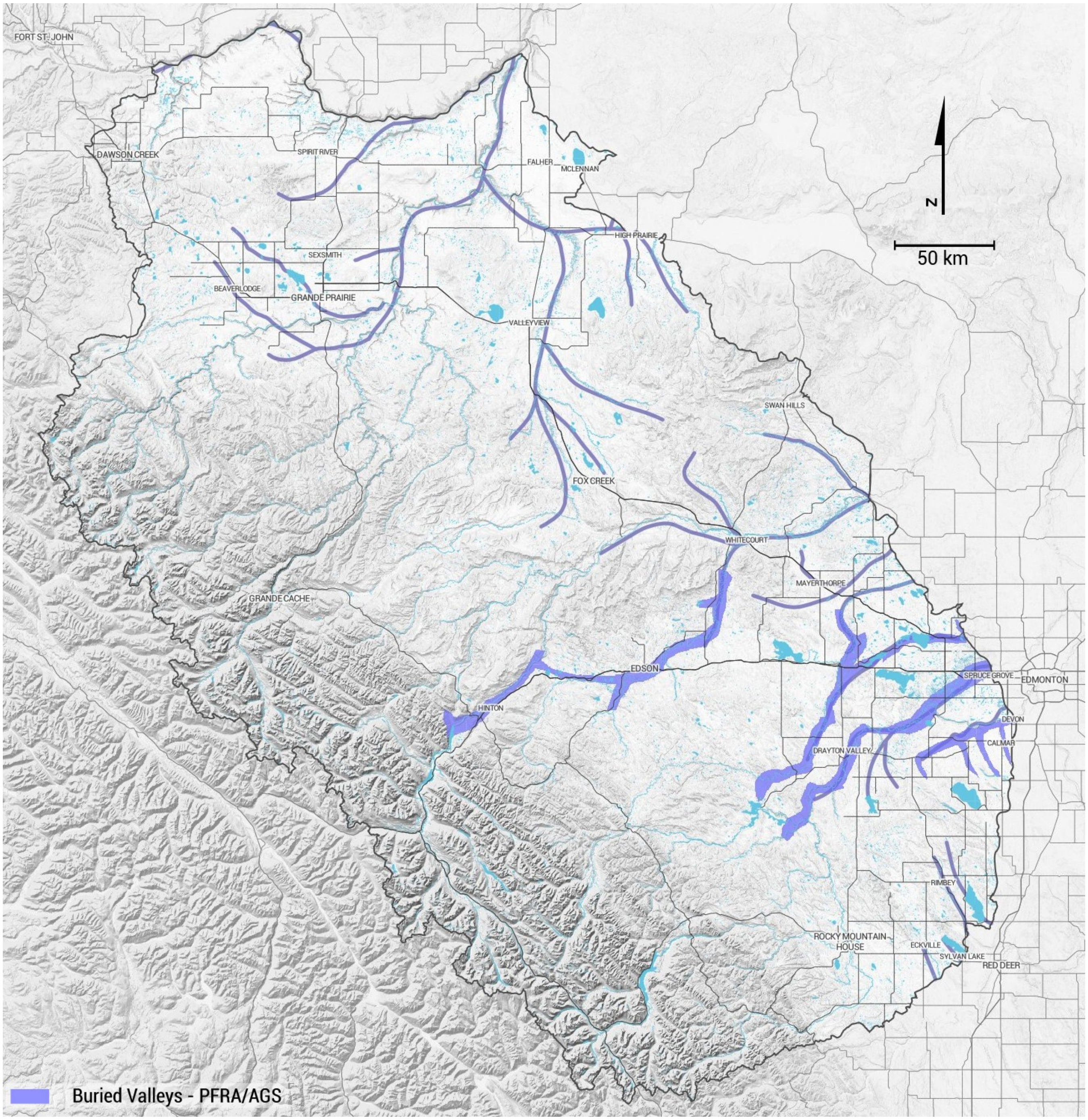

Figure 18. Buried valleys and thalwegs (Lemay 2009).

The surficial materials within the study area are predominantly Quaternary in age; deposited either during the last glaciation or more recently. An exception to this can be found in the Swan Hills area, where remnant fluvial deposits Tertiary in age sit atop local elevation high points. Presumably these deposits armoured the underlying sediments and resisted erosion or reworking during the last glaciation. Colluvial deposits in the Rocky Mountains are generated by weathering and erosion of the outcrop upslope.

Shallow Hydrogeology

Commentary on Year 1 project activities and results relating to shallow hydrogeology is available in the companion report on shallow groundwater. Potential groundwater yield for the majority of the study area is identified as 5-100 igpm (Lemay 2009). Over 100,000 groundwater wells have been licensed within the study area, with the densest development in the southeast portion in the triangle formed by Edson, Rocky Mountain House and Edmonton. Groundwater wells are predominantly drilled to less than 100 m, and average recommended rates are low but suitable for domestic needs. Within almost all sub-basins with significant amounts of drilled wells, some wells produced at rates in the range of 100 igpm or greater. Analysis results for potential groundwater yield and groundwater well development for the Medicine / Blindman Rivers sub-basin (05CC) in the southern portion of the study area is shown in Figures 19 and 20. Results of all sub-basin analyses are provided in Appendix A.

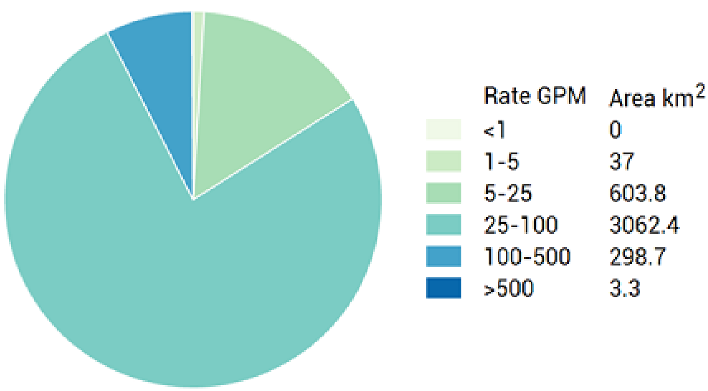

Figure 19. Potential groundwater yield in the Medicine / Blindman Rivers sub-basin (05CC).

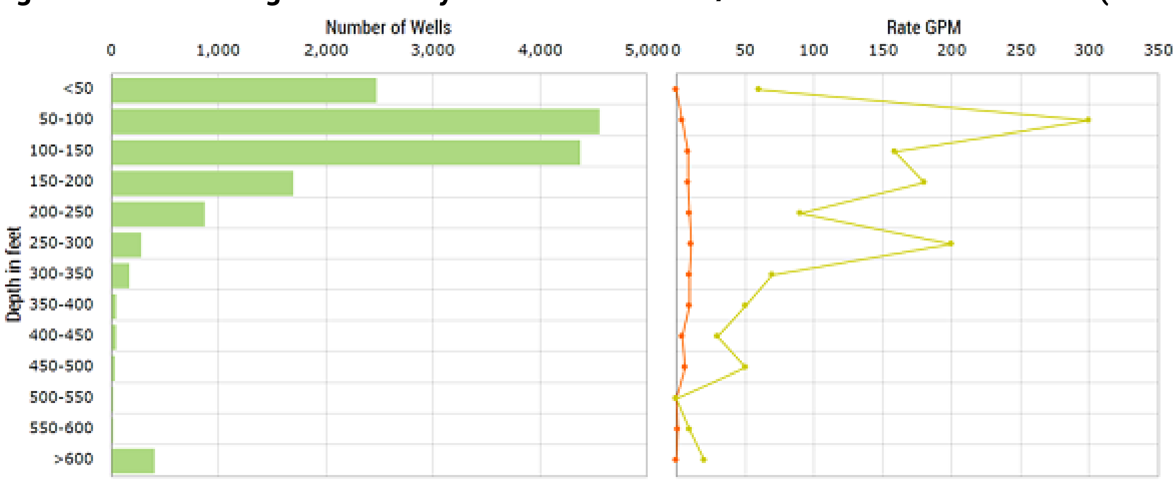

Figure 20. Licensed groundwater wells in the Medicine / Blindman Rivers sub-basin (05CC). On the left, columns indicate the number of wells drilled by depth range. On the right, the yellow line indicates the maximum recommended rate within each depth range, and the orange line the average recommended rate for all wells within each depth range.

Deep Hydrogeology

Commentary on Year 1 project activities and results relating to deep hydrogeology is available in the companion report on deep saline aquifers.

Hydrologic

Results of hydrologic analyses for annual and unit runoff, flow duration, seasonal flow characteristics, and flood frequencies are provided for individual hydrometric stations in Appendix B. Discussion of drought flow characteristics are provided here, along with regional assessment of the characteristics of individual analyses.

Hydrologic regimes are defined by climatic characteristics the study area. Accumulations of snow through the winter melt in the spring, and produce often violent flows in low lying watersheds where the melt occurs almost simultaneously (Figure 21).

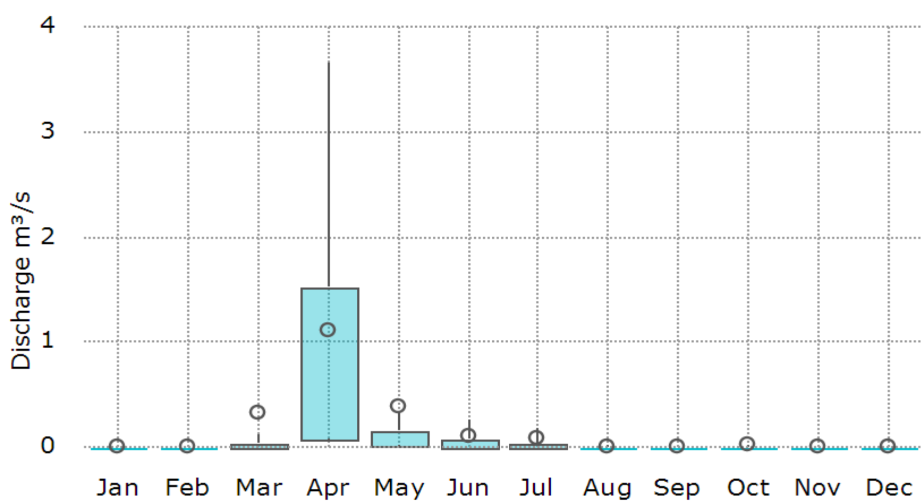

Figure 21. Station 07GJ005, Lalby Creek near Girouxville. Box and whisker plot, monthly stream flows 1977-1995.

In areas with substantial spring and summer precipitation, increased flow levels are prolonged, may peak later in the summer, and support prolonged flow in the river into the fall (Figure 22).

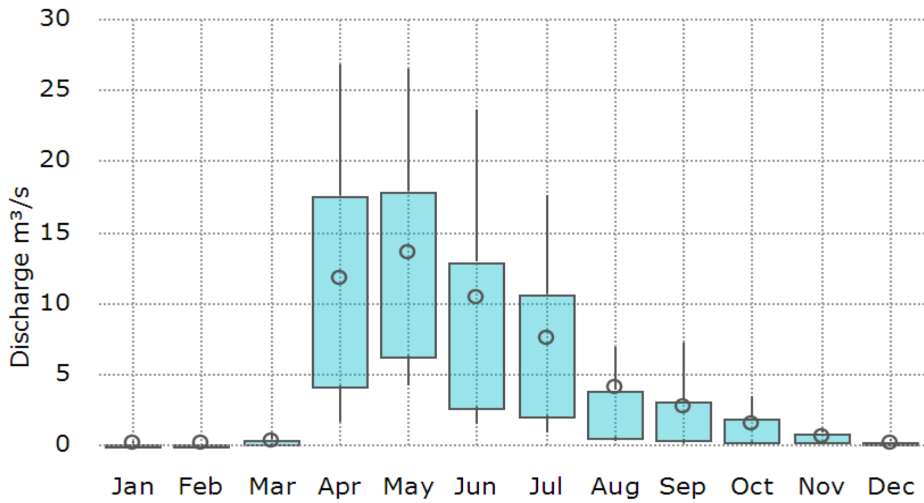

Figure 22. Station 07BF002, West Prairie River near High Prairie. Box and whisker plot, monthly stream flows 1921-30, 1959-2010.

During the late summer and early fall, secondary, smaller peaks in monthly runoff may occur due to late summer storm events (Figure 23). Spring temperatures across the region decrease with increasing elevation, causing snowpacks in higher parts of the study area to melt later than in lower areas. In hilly or mountainous watersheds this delay creates longer periods of elevated discharge in the river systems.

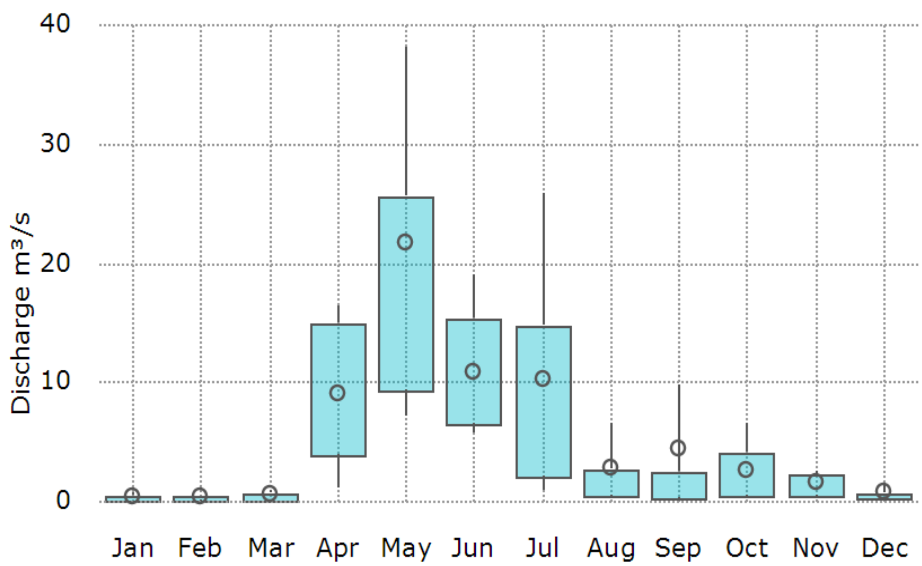

Figure 23. Station 07GD004, Redwillow River near Rio Grande. Box and whisker plot, monthly stream flows 1993-2010.

Low flow periods occur uniformly across the study area in the winter months. In smaller drainages towards the prairies, there is likely no flow through the winter. In more mountainous regions and in larger watersheds, some flow is maintained. Across much of the study area, winter low flows are difficult to quantify as hydrometric stations primarily are not operated through the winter.

Annual runoff

The magnitude of annual runoff varies across the study area, as a function of the watershed size, precipitation, land cover and other factors. For each hydrometric station, the total runoff for a given year can also fluctuate significantly, primarily in response to precipitation, as shown in Figure 24.

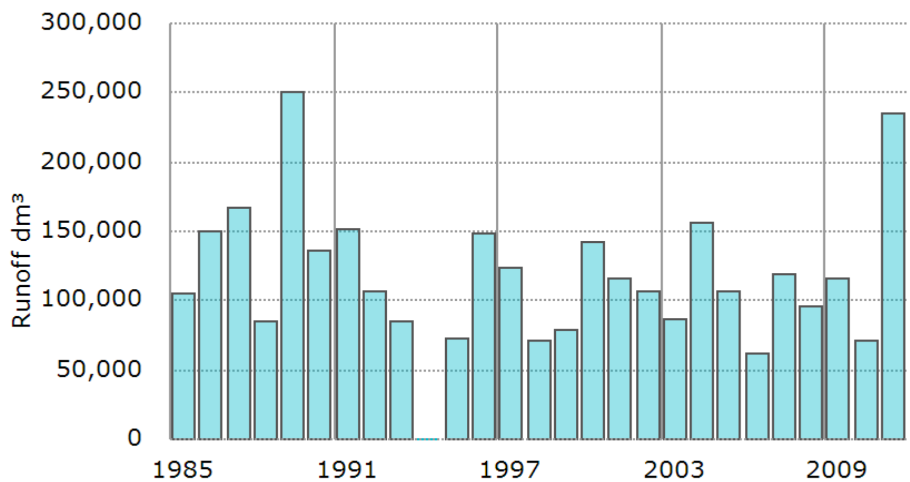

Figure 24. Annual runoff, Station 07GF008, Deep Valley Creek near Valleyview.

Mean annual runoff calculated for each individual hydrometric station in the project study area is shown in Table 6. No adjustments have been made for seasonally operated stations, or to naturalize stream flow in drainages with significant apportionments. Years with fragmented data have been removed from the calculations.

Table 6. Mean Annual runoff, dm^3 (1 dm^3 = $10^3 m^3$)

Station	Mean Runoff	Station	Mean Runoff	Station	Mean Runoff
05CC004	1222	**07AA009**	434985	**07BB010**	1766
05CC007	112789	**07AA010**	33973	**07BB011**	16633
05CC008	24577	**07AB002**	651473	**07BB014**	1049
05CC009	12163	**07AC001**	173892	**07BB903**	3796
05CC010	3144	**07AC002**	1559	**07BF001**	202241
05CC013	39393	**07AC003**	1544	**07BF002**	119212

Station	Mean Runoff	Station	Mean Runoff	Station	Mean Runoff
05DA002	223906	07AC004	3067	07BF007	575
05DA003	1959735	07AC005	1065	07BJ003	49171
05DA006	1155339	07AC006	949	07FD003	30869856
05DA007	197656	07AC007	927226	07FD006	24446
05DA008	39398	07AC008	25451	07FD007	175698
05DA009	1672122	07AD001	5650690	07FD015	3300
05DA010	13050	07AD002	5302886	07FD016	3279
05DB001	753837	07AD003	575	07FD020	3126
05DB002	127538	07AD004	274	07FD910	150
05DB003	329128	07AD005	2484	07FD912	185
05DB004	18258	07AD006	2361	07FD913	127
05DB005	34985	07AD007	100	07FD921	961
05DB006	486213	07AD008	96	07GA001	2342010
05DB007	361092	07AD009	859	07GA002	155268
05DC001	3678666	07AD010	3629	07GB001	133932
05DC002	2584721	07AE001	7036839	07GB002	955351
05DC003	468	07AE002	4214	07GB003	1025975
05DC004	61963	07AE003	5803	07GC001	1104563
05DC006	422727	07AF002	584879	07GC002	47836
05DC007	2422466	07AF003	6713	07GD001	74294
05DC008	1526	07AF004	3122	07GD002	16776
05DC010	2445189	07AF005	3158	07GD003	134083
05DC011	51609	07AF008	2317	07GD004	147442
05DC012	194580	07AF009	1790	07GE001	2793827
05DD004	39108	07AF010	19489	07GE003	7743
05DD005	1501152	07AF011	1862	07GE005	50596
05DD007	811482	07AF012	594	07GE006	2560
05DD008	119191	07AF013	111005	07GE007	5276
05DD009	143604	07AF014	90321	07GF001	716608
05DE001	7984734	07AF015	82798	07GF002	7166
05DE003	6548	07AF906	80826	07GF003	562
05DE006	3990298	07AF907	75828	07GF004	3037
05DE007	49630	07AF909	20941	07GF005	1541
05DE008	1162	07AF910	42153	07GF006	691
05DE009	4064	07AG001	1137110	07GF007	342
05DE010	4914044	07AG002	828275	07GF008	111626
05DE911	65356	07AG003	103485	07GG001	132975
05DF002	551	07AG004	1242605	07GG002	462493
05DF004	21608	07AG005	4945	07GG003	257376
05DF008	2558	07AG006	1676	07GH001	1291849

Station	Mean Runoff	Station	Mean Runoff	Station	Mean Runoff
05EA003	14053	**07AG007**	1173936	**07GH002**	1386936
05EA004	17546	**07AG008**	14144	**07GH004**	8790
05EA009	4163	**07AH001**	240083	**07GH005**	8470
05EA010	5965	**07AH002**	27690	**07GH906**	2892
05FA002	15445	**07AH003**	145716	**07GJ001**	10485409
05FA017	1141	**07BA001**	384192	**07GJ004**	13159
05FA019	6454	**07BA002**	65714	**07GJ005**	2468
05FA912	3797	**07BA003**	21174		
07AA001	317497	**07BB001**	76868		
07AA002	2701065	**07BB002**	543382		
07AA003	455606	**07BB003**	118094		
07AA004	466504	**07BB004**	42748		
07AA007	37603	**07BB005**	16799		
07AA008	98440	**07BB009**	5320		

By correlating the mean annual runoff with gross and effective drainage basin areas, mean annual runoff can be expressed as a function of watershed size using a best fit line based on the following equation (Kerr 2011):

$$V = C \times A^b$$

where V is the flow in dm^3
C is a coefficient
A is the drainage area size in km^2
b is an exponent

The results of this correlation for the coefficient 'C' and exponent 'b', using both the gross and effective drainage areas for each watershed are shown in Table 7.

Table 7. Correlation coefficient and exponent for mean annual runoff.

Drainage Area	C	b	R^2
Gross	50.082	1.1342	0.8294
Effective	57.039	1.1311	0.8605

Flow duration

The flow duration curve for each hydrometric station is provided in Appendix B. The curve characteristics at lower discharges indicate the ability of the basin to sustain low flows during dry seasons. For intermittent streams, the curve will drop to zero at some point before 99%, as for station 07GD001 (Figure 25).

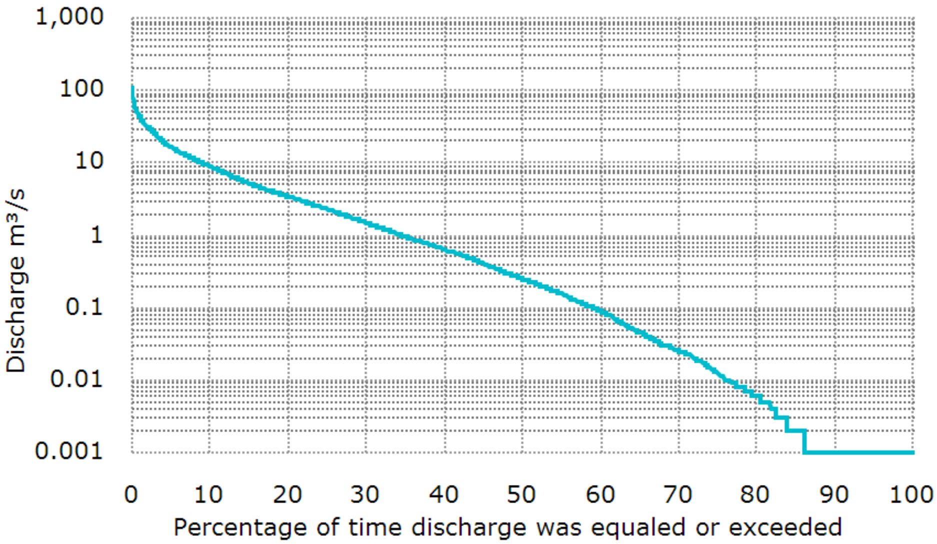

Figure 25. Station 07GD001, Beaverlodge River near Beaverlodge. Flow duration curve.

In the low-flow portion of the curve, a flatter profile indicates that moderate flows are sustained through the dry seasons, either by natural or artificial regulation, or by significant groundwater contributions to base flow. The high flow portion of the curve provides an indication of the 'flashiness' of the drainage. Watersheds which experience significant rain caused floods will have a steeper slope than watersheds where peak flows are typically associated with snow melt in the watershed, as significant flows are sustained for longer periods. The flow duration curves illustrate the flow characteristics of the drainage only for the period during which it has been monitored. For seasonally monitored stations, the curve is therefore not representative of the hydrologic conditions during the winter.

Flood frequency

Flood frequency analysis tells the likelihood of various discharges as a function of a recurrence interval, in years. For each station, the maximum daily discharge from each year that the station was monitored over the typical peak flow season was used to determine the design flows for 2, 5, 10, 25, 50, 100 and 200 year recurrence intervals. Individual results are provided in Appendix B. These values can be expressed as a function of watershed size using a best fit line based on the following equation (Kerr 2011):

$$Q^i = C \times A^b$$

where Q^i is the discharge in m^3/s for recurrence interval i.

C is a coefficient

A is the drainage area size in km^2

b is an exponent

The results of this correlation for the coefficient 'C' and exponent 'b', using both the gross and effective drainage areas for each watershed are shown in Table 8.

Table 8. Correlation coefficient and exponent for design floods.

Recurrence	Drainage Area	C	b	R^2
Q^2	Gross	0.0572	0.9699	0.8717
	Effective	0.0603	0.9691	0.8817
Q^5	Gross	0.148	0.9242	0.8938
	Effective	0.142	0.9345	0.9039
Q^{10}	Gross	0.2347	0.9028	0.8937
	Effective	0.2175	0.9175	0.9041
Q^{25}	Gross	0.3421	0.8953	0.8792
	Effective	0.3049	0.9151	0.8904
Q^{50}	Gross	0.4437	0.8879	0.8629
	Effective	0.3881	0.9102	0.875
Q^{100}	Gross	0.529	0.8892	0.8416
	Effective	0.4535	0.9143	0.8549
Q200	Gross	0.6331	0.8878	0.8185
	Effective	0.5352	0.915	0.8329

Drought flows

The analysis of drought flows was conducted on three temporal periods, full year (November 1 - October 31), winter (November 1 - April 30), and summer (May 1 - October 31). The seven day low flow with a recurrence interval of 10 years (7Q10) was calculated using the DFLOW program (EPA 2006). The analysis is performed on daily time series data, is highly sensitive to errors in input data sets, and requires at least 10 years of continuous data to produce results. Of the 183 hydrometric stations in the study area, 28 full year, 27 winter, and 94 summer results were calculated successfully and are shown in Table 9.

Table 9. Seven day low flow values (m^3/s) with recurrence interval of 10 years (7Q10). Full year (November 1 - October 31), Summer (May 1 - October 31) and Winter (November 1 - April 30).

Station	Full Year	Summer	Winter	Station	Full Year	Summer	Winter
5EA009		0		**5DB005**		0.39	
7GF002		0		**7GB001**		0.76	
7GF004		0		**7AF015**		0.8	
7GF005		0		**7AF014**		0.81	
7GF006		0		**7AH003**		0.82	
5CC008		0		**7GF008**		0.84	
5CC009		0		**5DA007**	0.34	1.01	0.34

Station	Full Year	Summer	Winter	Station	Full Year	Summer	Winter
5CC010		0		7AH001		1.03	
5DE003		0		5DD009	0.45	1.04	0.45
5DE009		0		5DD008		1.07	
5DF004		0		5DC012	0.35	1.12	0.3
5EA010		0		7AF013		1.2	
5FA019		0		5DB002	0.77	1.51	0.76
7BB004		0		7GA002		1.62	
7BB005		0		7AA001	0.29	1.78	0.29
7BB011		0		5DA002		1.88	
7FD006		0		7AC001		1.95	
7GD001		0		7AA009		2.19	
7GD002		0		7BB002	0.33	2.47	0.33
7GE003		0		7AA004	1.8	2.57	1.8
7AD004		0		7GF001		2.84	
5CC007	0.02	0.02	0.09	7GG002		2.85	1.34
7AF004		0.02		7BA001		3.14	
7AH002		0.02		5DB003		4.61	
7AA007		0.02		7AF002	1.01	4.67	1.03
7AF003		0.03		7GH002	1.45	5.43	
7AF005		0.03		5DB006	1.8	7.29	1.9
7GC002		0.03		7GB002		7.57	
7BF002	0	0.04	0	7GB003		7.63	
5DE911		0.04		7AB002		7.96	
7FD007	0.01	0.05	0.02	5DA009	3.43	8.97	3.44
5DA010	0.02	0.05	0.02	7AG007	2.69	9.06	2.77
5DE007		0.06		7AG001	0.54	9.29	0.56
7AG008		0.06		7AG004		9.45	
5DD005	0.08	0.09	0.76	5DB001	2.87	9.52	2.89
7AF010		0.14		5DC010	3.41	9.57	
7GD004	0.03	0.16	0.04	5DD007		11.2	
7AC008		0.22		7AC007		14.8	
7BJ003		0.23		7AA002	4.94	16.1	4.99
7BA002		0.24		5DC007	N/A	16.3	
7BA003		0.24		7GA001		20.9	
7GG003		0.27		5DC002	N/A	21.3	
5DC011		0.29		7GE001	7.71	24.9	7.57
5DD004		0.29		7AD001	14.5	44	13.9
7GG001	0.11	0.33	0.11	7AD002	15.9	44.1	15.9
7BF001		0.35		5DC001	14.7	46.5	14.8
7BB003	N/A	0.37	N/A	7GJ001	22.3	89.1	22.6

These values can be expressed as a function of watershed size using a best fit line based on the following equation (Kerr 2011):

$$Q^{season} = C \times A^{b}$$

where Q^{season} is the discharge in m^3/s for the season
C is a coefficient
A is the drainage area size in km^2
b is an exponent

The results of this correlation for the coefficient 'C' and exponent 'b', using both the gross and effective drainage areas for each watershed are shown in Table 10.

Table 10. Correlation coefficient and exponent for drought flows.

Period	Drainage Area	C	b	R^2
Full Year	Gross	0.0007	0.8996	0.3766
	Effective	0.0007	0.901	0.3765
Summer	Gross	0.0009	1.0158	0.5639
	Effective	0.0009	1.0179	0.5645
Winter	Gross	0.0006	0.9432	0.4904
	Effective	0.0006	0.9443	0.4899

The correlation between drought flows and watershed size performs less effectively than the similar procedure for annual discharge and flood design flows. A much smaller sample size was available as for many of the stations the data available did not support a calculation for 7Q10 discharge. Also, values of zero were excluded from the correlation as they are not able to be represented by an equation of that form. Exploratory analysis of the distribution of 7Q10 values in relation to watershed size suggests that separate populations may exist within the dataset that would be better represented by separate correlations. A method for partitioning the samples was not determined at this time.

Water Balance

A water balance can be created in a watershed by weighing water inputs to the system with outputs. Variations in precipitation between individual years may result in an excess or deficit in the equation, but for longer temporal periods an assumption can be made that the system is approximately in equilibrium. The speed at which groundwater, in communication with surface water, moves through the system is often several orders of magnitude slower than that of surface water. By assuming that groundwater recharge and discharge is in equilibrium as well over longer time periods, and that these processes operate within the boundaries of the surface water watersheds, these components cancel out. Inter-year precipitation differences and the speed of groundwater flow complicate coupling the inputs and outputs of the water balance for individual years (Trask and Fogg, 2009).

A simple approach to a water balance assesses long-term averages for the dominant processes within a watershed, and includes precipitation, as rain or snow, as the only input to the equation. The three primary processes as outputs are evaporation, transpiration, and channel flow. Using data compiled as part of the project, a water balance was prepared for each of the watersheds associated with a hydrometric gauge (Table 11). The gridded, annual precipitation data from ClimateWNA (PPT) and the mean annual runoff based on monthly mean values as published by the Water Survey of Canada (Q) were used, with the difference between the two attributed to evapotranspiration, loss to deep groundwater, consumptive use, and error in the individual data sets. For this analysis, the effective drainage basin areas were used where available. Stations notated with an * indicate watersheds where effective drainage basin size was not available in the database, in these cases gross drainage basin areas were substituted. Stations notated with an ** indicate watersheds where the drainage basin size in the database is known to be inaccurate, in these cases the actual drainage basin size has been estimated.

Table 11. Water Balance Calculations.

STATION CODE	STATION NAME	PPT	Q	ET/GW/ USE
05CC007	MEDICINE RIVER NEAR ECKVILLE	551.9	71.2	480.7
05CC008	BLINDMAN RIVER NEAR BLUFFTON	563.9	101.3	462.6
05CC009	LLOYD CREEK NEAR BLUFFTON	532.1	72.4	459.7
05CC010	BLOCK CREEK NEAR LEEDALE	557.3	72.6	484.7
05CC013	LASTHILL CREEK NEAR ECKVILLE	555.7	74.0	481.7
05DA002	SIFFLEUR RIVER NEAR THE MOUTH	1311.7	465.1	846.6
05DA003	NORTH SASKATCHEWAN RIVER AT WILSON'S RANCH	1213.4	765.5	447.9
05DA006	NORTH SASKATCHEWAN RIVER AT SASKATCHEWAN CROSSING	1223.5	886.1	337.4
05DA007	MISTAYA RIVER NEAR SASKATCHEWAN CROSSING	1285.0	789.0	496.0
05DA008	PEYTO CREEK AT PEYTO GLACIER	1441.3	1667.3	-226.0
05DA009	NORTH SASKATCHEWAN RIVER AT WHIRLPOOL POINT	1208.4	859.3	349.1
05DA010	SILVERHORN CREEK NEAR THE MOUTH	1324.4	637.7	686.7
05DB001	CLEARWATER RIVER NEAR ROCKY MOUNTAIN HOUSE	790.3	244.5	545.8
05DB002	PRAIRIE CREEK NEAR ROCKY MOUNTAIN HOUSE	609.1	163.0	446.1
05DB003	CLEARWATER RIVER ABOVE LIMESTONE CREEK	1015.6	267.5	748.1
05DB004	PRAIRIE CREEK NEAR RANGER STATION	639.0	220.0	419.0
05DB005	PRAIRIE CREEK BELOW LICK CREEK	625.8	184.3	441.5
05DB006	CLEARWATER RIVER NEAR DOVERCOURT	870.8	239.3	631.5
05DB007	CLEARWATER RIVER AT FORESTRY ROAD*	965.2	269.5	695.7
05DC001	NORTH SASKATCHEWAN RIVER NEAR ROCKY MOUNTAIN HOUSE	895.4	322.8	572.6
05DC002	NORTH SASKATCHEWAN RIVER AT SAUNDERS	1047.4	477.7	569.7
05DC003	MARTIN CREEK NEAR NORDEGG	631.0	132.0	499.0
05DC004	SHUNDA CREEK NEAR SAUNDERS	607.8	190.6	417.2
05DC006	RAM RIVER NEAR THE MOUTH	777.5	247.4	530.1
05DC007	NORTH SASKATCHEWAN RIVER BELOW TERSHISHNER CREEK	1160.1	585.5	574.6
05DC008	RAM RIVER AT RAM GLACIER	1613.1	457.6	1155.5
05DC010	NORTH SASKATCHEWAN RIVER BELOW BIGHORN PLANT	1160.0	609.3	550.7
05DC011	NORTH RAM RIVER AT FORESTRY ROAD	737.5	165.7	571.8
05DC012	BAPTISTE RIVER NEAR THE MOUTH	598.0	140.4	457.6
05DD004	BROWN CREEK AT FORESTRY ROAD	762.9	207.3	555.6
05DD005	BRAZEAU RIVER BELOW BRAZEAU PLANT	906.1	280.1	626.0
05DD007	BRAZEAU RIVER BELOW CARDINAL RIVER	1160.2	336.6	823.6
05DD008	CARDINAL RIVER NEAR THE MOUTH	962.9	236.3	726.6
05DD009	NORDEGG RIVER AT SUNCHILD ROAD	600.8	172.9	427.9

STATION CODE	STATION NAME	PPT	Q	ET/GW/ USE
05DE001	NORTH SASKATCHEWAN RIVER AT ROCKY RAPIDS	825.5	356.7	468.8
05DE003	WABAMUN CREEK NEAR DUFFIELD	534.2	19.5	514.7
05DE006	NORTH SASKATCHEWAN RIVER NEAR LODGEPOLE	828.7	202.3	626.4
05DE007	ROSE CREEK NEAR ALDER FLATS	563.6	97.7	465.9
05DE008	MODESTE CREEK NEAR BRETON	576.0	3.1	572.9
05DE009	TOMAHAWK CREEK NEAR TOMAHAWK	541.4	58.0	483.4
05DE010	NORTH SASKATCHEWAN RIVER AT HIGHWAY NO. 759	821.0	226.1	594.9
05DE911	MODESTE CREEK NEAR LINDALE**	569.1	87.5	481.6
05DF002	CONJURING CREEK NEAR WIZARD LAKE	514.7	42.7	472.0
05DF004	STRAWBERRY CREEK NEAR THE MOUTH	535.2	45.8	489.4
05DF008	WEED CREEK AT THORSBY	521.3	35.8	485.5
05EA003	STURGEON RIVER NEAR DARWELL	535.0	49.3	485.7
05EA004	STURGEON RIVER NEAR ONOWAY	541.6	27.7	513.9
05EA009	ATIM CREEK NEAR SPRUCE GROVE	529.6	50.0	479.6
05EA010	STURGEON RIVER NEAR MAGNOLIA BRIDGE	533.9	55.9	478.0
05FA002	PIGEON LAKE CREEK NEAR WESTEROSE	531.5	53.1	478.4
05FA017	PIGEON LAKE CREEK NEAR THE MOUTH	527.0	6.6	520.4
05FA019	PIGEON LAKE CREEK NEAR USONA	527.3	34.4	492.9
05FA912	MUSKEG CREEK NEAR WESTEROSE	524.9	50.2	474.7
07AA001	MIETTE RIVER NEAR JASPER	1101.4	505.4	596.0
07AA002	ATHABASCA RIVER NEAR JASPER	1088.7	690.0	398.7
07AA003	ROCKY RIVER AT HAWES	1060.4	326.0	734.4
07AA004	MALIGNE RIVER NEAR JASPER	1089.5	505.9	583.6
07AA007	SUNWAPTA RIVER AT ATHABASCA GLACIER	1357.9	1243.8	114.1
07AA008	FIDDLE RIVER AT HIGHWAY NO. 16	916.8	427.2	489.6
07AA009	WHIRLPOOL RIVER NEAR THE MOUTH	1194.6	747.8	446.8
07AA010	FIDDLE RIVER ABOVE MORRIS CREEK	952.0	167.4	784.6
07AB002	SNAKE INDIAN RIVER NEAR THE MOUTH	989.6	429.6	560.0
07AC001	WILDHAY RIVER NEAR HINTON	844.3	192.6	651.7
07AC002	NORTH FOX CREEK NEAR MUSKEG	642.4	90.7	551.7
07AC003	EAST CABIN CREEK NEAR MUSKEG	644.2	91.9	552.3
07AC004	HENDRICKSON CREEK NEAR THE MOUTH	653.8	123.2	530.6
07AC005	VOGEL CREEK NEAR THE MOUTH	649.4	93.4	556.0
07AC006	HINTON STUDY BASIN NO.14	663.2	77.8	585.4

STATION CODE	STATION NAME	PPT	Q	ET/GW/ USE
07AC007	BERLAND RIVER NEAR THE MOUTH	688.7	177.3	511.4
07AC008	LITTLE BERLAND RIVER AT HIGHWAY NO. 40	797.3	307.8	489.5
07AD001	ATHABASCA RIVER AT ENTRANCE	1022.3	606.5	415.8
07AD002	ATHABASCA RIVER AT HINTON	1010.4	556.0	454.4
07AD003	CACHE PERCOTTE CREEK NEAR HINTON	610.9	79.1	531.8
07AD004	WHISKEYJACK CREEK NEAR HINTON	623.3	93.1	530.2
07AD005	FISH CREEK NEAR HINTON	663.9	84.7	579.2
07AD006	OLDMAN CREEK NEAR HINTON	681.5	111.2	570.3
07AD007	CACHE PERCOTTE CREEK (NORTH FORK) NEAR HINTON	623.3	77.0	546.3
07AD008	HINTON STUDY BASIN NO.1	624.9	5.7	619.2
07AD009	HINTON STUDY BASIN NO.2	642.7	59.2	583.5
07AD010	HINTON STUDY BASIN NO.5	682.2	184.2	498.0
07AE001	ATHABASCA RIVER NEAR WINDFALL	834.5	356.5	478.0
07AE002	HINTON STUDY BASIN NO.6	664.7	177.1	487.6
07AE003	HINTON STUDY BASIN NO.7*	679.0	263.8	415.2
07AF002	MCLEOD RIVER ABOVE EMBARRAS RIVER	733.9	236.1	497.8
07AF003	WAMPUS CREEK NEAR HINTON	722.2	258.0	464.2
07AF004	DEERLICK CREEK NEAR HINTON	712.1	266.6	445.5
07AF005	EUNICE CREEK NEAR HINTON	706.8	205.9	500.9
07AF008	QUIGLEY CREEK NEAR HINTON	649.4	145.9	503.5
07AF009	NORTH ANDERSON CREEK NEAR HINTON	670.6	174.9	495.7
07AF010	SUNDANCE CREEK NEAR BICKERDIKE	607.2	117.6	489.6
07AF011	HINTON STUDY BASIN NO.15	670.3	94.5	575.8
07AF012	HINTON STUDY BASIN NO.16	629.6	73.8	555.8
07AF013	MCLEOD RIVER NEAR CADOMIN	1030.8	356.5	674.3
07AF014	EMBARRAS RIVER NEAR WEALD	625.8	150.5	475.3
07AF015	GREGG RIVER NEAR THE MOUTH	796.9	231.6	565.3
07AF906	GREGG RIVER NEAR HINTON*	783.9	222.0	561.9
07AF907	ERITH RIVER BELOW HANLAN CREEK*	638.5	169.3	469.2
07AF909	EMBARRAS RIVER AT ROBB*	679.5	172.5	507.0
07AF910	WHITEHORSE CREEK NEAR CADOMIN*	1156.6	373.8	782.8
07AG001	MCLEOD RIVER NEAR WOLF CREEK	658.0	180.8	477.2
07AG002	MCLEOD RIVER NEAR EDSON	667.4	128.0	539.4
07AG003	WOLF CREEK AT HIGHWAY NO. 16A	600.3	149.8	450.5

STATION CODE	STATION NAME	PPT	Q	ET/GW/ USE
07AG004	MCLEOD RIVER NEAR WHITECOURT	634.0	147.9	486.1
07AG005	HINTON STUDY BASIN NO.8	650.4	214.1	436.3
07AG006	HINTON STUDY BASIN NO.9	649.0	222.2	426.8
07AG007	MCLEOD RIVER NEAR ROSEVEAR	650.4	171.4	479.0
07AG008	GROAT CREEK NEAR WHITECOURT	600.5	144.0	456.5
07AH001	FREEMAN RIVER NEAR FORT ASSINIBOINE	625.5	158.5	467.0
07AH002	CHRISTMAS CREEK NEAR BLUE RIDGE	579.0	72.6	506.4
07AH003	SAKWATAMAU RIVER NEAR WHITECOURT	615.6	134.6	481.0
07BA001	PEMBINA RIVER BELOW PADDY CREEK	636.5	165.5	471.0
07BA002	RAT CREEK NEAR CYNTHIA	607.9	121.3	486.6
07BA003	LOVETT RIVER NEAR THE MOUTH	720.3	233.9	486.4
07BB001	LOBSTICK RIVER NEAR ENTWISTLE	575.1	57.9	517.2
07BB002	PEMBINA RIVER NEAR ENTWISTLE	615.4	141.1	474.3
07BB003	LOBSTICK RIVER NEAR STYAL	576.7	90.7	486.0
07BB004	PADDLE RIVER NEAR ROCHFORT BRIDGE	566.1	73.0	493.1
07BB005	LITTLE PADDLE RIVER NEAR MAYERTHORPE	561.8	77.1	484.7
07BB009	CONNOR CREEK NEAR SANGUDO	540.4	32.2	508.2
07BB010	CONNOR CREEK NEAR ROCHFORT BRIDGE	549.8	43.0	506.8
07BB011	PADDLE RIVER NEAR ANSELMO	570.6	74.7	495.9
07BB014	COYOTE CREEK NEAR CHERHILL	560.8	34.7	526.1
07BB903	ROMEO CREEK ABOVE ROMEO LAKE*	521.4	36.5	484.9
07BF001	EAST PRAIRIE RIVER NEAR ENILDA	614.2	154.0	460.2
07BF002	WEST PRAIRIE RIVER NEAR HIGH PRAIRIE	585.0	119.1	465.9
07BF007	BRIDGE CREEK NEAR ENILDA	525.3	112.0	413.3
07BJ003	SWAN RIVER NEAR SWAN HILLS	725.3	306.8	418.5
07FD006	SADDLE RIVER NEAR WOKING	510.7	57.2	453.5
07FD007	POUCE COUPE RIVER BELOW HENDERSON CREEK*	529.3	68.3	461.0
07FD015	DAWSON CREEK ABOVE SOUTH DAWSON CREEK*	536.6	31.8	504.8
07FD016	SOUTH DAWSON CREEK AT THE MOUTH*	532.8	37.8	495.0
07FD020	SPIRIT RIVER NEAR SPIRIT RIVER	498.4	42.6	455.8
07FD910	RYCROFT SURVEY NO. 3 NEAR RYCROFT*	454.5	21.7	432.8
07FD912	WHITBURN DRAINAGE PROJECT NEAR SPIRIT RIVER*	468.6	33.5	435.1
07FD913	YOUNG DRAINAGE PROJECT NEAR SPIRIT RIVER*	444.2	17.5	426.7
07FD921	VIXEN CREEK NEAR BELLOY*	472.5	14.5	458.0

STATION CODE	STATION NAME	PPT	Q	ET/GW/ USE
07GA001	SMOKY RIVER ABOVE HELLS CREEK	1047.7	610.1	437.6
07GA002	MUSKEG RIVER NEAR GRANDE CACHE	679.5	232.4	447.1
07GB001	CUTBANK RIVER NEAR GRANDE PRAIRIE	709.0	179.0	530.0
07GB002	KAKWA RIVER NEAR GRANDE PRAIRIE	805.5	283.8	521.7
07GB003	KAKWA RIVER AT HIGHWAY NO. 40	802.1	303.8	498.3
07GC001	WAPITI RIVER ABOVE MISTANUSK CREEK*	1044.2	374.8	669.4
07GC002	PINTO CREEK NEAR GRANDE PRAIRIE	615.3	106.3	509.0
07GD001	BEAVERLODGE RIVER NEAR BEAVERLODGE	519.4	49.2	470.2
07GD002	BEAVERTAIL CREEK NEAR HYTHE	529.1	46.9	482.2
07GD003	REDWILLOW RIVER NEAR BEAVERLODGE	618.6	90.2	528.4
07GD004	REDWILLOW RIVER NEAR RIO GRANDE*	655.8	131.2	524.6
07GE001	WAPITI RIVER NEAR GRANDE PRAIRIE	741.3	270.4	470.9
07GE003	GRANDE PRAIRIE CREEK NEAR SEXSMITH	510.3	62.6	447.7
07GE005	BEAR RIVER NEAR GRANDE PRAIRIE	492.5	34.5	458.0
07GE007	BEAR RIVER NEAR VALHALLA CENTRE	509.4	37.3	472.1
07GF001	SIMONETTE RIVER NEAR GOODWIN	613.2	140.7	472.5
07GF002	SPRING CREEK NEAR VALLEYVIEW	538.4	73.1	465.3
07GF003	WOLVERINE CREEK NEAR VALLEYVIEW	534.2	54.7	479.5
07GF004	SPRING CREEK (UPPER) NEAR VALLEYVIEW	543.1	85.5	457.6
07GF005	BRIDLEBIT CREEK NEAR VALLEYVIEW	537.5	88.6	448.9
07GF006	ROCKY CREEK NEAR VALLEYVIEW	535.5	52.5	483.0
07GF007	HORSE CREEK NEAR VALLEYVIEW	533.4	97.1	436.3
07GF008	DEEP VALLEY CREEK NEAR VALLEYVIEW	702.8	190.6	512.2
07GG001	WASKAHIGAN RIVER NEAR THE MOUTH	622.9	135.4	487.5
07GG002	LITTLE SMOKY RIVER AT LITTLE SMOKY	641.0	159.6	481.4
07GG003	IOSEGUN RIVER NEAR LITTLE SMOKY	601.7	133.6	468.1
07GH001	LITTLE SMOKY RIVER NEAR TRIANGLE	595.8	121.9	473.9
07GH002	LITTLE SMOKY RIVER NEAR GUY	590.4	129.0	461.4
07GH004	PEAVINE CREEK NEAR FALHER	466.3	38.4	427.9
07GH005	WABATANISK CREEK AT HIGHWAY NO. 676	513.8	67.7	446.1
07GJ001	SMOKY RIVER AT WATINO	667.9	215.0	452.9
07GJ004	BAD HEART RIVER NEAR HEART VALLEY	504.1	68.5	435.6
07GJ005	LALBY CREEK NEAR GIROUXVILLE	450.7	60.6	390.1

DISCUSSION

A large amount of data was compiled during Year 1 of the project for components of the surface water cycle. The size of the study area and natural drainage boundaries between the four major river systems flowing through it provided difficulties in determining partitions for analysis. Based on the technology available to conduct and communicate the results of the analyses, a decision was made to use numerous, smaller sub-divisions which would translate more effectively to operational level use of the data for interested parties.

Appendices to this report include the full set of analyses conducted during Year 1 for the surface water component. Through the NOLA mapping framework, results of the spatial thematic, and hydrologic analyses may also be accessed, and visual interpretation of several dozen high value spatial data layers may be performed.

Surface water occurs across the study area, the pattern of streams and rivers across the landscape is evidence of this. The timing and amount, however, varies substantially spatially. Annual precipitation is a key predictor of surface water volumes, and areas at higher elevation within the play fairways and towards the Rocky Mountains receive higher levels of precipitation. Winter precipitation amounts are relatively even throughout the region, with wetter areas on an annual basis receiving the balance of the difference during the summer months. The presence of elevated summer precipitation varies the hydrograph in these regions significantly and extends the period of elevated flows for a much longer period than where the relatively limited snow accumulations are the major source.

The interplay between land cover and surficial geology provides further indications of the magnitude of surface water resources in a region. Typically conifers are indicative of areas with more water at surface. Where black spruce are present in wetlands amongst deciduous forests or grasslands they may however indicate groundwater discharge areas or impervious sediments underlying. The recharge of groundwater from surface water predominantly occurs during the spring, as the ground melts and becomes saturated with melting snow for a significant period of time. Evapotranspiration rates increase with increased temperatures and solar radiation, this movement of water back to the atmosphere is interlinked with the carbon cycle fixing CO^2 during photosynthesis.

Based on the data provided, the potential for surface water, shallow groundwater, and deep groundwater can be briefly assessed across the study area. Mini-hydrologic assessments can be performed, by delineating watersheds for drainages of interest and reviewing precipitation patterns and amounts, previous estimates of regional unit runoff, historic measurements from nearby hydrometric stations, and other data. Watershed size can be used with correlation coefficients to provide approximate estimates of hydrologic characteristics.

Year 2 work will build on these results substantially and across all components develop high-value products for use in operational planning. The spatial database compiled during Year 1 of the project is provided to partner companies as a Year 1 deliverable, for integration into their corporate systems.

RECOMMENDATIONS

In order to efficiently estimate runoff in ungauged rivers and streams within the study area, hydrologically connected spatial data for drainage networks and watersheds should be produced. This will allow for the dynamic assessment of surface water resources throughout the region. Effective management of water resources at the catchment or watershed scale requires detailed understanding of the dynamics of water movement across the surface. Such a dataset would provide for this ability.

Hydrometric stations are well distributed across the study area, but some notable gaps exist in the data. Fox Creek is located within the heart of the combined play fairways, and near the drainage divide between the Peace and Athabasca River watersheds. This area is interpreted as having higher runoff than the areas to the north and south, but has limited coverage of hydrometric stations especially in the headwaters of the watersheds where significant demand for water may occur in the future. Collection of new data in this area should be considered. More broadly, less than 50 of the 183 stations within the study area have more than 5 years of data collected through the winter months. A greater understanding of winter conditions would be useful in the assessment of winter flow capabilities across the region. Year 2 activities will consider in detail the coverage of gauged watersheds in the region and produce more detailed recommendations for new data collection.

Current active weather stations are well distributed across the study area. Some gaps, however, do exist. West of Fox Creek and south of Grande Prairie, and also northwest of Rocky Mountain House, new stations could perhaps be co-located with active, real-time monitored hydrometric stations currently in place. There are no snow pillows installed west of Whitecourt, in the headwaters of either the Smoky or the Athabasca Rivers. While snow courses exist in the regions, the addition of snow pillows would provide substantial benefit in terms of real-time data collection.

Any new collection of hydrometric or weather data should complement the existing programs operated by the federal and provincial governments. Ideally new monitoring stations would be managed in partnership with these programs as that would ensure quality data was collected, made available and archived through the authoritative sources for such information.

The distribution and characteristics of water licenses for surface water and non-saline groundwater are relevant in the consideration of surface water resources. Year 2 activities will address the compilation and analyses of these data sets.

The data provided through Year 1 of the project should allow for industry partners to begin developing longer term regional water sourcing and management strategies, as appropriate based on drilling results and development plans. The geographic interplay between the surface water, non-saline and saline groundwater components of the project and the temporal availability of surface water (and possibly non-saline groundwater) resources will be key in this regard. By combining the data provided through this project with other relevant information such as land holdings, infrastructure (roads) and other access constraints, industry partners may begin to evaluate realistic access options for accessing water sources.

To ensure the project outcomes meet the operational needs of partners, company representatives may consider pilot testing project results with operational staff, depending on interest. The Integrated Water Resources team would like to participate in such activities as feedback would be useful to the project team in the delivery of continuing work within the project.

CONCLUSION

The data compilation and analysis activities completed for the surface water component of the Integrated Assessment of Water Resources for Unconventional Oil and Gas Plays, West-Central Alberta Project during Year 1 have produced a significant body of knowledge on the surface water resources within the project area. The work has focused on characterizing the key components of the water cycle, including precipitation, evapotranspiration, and runoff. Through the compilation of detailed data sets covering a broad area, results can be interpreted at varying scales from the entire study area down to individual watersheds associated with hydrometric stations.

Combined, project activities for the three components of the project have laid a solid foundation for continuing, more detailed work in Year 2 building on these results. Surface water related activities will focus on compiling, assessing and integrating water licensing and consumptive use data with detailed modeling on surface water availability, distributed throughout the project area. This work will provide insight into the hydrologic resources in basins without hydrometric stations over the course of a typical year.

As results continue to be generated, and integrated through the mapping framework NOLA, concerned parties will have the ability to interact with project results and build an understanding of the characteristics of the surface water, non-saline and saline groundwater resources across the region. This will be useful to industry when developing water sourcing and management strategies, and also to government and other public stakeholders interested in the topics.

Project results will be public on completion of the review period, and they are intended to act as a resource for all stakeholders to be able to engage in discussions around water sourcing options from a knowledgeable point of view with regards to the viability of surface water, non-saline and saline groundwater across the region.

APPENDICES

- Sub-basin analysis results, Appendix A (separate document)
- Hydrometric station based analyses, Appendix B (separate document)
- Spatial data compilation metadata, Appendix C (separate document)

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