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Year 2 Summary Report
Surface Water

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

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Prepared by:
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PREFACE

The Integrated Assessment of Water Resources for Unconventional Oil and Gas Plays, West Central Alberta (WCAB) project was formulated in response to a Petroleum Technology Alliance of Canada (PTAC) call for proposals, asking for a collaborative water research project modeled after the successful, Geoscience BC led, Montney Water Project (MWP) undertaken in BC from 2010-2012. The core team of consultants which delivered the MWP, Petrel Robertson Consulting Ltd., Strategic West Energy Ltd., and Foundry Spatial Ltd., developed a response to the call for proposals which was well received. In early 2012, PTAC committed to seed funding for the project, contingent on suitable funding contributions being received from industry partners. An early presentation to the Canadian Association of Petroleum Producers (CAPP) Water Committee provided feedback on the proposed scope, and members of the committee emphasized the importance of engaging government organizations with responsibility for water management. Eight oil and gas producers interested in participating in the project were assembled during early 2012 with the project officially kicking off in June 2012.

The two key government agencies identified for participation in the project were the Ministry of Environment and Sustainable Resource Development (ESRD) and the Alberta Energy Regulator (AER, at the time Energy Resources Conservation Board / ERCB). The primary point of contact was through the Water Policy Branch, ESRD, with active participation also from the Alberta Geological Survey and other groups within AER. Several conference calls and meetings occurred over 2012, with staff participating in regular project update meetings and receiving project updates beginning in late 2012.

In June 2013, a project workshop focused on surface water was convened in Edmonton, with participation from ESRD, BC Oil and Gas Commission, BC Ministry of Environment, oil and gas producers and the project team. Following the workshop the project team worked with a team from ESRD to develop a Memorandum of Understanding relating to the project that resulted in the provision of high-value datasets to facilitate project activities. The Year 2 workplan for the WCAB project was refined based on input from ESRD staff, with the goal of ensuring that project outcomes would align with their ;decision making needs and processes.

A core goal from the outset of the WCAB project was to execute surface water hydrology modeling to allow the development of a decision support tool using the NOLA suite of technologies. Active participation of ESRD hydrologists over the past two years has ensured project activities and products are well aligned with the water decision making process in Alberta, including factors such as temporal time-steps and environmental flow consideration methods.

On July 1, 2013, the Energy Resources Conservation Board became the Alberta Energy Regulator, in the process assuming many new responsibilities for regulating the oil and gas industry. These new responsibilities include the authority to issue water approvals for industry use. In May 2014, the Alberta Environmental Monitoring, Evaluation and Reporting Agency (AEMERA) was launched with a mandate including monitoring, evaluating and reporting on water indicators to better inform decision-making. The project team continues to work with ESRD, AER and industry partners to identify potential opportunities to see NOLA developed in Alberta to provide enhanced information on surface water resources in West-Central Alberta.

The core focus of Alberta government participation in the WCAB project was on surface water related work, with groundwater policy staff also maintaining an active presence at project meetings. The Alberta Geological Survey provided an update on government led groundwater research initiatives at a project meeting in early 2014.

EXECUTIVE SUMMARY

The successful development of unconventional resources in Alberta will require access to substantial volumes of water. This water may be sourced from saline or non-saline groundwater, surface water, recycled industrial water, or treated municipal wastewater, among other sources. A key difference between shale gas development and other industrial uses, is the length of time that an individual water source may be required. The primary consumption of water occurs during a small window of time, associated with the hydraulic fracturing based stimulation of a well. For a single well, this use may occur over a period of days to weeks, or for a multi-well pad, this centralized demand may extend to several months or years. Following the stimulation of the wells at any given location, the water demand will stop, and then re-emerge at a different location where new drilling is occurring.

Considering surface water resources, for a long term industrial user of water at a single location, substantial effort can be put into an evaluation of the hydrology associated with a given site, and that effort will only need to be expended once. For smaller, transitory water demands such as those associated with shale gas development, a desire may exist to rapidly evaluate multiple potential sites, both to identify the potential resource and also to identify existing water users in an area. In order to quickly and most accurately estimate the potential resource, a continuous estimation of runoff across the landscape is required. The second year of the WCAB project, and the work described in this report, undertook to create a continuous estimate of surface water resources across 142,000 km^2 of western Alberta. The modeling process was tailored to the specific regulatory environment in Alberta by modeling long-term normal runoff conditions at the weekly time step, and also by estimating low flow parameters required for the implementation of *A desk-top method for establishing environmental flows in Alberta rivers and streams* (Locke and Paul, 2011).

This report summarizes work undertaken in Year 2 of the WCAB project. In Year 1, a large amount of data was compiled, processed, and analyzed to build a foundational understanding of the streamflow hydrology and various components of the hydrologic cycle. This data provided the framework for the hydrologic modeling undertaken in Year 2.

Significant progress was also made in building improved understandings of the saline and non-saline groundwater resources of the project study area in both years of the WCAB project. Reports describing these activities are available on the project website.

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 Canada Resources, ConocoPhillips Canada, Encana Corporation, Husky Energy, Mosaic Energy, NuVista Energy, Penn West Petroleum, Shell Canada and Talisman Energy.

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INTRODUCTION

The study area for the surface water component of this project was 142,000 km^2 of west-central Alberta, bounded in the north by the Peace River, and extending south-eastward nearly to Edmonton and Red Deer (Figure 1). The study area included the headwaters of the Smoky, Athabasca, and North Saskatchewan Rivers, and portions of the Red Deer and Battle River watersheds. This region covers the Montney and Duvernay oil and gas plays in Alberta.

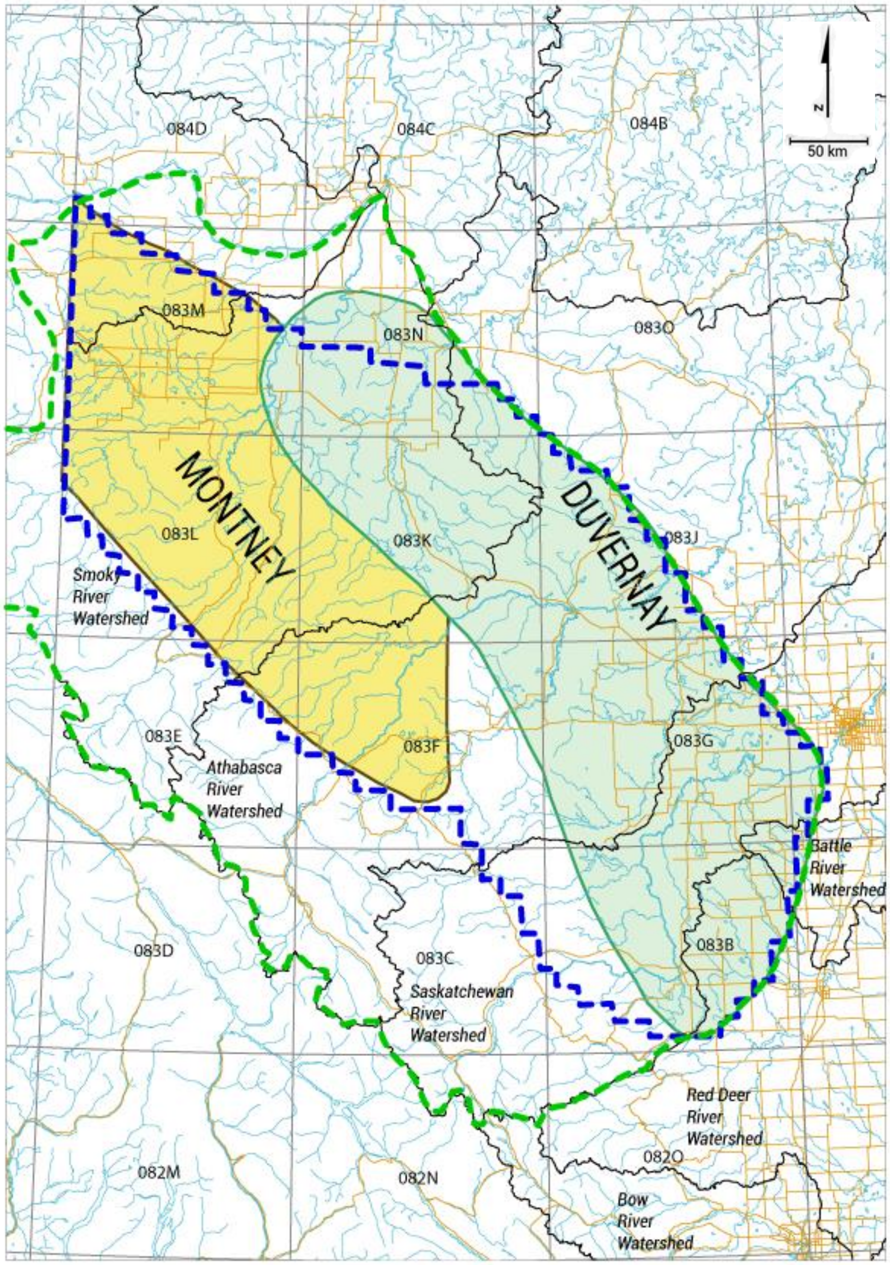

Figure 1. Integrated Assessment of Water Resources for Unconventional Oil and Gas Plays, West-Central Alberta, surface (green, 142,000 km^2) and subsurface (blue, 91,000 km^2) study areas.

The scope of work undertaken in Year 2 of the WCAB project had two main goals: (1) build a thorough understanding of the hydrology of the gauged basins in the study area, driven by the vast amounts of data compiled during Year 1 of the project, and (2) expand on this understanding to build a continuous, regional hydrologic model across the study area at an annual, monthly, and weekly time-step.

Project activities were designed to provide the greatest coverage and detail possible. This was undertaken by gap-filling hydrometric records, estimating winter flows at locations with no measurements, and using regression estimates and interpolation to estimate hydrologic conditions at ungauged locations. Associated limitations with the products are driven by both the methods used and input data availability, and include difficulties in estimating winter or other low flows in areas of sparse data, and estimating the general hydrology of areas not covered by representative hydrometric gauges, such as high alpine watersheds, or small, arid prairie drainages.

The following sections in this report describe in detail the methods and results used to achieve these two goals.

DATA

Gauged Basin Hydrology

During Year 1 of the WCAB project, an extensive amount of data was collected relevant to understanding surface water availability. This data was analyzed and used to differentiate the study area based on individual, thematic characteristics, at the scale of the 33 Environment Canada sub-sub basins or fundamental drainage areas within the project study area (Figure 2). This scale of analysis provided a regional picture of surface water availability, and identified broad trends in runoff generating capacity, primarily at the annual timescale (Foundry Spatial 2013).

During Year 2 of the project, the scope of the analysis was expanded to look in detail at gauged basins in the study area. Watershed boundaries associated with 200 hydrometric gauges in the study area were defined using a combination of the Alberta ArcHydro data product (Pan 2008) and the BC Freshwater Atlas (Gray 2009).

The usefulness of hydrometric data for this study varied station by station. Of the 200 stations, 182 had flow measurements (the remainder being level only). There were 106 flow stations which were determined to have a suitable period of record representative for annual hydrologic modeling. The stations were further refined to 72 stations with long periods of record, providing sufficient data to determine weekly flow characteristics for the open water season. The smallest subset of the stations were those with substantive winter flow measurements, of which there were only 45. The spatial distribution of each subset matches reasonably well with the gross distribution of monitoring locations (Figure 3).

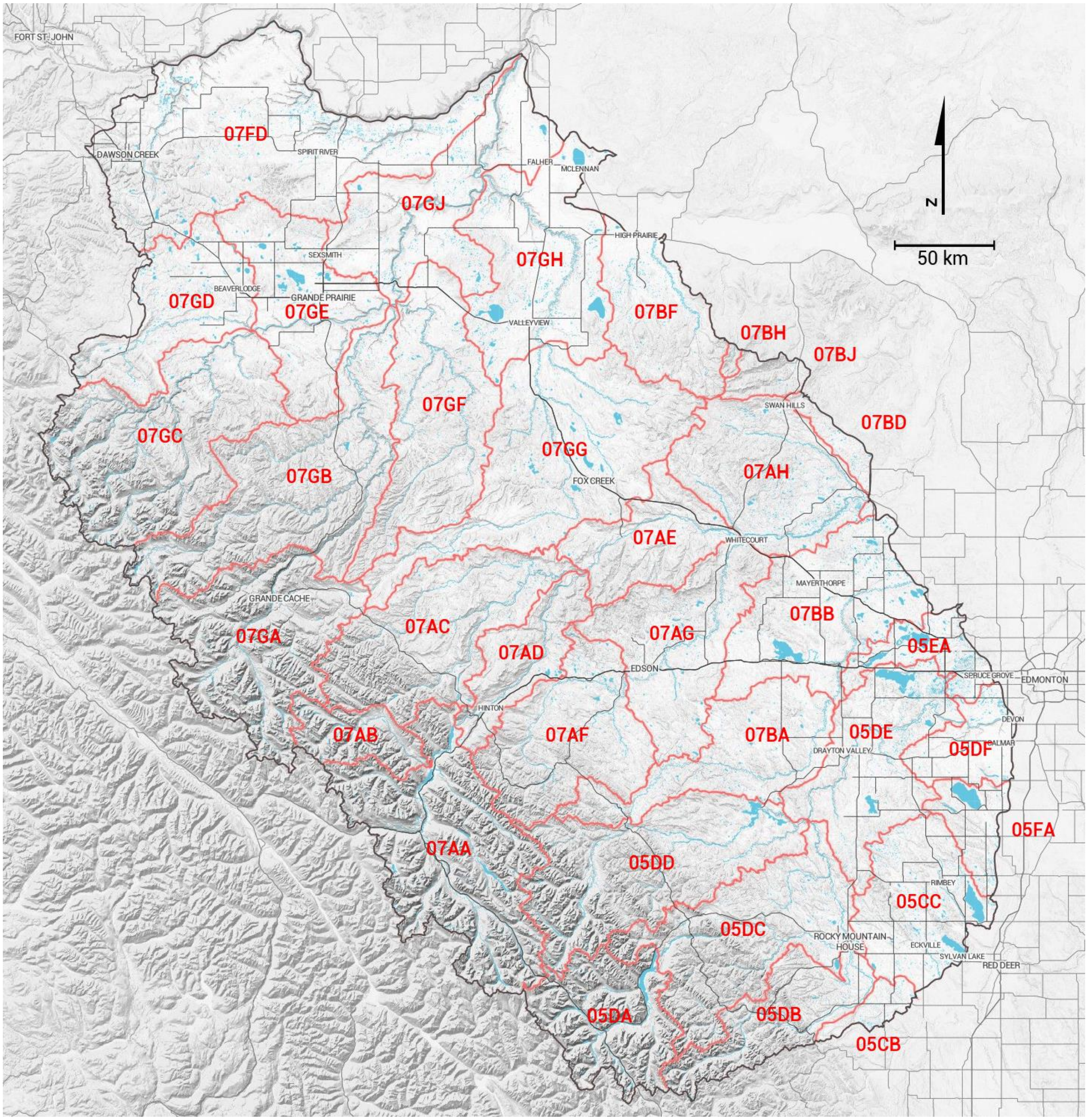

Figure 2. Environment Canada sub-sub river basins.

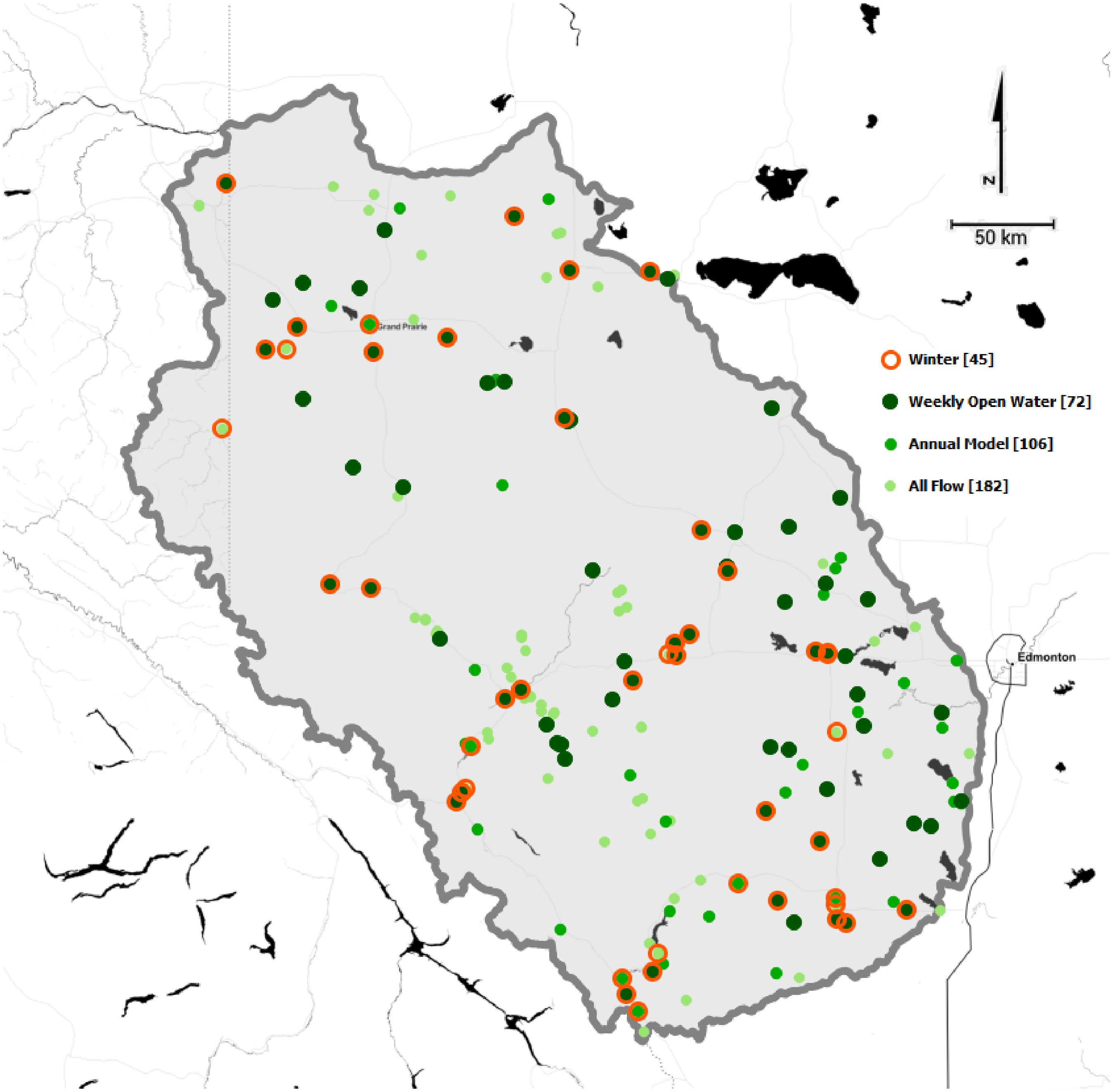

Figure 3. Spatial distribution of hydrometric monitoring stations used for hydrologic modeling purposes.

The ArcHydro and BC Freshwater Atlas data products provide a much greater resolution of detail when compared with the Environment Canada fundamental drainage areas. In general, the datasets delineate the same drainage divides when considered at similar scales.

Upstream Basin Generation

The Alberta ArcHydro data product is a set of regional basin scaled hydrologic layers defined using DEM based watershed delineation and network generation. The DEM used in the Alberta ArcHydro has integrated the Simplified Linear Network for Alberta hydrography with the Provincial 100m DEM, commonly referred to as "stream burning", which ensured that drainage paths occur along known drainage paths. From this DEM, hydrologically connected layers including catchment basins, drainage lines, adjoint catchment basin and drainage points were created. For this study, we used 5 Alberta ArcHydro regional basins: Battle River, Peace River, Red Deer River, Athabasca River and North Saskatchewan River. Layers from each region were merged together into study area wide spatial datasets and further processing was done on the edge cases. Regional scale layers merged for this study were:

- Catchment layer - A seamless polygonal coverage (ie. No gaps between polygons and no overlapping polygons) composed of fundamental drainage polygons which represent the smallest drainage subdivision and have an average area of 9 km^2.
- Adjoint catchment layer - An overlapping polygonal coverage composed of pre-generated and dissolved upstream basins for each fundamental polygon within the catchment layer.

The BC Freshwater Atlas is a standardized province wide dataset derived from the 1:20 000 scale TRIM 1 topographic base and is used for mapping hydrologic features. To generate catchment basins, a seamless hydrologically connected polygon coverage within the atlas called the fundamental watershed polygons layer was used. The fundamental watersheds were delineated as polygonal units from height of land boundaries generated from the TRIM DEM and TRIM hydrographic data and have an average area of 0.3 km^2. Each polygon contains two hierarchical keys, the *fwa watershed code* and the *local watershed code*, which provide the ability to perform upstream and downstream queries.

To generate an upstream basin on Alberta contained hydrographic stations, a root fundamental polygon (polygon which contains the hydrometric station) was selected from the catchment layer and merged with the polygon from the adjoint catchment layer with the same *gridid* as the root polygon. When creating an upstream basin on the BC contained hydrographic stations, a root fundamental polygon is identified and by using the hierarchical keys, upstream polygons were selected and dissolved together. The logic for the upstream SQL query is described in Appendix 1.

To delineate trans-boundary basins, an additional linking field was added to both the Alberta and BC fundamental polygons that mapped the adjacent BC/AB polygons together when a stream traveled cross boundary. If there was a polygon with a linking key in the upstream catchment basin, it would be dissolved with the upstream catchment basin of the linking key root polygon as well. Additionally, a hole polygon layer was created to fill in any gaps between the Alberta and BC fundamental polygons as they did not seamlessly match. The hole polygons were given linking keys to adjacent polygons where it was applicable (Ie. part of the same watershed).

Modeling Data

Hydrometric data has been collected and catalogued by the Water Survey of Canada since 1908. These data are reviewed and published by Environment Canada in a digital database called HYDAT (Environment Canada 2013). Based on a review of data availability and quality for these stations, 182 stream gauges were selected for further review and analysis during Year 1 of the project.

Land Cover is a term 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. Some vectors had vegetation cover type classifications of shadow or cloud. They were removed from the vector dataset and infilled with vectorized raster cells from the CEC Landcover 2005 raster (CEC 2013). The CEC Landover 2005 data also intends to provide a representation of the landbase in Canada around the year 2000. The raster cover type classifications (ex. grassland, mixed forest) were then translated to the Geobase vector classifications. The final vegetation vector dataset was clipped to each of the 182 basins and vegetation classifications percentage tables were calculated.

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 within watersheds 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 (AET) 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.

To represent temperature and precipitation in our study, we chose the University of BC product, ClimateWNA (Wang 2012), as well as the University of Alberta modified version, ClimateAB (Wang 2006). Both provide 30 year climate normals in a scale free format, allowing researchers to generate climate data at a spatial resolution appropriate for their analysis. The programs interpolate climate data with the Parameter-elevation Regressions on Independent Slopes Model (PRISM), an expert interpolation approach (Daly 2008) which uses physiographic information to predict climate patterns in mountainous terrain. AET is represented through a global, gridded product provided by the Consultative Group on International Agricultural Research (CGIAR), and uses a modified Hargreaves method to determine AET (Trabucco 2010). Continuous estimates of climate variables were required for our study in order to estimate normal conditions in areas without historical measurements.

With limited coverage of the study area by weather stations, extrapolations were required to be made. Using data products created with the PRISM methodology provides a defensible means of doing so. Comparison of the ClimateAB product with products generated using other methodologies, such as those created by the Alberta Agroclimatic Information Service (ACIS), illustrate the benefits of the physiographic and meteorological adjustments implemented in the PRISM methodology. Differences between the products are perhaps most noticeable in the mountains, where the ACIS product suggests a maximum of less than 700 mm. of precipitation within the study area. The ClimateAB product suggests significant areas of precipitation greater than 700 mm. Areas of precipitation greater than 700 mm are further supported by gauged hydrometric basins with greater than 700mm mean annual precipitation. Limitations exist in the PRISM methodology itself, such as lack of representation of rain shadows or coastal climate gradients. In the case of this study the ClimateAB product was found to be suitable.

Data sources for the previous calculations were drawn from the database compiled during Year 1 activities and are shown in Table 1.

Table 1. Thematic layers and data sources.

Thematic Layer	**Source**
Runoff	Water Survey of Canada, HYDAT database October 2013[1]

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[1] https://www.ec.gc.ca/rhc-wsc/default.asp?lang=En&n=9018B5EC-1

Elevation	CGIAR - SRTM 4.1, 90m resolution[2]
Basin X, Y	ArcHydro[3], BC Freshwater Atlas centroids[4]
Mean Annual, Monthly Precipitation	ClimateAB 1961-90[5], ClimateWNA 1961-90[6], 400m resolution
Mean Annual Evapotranspiration	CGIAR 1950-2000[7], 30 arc-second resolution
Mean Annual, Monthly Temperature	ClimateWNA 1961-90[6], 400m resolution
Land Cover Components	Geobase LCC2000[8], CEC Land Cover 2005[9]

ANALYSIS

Basin averages for the following parameters were produced in preparation for modeling:

1. Monthly runoff, January – December, period of record varies (mm)
2. Monthly runoff, January – December, period of record varies (% of annual)
3. Basin mean elevation, SRTM geodetic elevation (m asl)
4. Basin centroid X and Y coordinates (Alberta 10TM Forest / EPSG 3400)
5. Basin mean monthly precipitation, January – December, 1961-90 (mm)
6. Basin mean seasonal precipitation, Nov-Apr/May-Oct, 1961-90 (mm)
7. Basin mean annual precipitation, 1961-90 (mm)
8. Basin mean monthly precipitation, January – December, 1961-90 (% of annual)
9. Basin mean seasonal precipitation, Nov-Apr/May-Oct, 1961-90 (% of annual)
10. Basin mean monthly actual evapotranspiration, January – December, 1950-2000 (mm)
11. Basin mean annual actual evapotranspiration, 1950-2000 (mm)
12. Basin mean monthly average temperature, January – December, 1961-90 (C)
13. Basin land cover components, circa 2000

Initial analysis included a comparison between calculated precipitation inputs at the basin scale, and gauged runoff at hydrometric stations. Climate inputs were generated using the ClimateWNA data product. This first, rough analysis was undertaken with the objective of evaluating the suitability of the ClimateWNA product for predicting precipitation amounts in the region. Significant discrepancies

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[2] http://www.cgiar-csi.org/data/srtm-90m-digital-elevation-database-v4-1
[3] Alberta Research Council, unpublished report to Alberta Environment, 2008
[4] http://geobc.gov.bc.ca/base-mapping/atlas/fwa/fwa_data.html
[5] http://www.ualberta.ca/~ahamann/data.html
[6] http://climatewna.com/
[7] http://www.cgiar-csi.org/data/global-high-resolution-soil-water-balance
[8] http://www.geobase.ca/geobase/en/data/landcover/csc2000v/description.html
[9] http://www.cec.org/atlas/files/land_cover/LandCover_IMG.zip

between gauged runoff and modeled precipitation were observed using the ClimateWNA product, in particular in mid-elevation watersheds on the eastern slopes of the Rocky Mountains and foothills.

The ClimateAB product was processed and evaluated and determined to produce more accurate representations of precipitation within Alberta. As the ClimateAB product did not extend to the western extent of the study area in BC, composite climate inputs were generated using ClimateAB and ClimateWNA to ensure complete coverage for the study area. Significant discrepancies exist in the volume of precipitation between ClimateAB and ClimateWNA along the BC – Alberta border in the study area and as such accuracy in generated products is likely lower west of the border. This location corresponds with areas where difficulties were encountered during previous hydrologic modeling work in BC. At the time these were also believed to be due to error in the precipitation field inputs and the comparison during this work between ClimateAB and ClimateWNA inputs supports that hypothesis.

After the upstream basin generation of the 182 chosen hydrometric stations, a comparison of the area enclosed by these contributing areas with published areas from the database (Environment Canada 2013) identified numerous erroneously located stations. Subsequent efforts were made to correctly locate stations and regenerate contributing areas. In several cases for small gauged drainages, the limited spatial resolution and, in some cases, accuracy of the ArcHydro watershed data contributed to substantial error between calculated and published areas. In some cases, the ArcHydro data was found to incorrectly represent the actual drainage in the landscape, as confirmed by review of satellite imagery and other higher resolution stream network data.

Archived streamflow measurements at hydrometric stations operated by the Water Survey of Canada and Government of Alberta were collected and analyzed during Year 1 of the project (Environment Canada 2013, Foundry Spatial 2013). These measurements were further processed to calculate mean annual flow values for each gauge. Watershed size was combined with mean annual flow to calculate mean annual runoff in area independent units (mm). For each individual gauge, the hydrometric record was assessed and years with partial data incongruent with the typical operating year for the station were removed from the calculations. Geographic comparison between gauges identified basins where the gauged record was determined not to be representative of normal conditions. Corroborating factors thought to contribute to error in many cases was determined as short period of record, old data, small basin, seasonal monitoring and highly variable inter-annual flows.

The quality assurance process narrowed the sample for subsequent hydrologic modeling, through 5 iterations, from 182 to 106 basins (Figure 4). These basins were deemed to provide accurate representations of the regional hydrology, based on geographic distribution, accuracy of watershed delineation, watershed size, quality of hydrometric record, and overlap / duplication with other gauges on the same or a hydrologically related drainage.

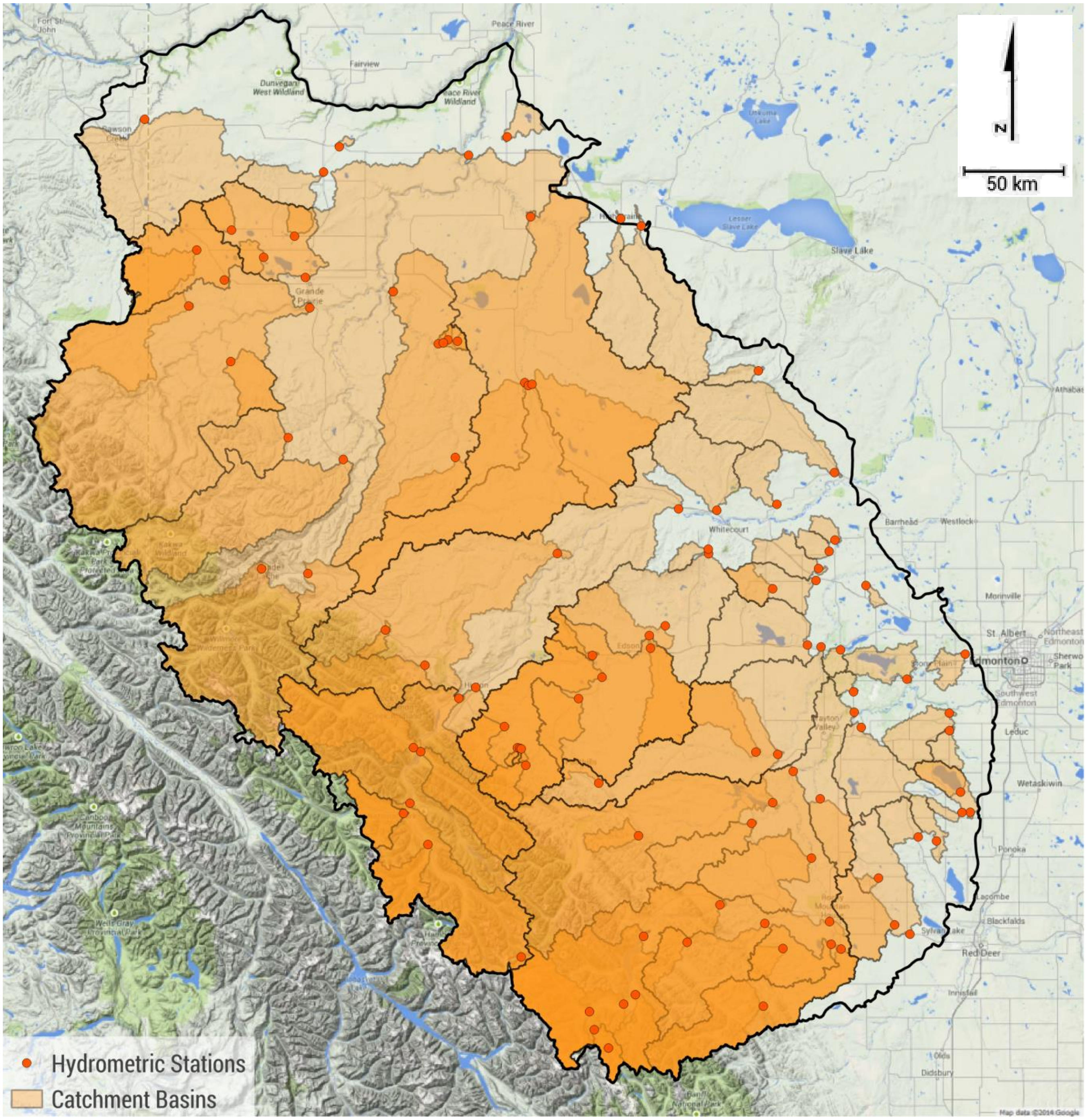

Figure 4. Hydrometric stations and associated catchment basins used in the hydrologic modeling.

Gauged basins with regulated stream flows in the study area are on the North Saskatchewan and Brazeu Rivers, Muskeg and Pigeon Lake Creek, the Kleskun Hills Main Drain, and the Paddle River (Figure 5). Naturalized stream flow values for several basins within the study area were provided by the Alberta Ministry of Environment and Sustainable Resource Development (AESRD) (Z. Islam, personal communication, October 4, 2013). The stations with naturalized flow data available are on the North

Saskatchewan and Brazeau Rivers. Mean unit runoff for these gauges was calculated using the naturalized flows and used in place of averages generated from the HYDAT database of measured flows.

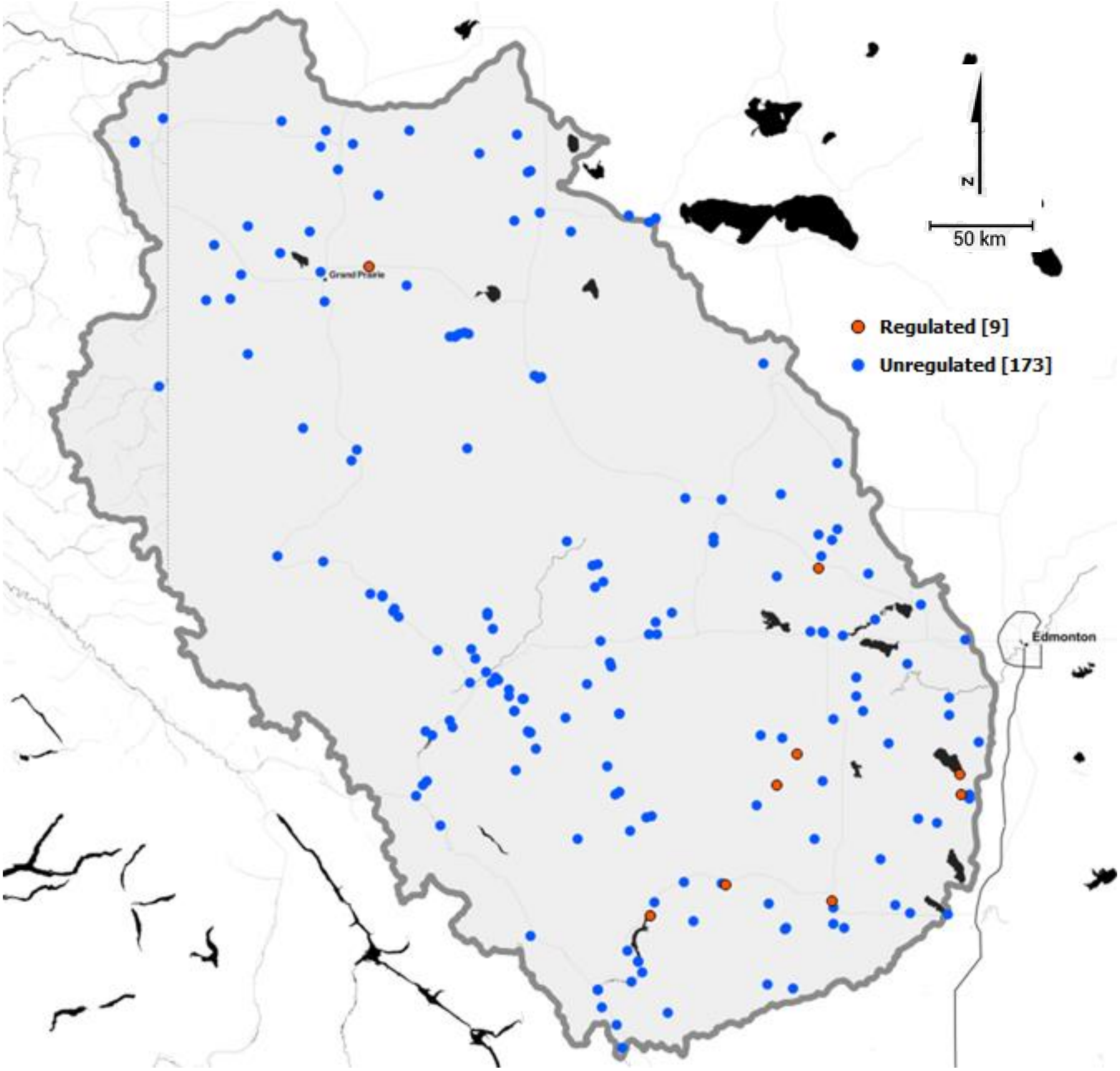

Figure 5. Location of regulated and unregulated hydrometric stations.

Annual runoff was augmented for seasonal stations by estimating winter flows using complementary stations and the shape of the existing seasonal hydrograph. The seasonal adjustment typically added 7-12% to the total annual runoff in these cases.

For some short record stations on major systems, such as 05DE010 (North Saskatchewan River at Highway No. 759), the adjustment was much larger. Calculated runoff values generated from the review of the hydrometric record, and final adjusted values used in the modeling are provided in Table 2.

Table 2. Annual unit runoff for hydrometric stations used in the annual modeling.

Station	HYDAT (mm)	Adjusted (mm)
05CC007	70.1	70.1
05CC008	103.8	103.8
05CC009	70.9	70.9
05CC010	67.9	67.9
05CC013	78.4	78.4
05DA002	476.9	519.3
05DA006	957.5	985.6
05DA007	812.6	812.6
05DA009	887.4	950.2
05DA010	645.6	645.6
05DB002	167.4	167.4
05DB003	264.1	300.5
05DB005	185.9	200.4
05DB006	235.7	235.7
05DC001	407.5	377.8
05DC002	611.8	545.3
05DC006	249.9	249.9
05DC010	632.2	663.3
05DC011	160.5	179.4
05DC012	142.7	142.7
05DD004	210	248.7
05DD005	282.1	328.8
05DD009	176.7	176.7
05DE003	19.8	19.8
05DE006	202.3	312.1
05DE007	100.2	104.2
05DE009	55.8	55.8
05DE010	243.3	302
05DE911	75.9	75.9
05DF004	44.9	44.9
05DF008	34.9	34.9
05EA009	21	21
05EA010	57.8	57.8
05FA002	54.3	54.3
05FA019	33.4	33.4
05FA912	51.6	51.6
07AA001	505.5	505.5
07AA002	707.4	707.4
07AA003	413.6	413.6
07AA007	1187.6	1187.6
07AF013	359.7	392.1
07AF014	154.9	167.3
07AF015	241.3	263
07AG001	197.2	197.2
07AG003	147.6	147.6
07AG004	147.6	147.6
07AG007	172.9	172.9
07AG008	143.4	143.4
07AH001	156.2	164
07AH002	75.2	79
07AH003	134.6	141.3
07BA001	162.9	162.9
07BA002	117.8	123.7
07BA003	236.6	260.3
07BB002	145.7	145.7
07BB003	90.9	90.9
07BB004	73	73
07BB005	54.3	56
07BB009	34.4	34.4
07BB011	79	79
07BB014	33.8	33.8
07BB903	36.5	36.5
07BF001	156.6	164.4
07BF002	118.3	118.3
07BJ003	292.9	316.4
07FD006	60.2	60.2
07FD007	68.2	68.2
07FD910	20.9	20.9
07GA001	620.9	620.9
07GA002	233.1	233.1
07GB001	179.7	199.4
07GB003	303.3	330.6
07GC002	106.5	113.9
07GD001	45	45
07GD002	40.5	41.7
07GD004	138.9	138.9
07GE001	266.6	266.6
07GE003	65.8	65.8
07GE005	30.8	30.8
07GE006	21.2	21.2

07AA009	783.9	783.9
07AB002	452.5	506.8
07AC001	193.5	216.7
07AC007	178.6	200.1
07AC008	310.4	335.3
07AD001	632	632
07AD002	561.3	561.3
07AE001	411.4	411.4
07AF002	237.1	237.1
07AF003	266.1	266.1
07AF004	295.6	295.6
07AF005	227.3	227.3
07AF010	121.2	121.2
07GE007	36.9	36.9
07GF001	143.8	143.8
07GF002	84.2	84.2
07GF003	6.6	54.6
07GF004	77.5	77.5
07GF006	53.8	53.8
07GF008	198.8	224.6
07GG001	136.5	136.5
07GG002	159.9	179.1
07GG003	132.5	141.8
07GH002	129.1	129.1
07GJ001	211.1	211.1
07GJ005	24.4	24.4

Quantitative Modeling

The gauged basin analysis produced basin scale variables which were subsequently used for the quantitative modeling process. The unit runoff generated from the gauged hydrometric data was generally used as the response variable with a range of combinations of basin characteristics used as predictors or for the manipulation of other input variables.

Surface water quantity modeling was undertaken at three temporal scales for the project. Modeling was completed for the full year, for each individual month, and for each week of the year. Each time step endeavoured to model normal, or long term average conditions. Annual unit runoff was modeled directly. Percentage monthly runoff was modeled and then combined with the annual runoff to calculate monthly unit runoff. Weekly runoff was modeled directly and then normalized using the annual runoff values, to ensure continuity between the annual value and the sum of the individual weeks.

Annual

A spatially detailed annual water balance was developed to constrain the total amount of runoff generation across the study area, produce estimates for ungauged basins and areas in gauged basins distant from gauges, and to provide an anchor for continuity corrections for other time steps. The annual water balance model used precipitation inputs from the composite ClimateAB/ClimateWNA dataset, estimates of actual evapotranspiration from CGIAR, basin land cover components, compiled estimates of vegetation based actual evapotranspiration from the literature, and calculated unit runoff values for the gauged basins. The water balance equation took the form:

$$P - AET = Q$$

Where P is the precipitation input, AET is the actual evapotranspiration losses, and Q is the resulting discharge.

Evapotranspiration values calculated by CGIAR used a modified Hargreaves (Trabucco 2010) approach to estimate actual evapotranspiration. In their approach, constants are applied to control maximum soil water content and vegetation characteristics. The vegetation constant assumed a reference crop, with value of 1. Field measurements and other research investigating actual evapotranspiration in Canada have demonstrated the influence of varying vegetation and land cover type on actual evapotranspiration rates. A selection of relevant published values is shown in Table 3. Many of these estimates were measured directly using eddy flux covariance systems implemented as part of the Boreal Ecosystem-Atmosphere Study (BOREAS) conducted by various agencies in the US and Canadian governments.

Table 3. Ecosystem types and published annual Actual Evapotranspiration Values.

Ecosystem Type	**Location**	**Annual AET (mm)**
Subarctic Boreal Fen[10]	Northern Manitoba	341, 313
Coniferous[11]	Canada	276 (σ 71)
Mixed[11]	Canada	405(σ 78)
Deciduous[11]	Canada	492(σ 86)
Shrub[11]	Canada	195(σ 51)
Burnt[11]	Canada	184(σ 30)
Barren[11]	Canada	126(σ 32)
Crop[11]	Canada	341(σ 63)
Grass[11]	Canada	275(σ 42)
Urban[11]	Canada	195(σ 32)
Snow/Ice[11]	Canada	51(σ 7)
Boreal Aspen[12]	Northern Saskatchewan	400-420
Old Black Spruce[13]	Central Saskatchewan	345, 366
Old Black Spruce[14]	Central Saskatchewan	225
Boreal Aspen[15]	Central Saskatchewan	403
Pine[16]	Sweden	399
Jack Pine[17]	Southeast Manitoba	240
Jack Pine[18]	Central Saskatchewan	218
n/a[19]	50-70 N	300-400
Old Aspen[20]	Central Saskatchewan	270-375
Old Black Spruce[20]	Central Saskatchewan	280-330
Old Jack Pine[20]	Central Saskatchewan	222-254
Old Aspen[21]	Central Saskatchewan	300-450

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[10] Chapman (1987)
[11] Liu (2003)
[12] Blanken (2001)
[13] Arain (2003)
[14] Jarvis (1997)
[15] Black (1996)
[16] Grelle (1997)
[17] Amiro (1987)
[18] Nijssen (1997)
[19] Budyko (1974)
[20] Kljun (2006)
[21] Krishnan (2006)

Land cover basin composition was incorporated in the annual water balance model and used to scale the actual evapotranspiration estimates generated by CGIAR, in effect re-incorporating vegetation variability into the estimates. Within the study area, 28 land cover classes were found. The percent of the study area covered by each land cover class is shown in Table 4.

Table 4. Land cover types and proportion of the study area.

Land Cover Class	% of study area
Coniferous Dense	35.2
Broadleaf Dense	16.3
Perennial Cropland and Pasture	10.4
Annual Cropland	8.3
Rock/Rubble	5.3
Herb	5.2
Shrub tall	4.0
Wetland - Shrub	3.2
Wetland - Treed	2.4
Coniferous Open	1.8
Water	1.6
Grassland	1.3
Exposed Land	1.1
Broadleaf Open	0.9
Snow/Ice	0.7
Mixedwood Dense	0.5
Shrub low	0.5
Developed	0.4
Coniferous Forest	0.3
Wetland - Herb	0.3
Bryoids	0.1
Shrubland	0.1
Mixed Forest	0.1
Mixedwood Open	0.1
Broadleaf Sparse	0.0
Coniferous Sparse	0.0
Mixedwood Sparse	0.0
Wetland	0.0

Ranges for each land cover type were supplied to a Monte Carlo simulation, which varied these values and calculated annual runoff estimates for individual basins, by solving the water balance equation for runoff.

We used a Monte Carlo simulation written in R to adjust the annual evapo-transpiration (AET) basin averages per vegetation classification type. A base AET value of 340 mm was chosen to represent the reference crop type (Liu 2003). For each of the 28 different land cover classes that were found within the 106 basin areas, a land cover specific AET base and range were chosen to incorporate variability into the AET estimate. These land cover specific AET values were combined with the reference crop AET to create a ratio, which was then used to scale the input AET value. The Monte Carlo simulation iterated over each basin and produced 5000 random numbers within the 28 land cover class AET ranges. The new AET scaling factor was brought into the original runoff formula producing the following equation:

$$P - (AET \times [vegetation\ scaling\ factor]) = Q$$

Model error was determined as:

$$Percent\ error = \frac{Modeled\ Runoff - Measured\ Runoff}{Measured\ Runoff} \times 100$$

Summary error statistics including mean error, median error, mean absolute error, and percent of gauged basins within ± 20% error were monitored. The top performing simulation, which minimized mean absolute error and maximized the number of basins within 20% of mean measured values, was selected to be applied across the study area. Example reference values associated with each land cover class are shown in Table 5. The actual AET values used in the modeling for each land cover class varied across the landscape associated with local climate characteristics.

Table 5. Land Cover Classes, Reference AET and Optimized AET values.

Land Cover Class	Reference AET (mm)	Range (mm)	Optimized AET (mm)
Annual Cropland	380	60	400.5
Broadleaf Dense	420	80	378.4
Broadleaf Open	410	80	363.5
Broadleaf Sparse	400	80	392.4
Bryoids	225	40	223.8
Coniferous Dense	285	75	331.5
Coniferous Forest	275	75	348.6
Coniferous Open	275	75	306.5
Coniferous Sparse	265	75	215.6
Developed	175	40	175.3
Exposed Land	150	50	162.1
Grassland	300	60	263.3
Herb	250	40	222.7
Mixed Forest	325	75	337.7
Mixedwood Dense	335	75	409.7
Mixedwood Open	315	75	293.4
Mixedwood Sparse	305	75	289.7
Perennial Cropland and Pasture	380	60	384.3
Rock/Rubble	150	50	117.7
Shrub low	250	40	258.5
Shrub tall	250	40	219.1
Shrubland	250	40	228.3
Snow/Ice	50	10	49.7
Water	380	150	477.5
Wetland	275	75	243.6
Wetland - Herb	275	75	336.8
Wetland - Shrub	275	75	301.1
Wetland - Treed	275	75	216.8

Visual and statistical assessment of the mean annual modeled runoff was performed, as a gut-check to qualitatively assess model performance. Areas of negative runoff were observed and investigated. Negative runoff was accepted as valid in open water areas, river valley bottoms, and in areas of previously defined non-contributing areas by the Prairie Farm Rehabilitation Administration. Areas of negative runoff also overlap with areas of irrigated agricultural land. Irrigated agricultural activities are not extensive within the study area, occuring mainly in the Grande Prairie and Red Deer regions, as shown in Figure 6.

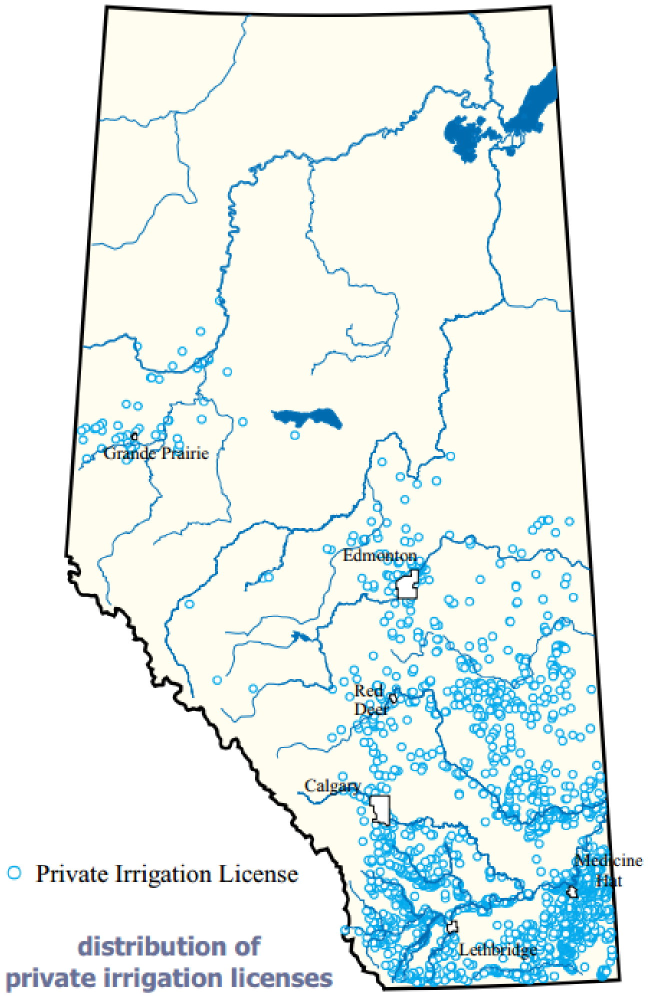


Figure 6. Irrigation Licenses in Alberta (from: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/irr7197/$FILE/irrigationinalta-part1.pdf)

Actual evapotranspiration values produced during the annual water balance calculations were compared with published values from four weather stations in the project study area. Areal evapotranspiration estimates for individual years based on climate measurements were calculated at these weather stations using Morton's method (Morton 1983, AESRD 2013) and are shown in Table 6. The values calculated during the water balance calculations fall within the range of values observed at each climate station, and are generally at the high end of the range. This may be due to several factors, such as differing methodology in calculating evapotranspiration rates, use of different data sets, or the absence of a specific groundwater recharge term in the water balance equation. Previous research has estimated an average of 22mm of annual groundwater recharge across the province (Golder 2008).

Table 6. Evapotranspiration estimates generated by Morton's Method (AESRD 2013) and model derived AET.

Location	Year From	Year To	Count*	Areal Evapotranspiration (mm)			Calculated AET (mm)
				Mean	Min	Max	Mean
Beaverlodge	1936	2009	58	355	235	461	412-422
Edson	1973	2009	35	405	314	483	472-480
Grande Prairie	1980	2009	30	328	246	420	403-412
Jasper	1977	2009	31	350	243	501	401-422

Within the project study area, in many cases gauged basins exist in nested relationships. These nested relationships may include cases where a gauge is on a tributary of a larger gauged river, where several gauges are located along the main stem of a river, or in a combination of the two previous scenarios. Watershed boundaries in these cases were divided into incremental drainage areas, isolating contributing areas. Runoff generation from these contributing areas was then calculated from the measured and modeled data. During this QA process additional hydrometric stations were dropped from the model due to their measured runoff values conflicting significantly with hydrologically adjacent gauges.

Monthly

Following the annual water balance modeling, monthly estimates of runoff were calculated. These estimates were generated using a regression based process relating basin scale characteristics to observed monthly runoff. Measured hydrometric data was processed to calculate mean monthly runoff as percent of annual. The sample of hydrometric stations used for monthly modeling was restricted to 94 stations from that used in the annual modeling. Some stations which were deemed representative for annual runoff modeling did not provide suitably robust data when considered at monthly subdivisions. Months of operation for each hydrometric station are shown in Table 7.

Table 7. Hydrometric stations used in monthly modeling.

				Months of operation											
Number	**Station Name**	**Year From**	**Year To**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
05CC007	MEDICINE RIVER NEAR ECKVILLE	1962	2010	38	40	48	49	49	49	49	49	49	49	43	38
05CC008	BLINDMAN RIVER NEAR BLUFFTON	1965	2010		8	46	46	46	46	46	46	46	46	17	
05CC009	LLOYD CREEK NEAR BLUFFTON	1965	2010		6	46	46	46	46	46	46	46	46	19	
05CC010	BLOCK CREEK NEAR LEEDALE	1976	2010		7	34	34	34	34	35	35	35	35	14	
05CC013	LASTHILL CREEK NEAR ECKVILLE	2006	2010			5	5	5	5	5	5	5	5		
05DA002	SIFFLEUR RIVER NEAR THE MOUTH	1915	1996				16	24	25	25	24	24	25	11	
05DA006	NORTH SASKATCHEWAN RIVER AT SASKATCHEWAN CROSSING	1950	1970	4	4	4	11	19	20	20	20	21	19	5	4
05DA007	MISTAYA RIVER NEAR SASKATCHEWAN CROSSING	1950	2010	44	44	44	54	60	60	60	61	61	59	46	45
05DA009	NORTH SASKATCHEWAN RIVER AT WHIRLPOOL POINT	1970	2011	41	41	41	41	42	42	42	42	42	42	42	42
05DB002	PRAIRIE CREEK NEAR ROCKY MOUNTAIN HOUSE	1922	2010	49	51	59	62	63	63	63	64	64	64	52	50
05DB003	CLEARWATER RIVER ABOVE LIMESTONE CREEK	1959	1992			1	21	33	34	34	34	34	34	16	
05DB005	PRAIRIE CREEK BELOW LICK CREEK	1973	2010		9	37	37	38	38	38	38	38	38	15	
05DB006	CLEARWATER RIVER NEAR DOVERCOURT	1975	2010	35	35	35	35	35	35	35	35	36	36	36	36
05DC001	NORTH SASKATCHEWAN RIVER NEAR ROCKY MOUNTAIN HOUSE	1913	2010	37	37	58	69	85	86	86	85	85	85	54	42
05DC002	NORTH SASKATCHEWAN RIVER AT SAUNDERS	1915	1978	9	9	8	23	34	34	34	35	33	33	24	9
05DC006	RAM RIVER NEAR THE MOUTH	1967	2010	35	37	42	44	44	44	44	44	44	44	42	36
05DC010	NORTH SASKATCHEWAN RIVER BELOW BIGHORN PLANT	1972	2010	38	38	38	38	38	38	38	38	39	39	39	39

				Months of operation											
Number	**Station Name**	**Year From**	**Year To**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
05DC011	NORTH RAM RIVER AT FORESTRY ROAD	1975	2010				15	36	36	36	36	36	36	12	
05DC012	BAPTISTE RIVER NEAR THE MOUTH	1984	2010	26	26	26	26	26	26	25	27	27	26	27	27
05DD004	BROWN CREEK AT FORESTRY ROAD	1915	2011				18	37	40	38	40	40	38	10	
05DD005	BRAZEAU RIVER BELOW BRAZEAU PLANT	1956	2010	54	54	54	54	54	54	54	54	54	54	53	54
05DD009	NORDEGG RIVER AT SUNCHILD ROAD	1971	2010	39	39	39	39	39	39	39	39	40	40	40	40
05DE006	NORTH SASKATCHEWAN RIVER NEAR LODGEPOLE	1969	1977				2	9	9	9	9	9	9	5	
05DE007	ROSE CREEK NEAR ALDER FLATS	1972	2010		13	39	39	39	39	39	39	39	39	13	
05DE009	TOMAHAWK CREEK NEAR TOMAHAWK	1984	2010		10	26	26	25	27	27	27	27	27	11	
05DE911	MODESTE CREEK NEAR LINDALE	1996	2010	1		14	15	15	15	15	15	15	15	1	
05DF004	STRAWBERRY CREEK NEAR THE MOUTH	1966	2011		18	45	45	45	45	45	46	46	45	14	
05EA010	STURGEON RIVER NEAR MAGNOLIA BRIDGE	1981	2010		10	29	29	29	30	30	30	30	30	11	
05FA019	PIGEON LAKE CREEK NEAR USONA	1979	1995		9	17	17	17	17	17	17	17	17	12	
07AA001	MIETTE RIVER NEAR JASPER	1914	2011	43	43	43	44	45	46	46	46	46	46	44	44
07AA002	ATHABASCA RIVER NEAR JASPER	1913	2010	56	57	57	59	59	59	59	59	59	59	59	58
07AA003	ROCKY RIVER AT HAWES	1913	1919	5	5	5	6	6	6	6	6	6	6	6	5
07AA007	SUNWAPTA RIVER AT ATHABASCA GLACIER	1948	2010				11	50	54	53	55	55	50	11	
07AA009	WHIRLPOOL RIVER NEAR THE MOUTH	1966	1996			1	25	31	31	31	31	30	25	10	
07AB002	SNAKE INDIAN RIVER NEAR THE MOUTH	1971	1993				17	23	23	23	23	23	19	8	
07AC001	WILDHAY RIVER NEAR HINTON	1965	2011		1	4	31	47	47	47	47	47	47	15	
07AC007	BERLAND RIVER NEAR THE MOUTH	1986	2010	2	12	25	25	25	25	25	25	25	25	10	
07AC008	LITTLE BERLAND RIVER AT HIGHWAY NO. 40	1986	2010		6	25	25	25	25	25	25	25	25	8	
07AD001	ATHABASCA RIVER AT ENTRANCE	1915	1974	28	28	28	31	31	32	32	33	32	31	31	29

				Months of operation											
Number	**Station Name**	**Year From**	**Year To**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
07AD002	ATHABASCA RIVER AT HINTON	1961	2011	50	50	50	51	51	51	51	51	51	51	51	51
07AE001	ATHABASCA RIVER NEAR WINDFALL	1960	2010	20	32	50	51	51	51	51	51	51	51	32	18
07AF002	MCLEOD RIVER ABOVE EMBARRAS RIVER	1954	2011	57	57	57	57	57	57	57	57	57	57	58	58
07AF003	WAMPUS CREEK NEAR HINTON	1966	2011	2	2	21	44	45	45	45	45	46	46	19	2
07AF004	DEERLICK CREEK NEAR HINTON	1966	1990	2	1	10	23	24	24	24	24	24	25	16	1
07AF005	EUNICE CREEK NEAR HINTON	1967	1992	2	1	12	24	25	25	25	25	25	25	14	3
07AF010	SUNDANCE CREEK NEAR BICKERDIKE	1972	2011		19	39	39	39	39	39	40	40	40	13	
07AF013	MCLEOD RIVER NEAR CADOMIN	1984	2011		7	27	28	28	28	28	28	28	28	8	
07AF014	EMBARRAS RIVER NEAR WEALD	1984	2011		9	27	27	27	27	28	28	28	28	8	
07AF015	GREGG RIVER NEAR THE MOUTH	1985	2010		5	25	25	25	25	25	26	26	26	8	
07AG001	MCLEOD RIVER NEAR WOLF CREEK	1914	1984	35	35	42	43	43	42	43	43	44	43	37	36
07AG003	WOLF CREEK AT HIGHWAY NO. 16A	1954	2010	56	56	56	56	56	56	56	56	56	56	57	57
07AG004	MCLEOD RIVER NEAR WHITECOURT	1968	2010	3	16	42	42	43	43	43	43	43	43	17	2
07AG007	MCLEOD RIVER NEAR ROSEVEAR	1984	2011	27	27	27	27	28	28	28	28	28	28	28	28
07AG008	GROAT CREEK NEAR WHITECOURT	1984	2010		8	26	26	26	26	27	26	27	27	10	
07AH001	FREEMAN RIVER NEAR FORT ASSINIBOINE	1965	2010	1	13	45	45	45	46	46	46	46	46	21	
07AH002	CHRISTMAS CREEK NEAR BLUE RIDGE	1972	2010		9	38	38	38	38	38	39	39	39	17	
07AH003	SAKWATAMAU RIVER NEAR WHITECOURT	1972	2010		14	38	38	38	38	38	39	39	39	15	
07BA001	PEMBINA RIVER BELOW PADDY CREEK	1956	1993		13	37	38	38	38	38	38	38	37	12	
07BA002	RAT CREEK NEAR CYNTHIA	1972	2010		14	38	39	39	39	39	39	39	39	14	
07BA003	LOVETT RIVER NEAR THE MOUTH	1975	2010		1	2	18	36	36	36	36	36	36	13	
07BB002	PEMBINA RIVER NEAR ENTWISTLE	1914	2010	65	65	64	64	65	65	65	65	65	65	66	66
07BB003	LOBSTICK RIVER NEAR STYAL	1954	1986	32	32	32	32	32	32	32	32	32	32	33	33

				Months of operation											
Number	**Station Name**	**Year From**	**Year To**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
07BB004	PADDLE RIVER NEAR ROCHFORT BRIDGE	1963	2010		16	48	48	48	48	48	48	48	47	21	
07BB005	LITTLE PADDLE RIVER NEAR MAYERTHORPE	1963	2010		13	48	48	48	48	48	48	48	47	19	
07BB009	CONNOR CREEK NEAR SANGUDO	1972	1988		1	10	10	10	10	11	11	11	11	6	
07BB011	PADDLE RIVER NEAR ANSELMO	1980	2010		9	31	31	31	31	31	31	31	30	14	
07BB014	COYOTE CREEK NEAR CHERHILL	1981	2011		8	30	30	30	30	31	31	31	31	10	
07BF001	EAST PRAIRIE RIVER NEAR ENILDA	1921	2010		15	54	63	63	62	62	62	62	62	11	
07BF002	WEST PRAIRIE RIVER NEAR HIGH PRAIRIE	1921	2010	40	41	53	63	63	62	62	62	62	62	41	41
07BJ003	SWAN RIVER NEAR SWAN HILLS	1970	2011		17	41	41	41	42	42	42	42	42	13	
07FD006	SADDLE RIVER NEAR WOKING	1967	2010		21	44	44	44	44	44	44	44	44	11	
07FD007	POUCE COUPE RIVER BELOW HENDERSON CREEK	1971	2010	37	37	37	38	38	38	36	36	37	37	37	37
07GA001	SMOKY RIVER ABOVE HELLS CREEK	1968	2010	19	25	42	43	43	43	43	43	43	43	26	19
07GA002	MUSKEG RIVER NEAR GRANDE CACHE	1972	2010	16	21	39	39	39	39	39	39	38	37	22	15
07GB001	CUTBANK RIVER NEAR GRANDE PRAIRIE	1970	2010		17	28	31	41	41	41	41	41	41	9	
07GB003	KAKWA RIVER AT HIGHWAY NO. 40	1994	2010		5	16	16	17	17	17	17	17	17	3	
07GC002	PINTO CREEK NEAR GRANDE PRAIRIE	1986	2009		14	24	24	24	24	24	24	24	24	6	
07GD001	BEAVERLODGE RIVER NEAR BEAVERLODGE	1968	2011	9	24	44	44	44	44	44	44	44	44	18	8
07GD002	BEAVERTAIL CREEK NEAR HYTHE	1983	2009	1	16	26	27	27	27	27	27	27	27	8	
07GD004	REDWILLOW RIVER NEAR RIO GRANDE	1993	2010	17	17	17	17	17	17	18	17	18	18	18	18
07GE001	WAPITI RIVER NEAR GRANDE PRAIRIE	1917	2010	51	51	51	50	50	50	50	50	50	50	51	52
07GE003	GRANDE PRAIRIE CREEK NEAR SEXSMITH	1969	2011		23	42	42	42	42	42	42	43	43	12	
07GE005	BEAR RIVER NEAR GRANDE PRAIRIE	1983	1987	5	4	4	4	4	4	4	4	4	4	4	4
07GE006	COLQUHOUN CREEK NEAR GRANDE PRAIRIE	1983	1995		12	12	13	13	13	13	13	13	13	5	

				Months of operation											
Number	**Station Name**	**Year From**	**Year To**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
07GE007	BEAR RIVER NEAR VALHALLA CENTRE	1984	2010		15	26	26	26	27	26	26	26	26	8	
07GF001	SIMONETTE RIVER NEAR GOODWIN	1969	2010	17	29	41	41	41	41	42	42	42	42	25	17
07GF002	SPRING CREEK NEAR VALLEYVIEW	1965	1987	1	2	17	21	21	22	22	22	22	22	19	2
07GF004	SPRING CREEK (UPPER) NEAR VALLEYVIEW	1967	1987	17	15	19	21	21	21	21	21	21	21	21	17
07GG001	WASKAHIGAN RIVER NEAR THE MOUTH	1968	2010	40	41	43	43	43	43	43	43	43	43	41	41
07GG002	LITTLE SMOKY RIVER AT LITTLE SMOKY	1967	2010		15	43	43	43	44	44	44	44	44	14	1
07GG003	IOSEGUN RIVER NEAR LITTLE SMOKY	1969	2010		14	41	41	41	41	42	42	42	42	11	
07GH002	LITTLE SMOKY RIVER NEAR GUY	1959	2010	51	51	51	51	51	51	51	51	51	52	52	52
07GJ001	SMOKY RIVER AT WATINO	1915	2010	61	61	61	61	63	64	64	64	64	64	63	62
07GJ005	LALBY CREEK NEAR GIROUXVILLE	1977	1995		10	18	18	18	18	18	18	19	19	4	

Basin characteristics generated from the gauged basin analysis were used as inputs to regression models. From the 94 stations, those with suitable representation of winter flows were identified. The majority of hydrometric stations in the study area operate during open water season only, typically April to October. Regression models were created for winter months from the 45 stations with full year data, and for May to October from the 94 station sample. Within the 94 stations, 8 had no data for April, therefore, a subset of 86 were used to build the April regression. A different set of regression coefficients were calculated for each month. The data used to develop the model varies within the period of 1913 – 2010. For each monthly model, the percent monthly runoff was used as the response variable, and explanatory variables were tested for significance. Significance of individual variables, residual standard error of the model, R-squared values of the model, and the relevance and regional characteristics of individual explanatory variables in runoff dynamics were all considered when evaluating explanatory variables for inclusion.

The average size of full year stations is considerably larger than the average for the seasonal stations, as shown in Figure 7. Only 5 of the 48 smallest watersheds have suitable winter flow records. The threshold for winter gauging appears to be approximately 800 km^2. Collecting winter flow measurements reliably is a significant challenge in environments such as Western Alberta, and many of the smaller basins may in fact be completely frozen to bed in the coldest parts of winter. This size threshold is an important consideration for future watershed based consideration of unit runoff values, as winter hydrology estimates for watersheds smaller than 800 km^2 were not well covered by the model domain.

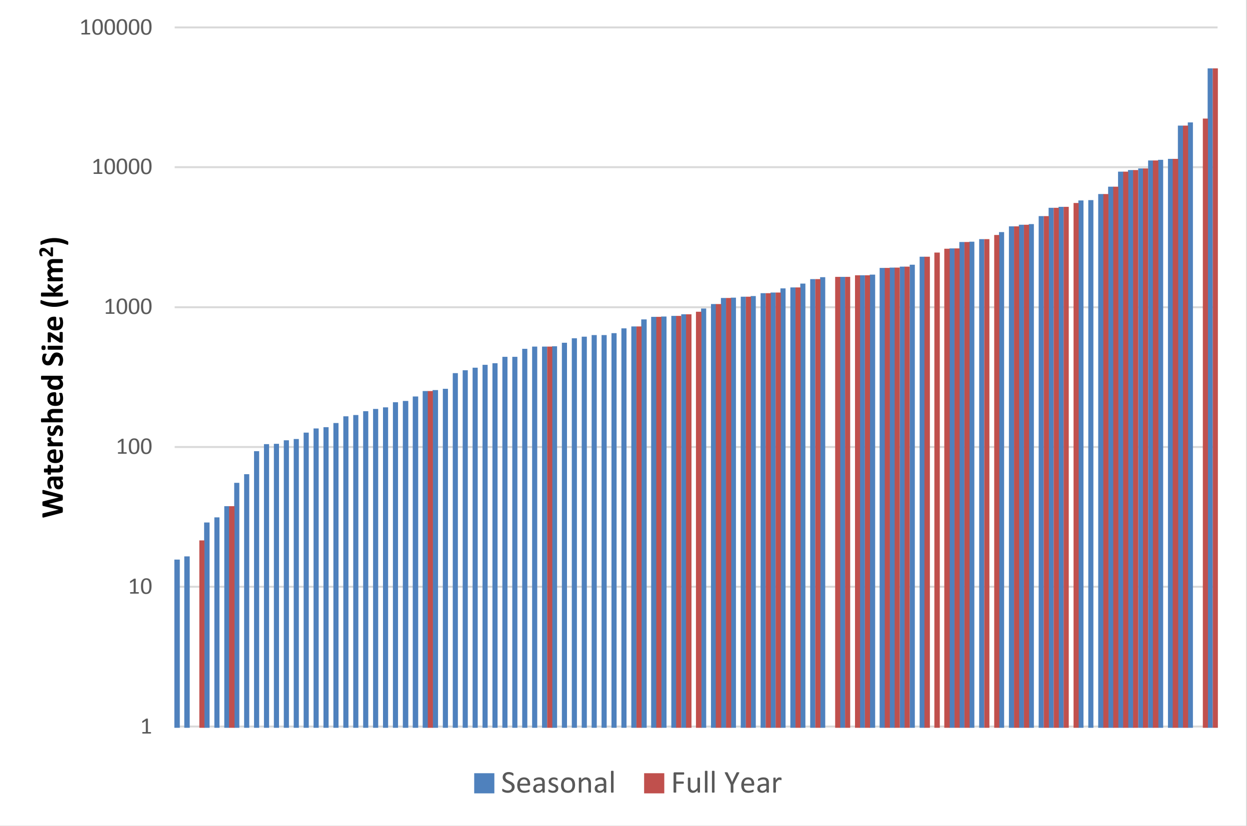


Figure 7. Size distribution of watersheds used for the open water ('Seasonal') and winter ('Full Year') months.

Weekly Modeling

Water allocations in Alberta typically specify approved volumes at a weekly time step. In order for the hydrologic modeling undertaken by the project to support this policy environment, significant effort was directed towards predicting runoff at the weekly timescale. Furthermore, the proposed methods outlined in *A Desk-top Method for Establishing Environmental Flows in Alberta Rivers and Streams* (Locke and Paul 2011) requires estimates of 80% exceedance flows for individual time steps. While the Alberta Desktop Method is considered a recommendation at this point rather than firm policy, a desire was expressed by Alberta government staff participants in the project to produce estimates for 80% exceedance flows at the weekly time step also. Flow duration curves are often used to determine 80% exceedance flows and for other calculations suggested in the Alberta Desktop Method. An example of a flow duration curve with calculations is shown in Figure 8.

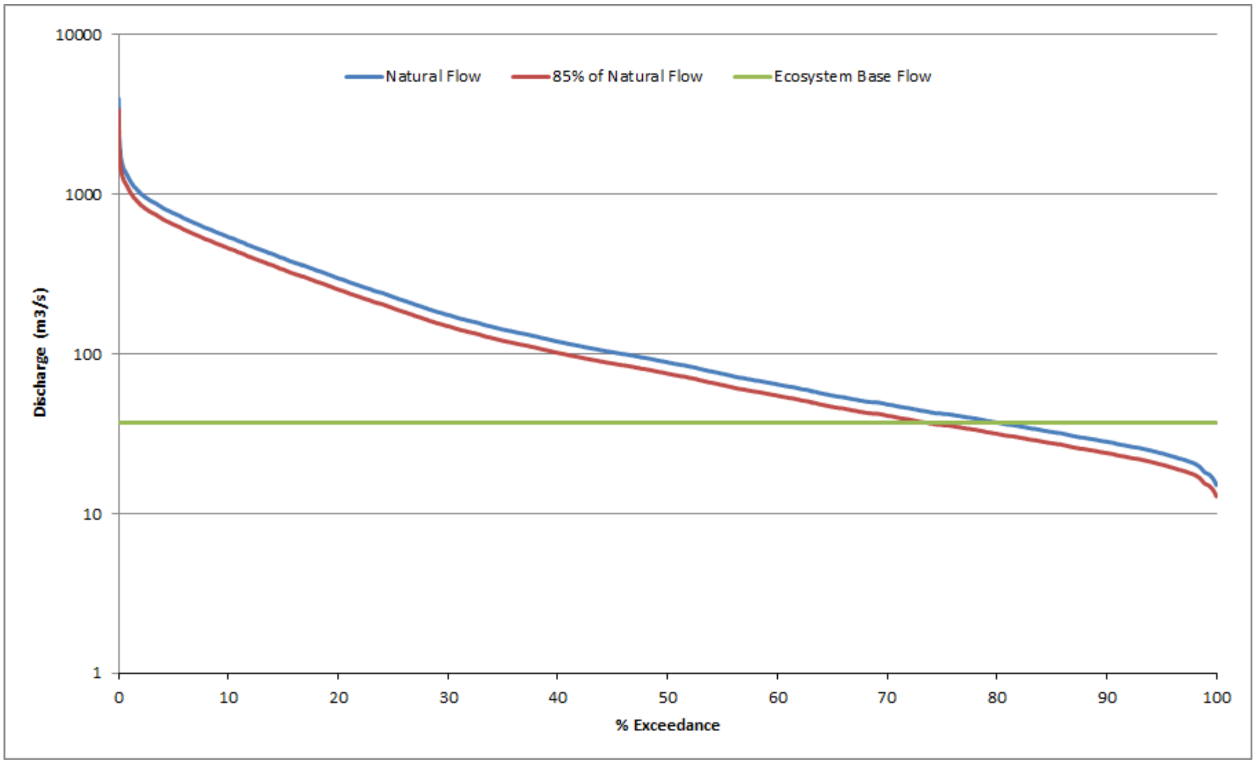


Figure 8. Example flow duration curve showing *Alberta Desktop Method* calculations.

Initial exploratory work began by processing daily hydrologic measurements into weekly flow duration curves, for each week of the year and each hydrometric station. Individual flow durations curves were plotted using daily unit runoff values rather than discharge, and further normalized using the mean daily unit runoff to allow for comparison of flow duration curves between stations. The objective of this exploratory analysis was to investigate the shape of flow duration curves. Previous research investigating physical controls on flow duration curves (Yokoo and Sivapalan 2011, Sauquet and Catalogne 2011, Cheng et al 2012, Viola et al 2010, Vogel and Fennessey 1994, Fennessey and Vogel 1990) identified potential predictors and distributions and informed much of this exploratory work. Basin elevation, area, and annual unit runoff were used to partition the curves and in some cases identified encouraging structure in the data. Samples of normalized flow duration curves are shown in Figure 9.

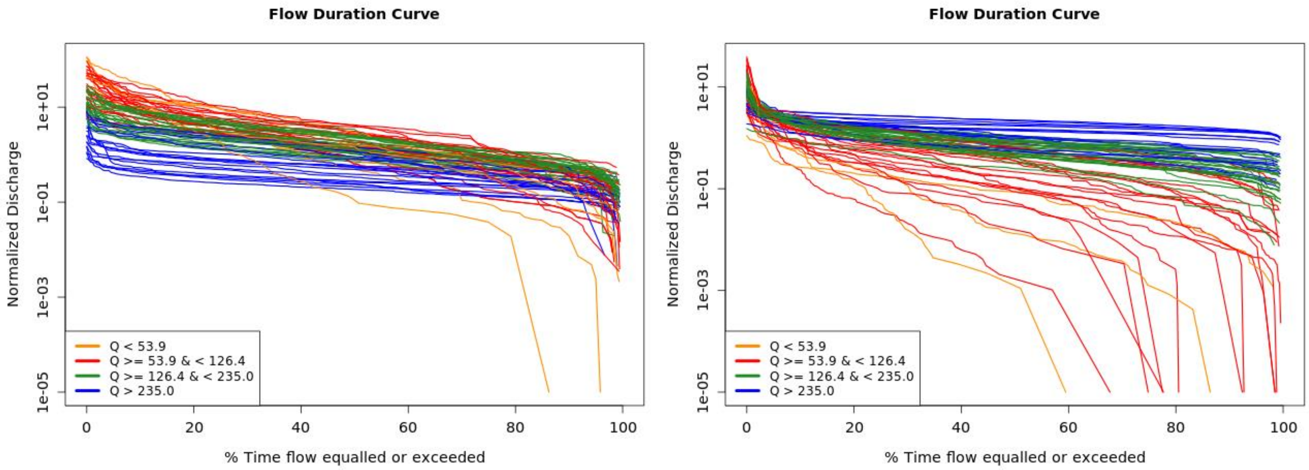


Figure 9. Flow duration curves for weeks 17 (left) and 34 (right) showing normalized discharge. Curves partitioned by mean annual runoff.

In order to generate synthetic flow duration curves for ungauged basins, distributions representing the shape of the curve were required to be fitted to the observations. Exponential and mixed gamma distributions were identified as potential appropriate methods for theoretical approximations of the empirical cumulative density functions for flow. Attempts to fit these distributions suggested that a gamma or log-normal distribution would be an appropriate fit within the study area. Theoretical cumulative density functions generated for hydrometric station 07GJ001 for two weeks are shown in Figure 10.

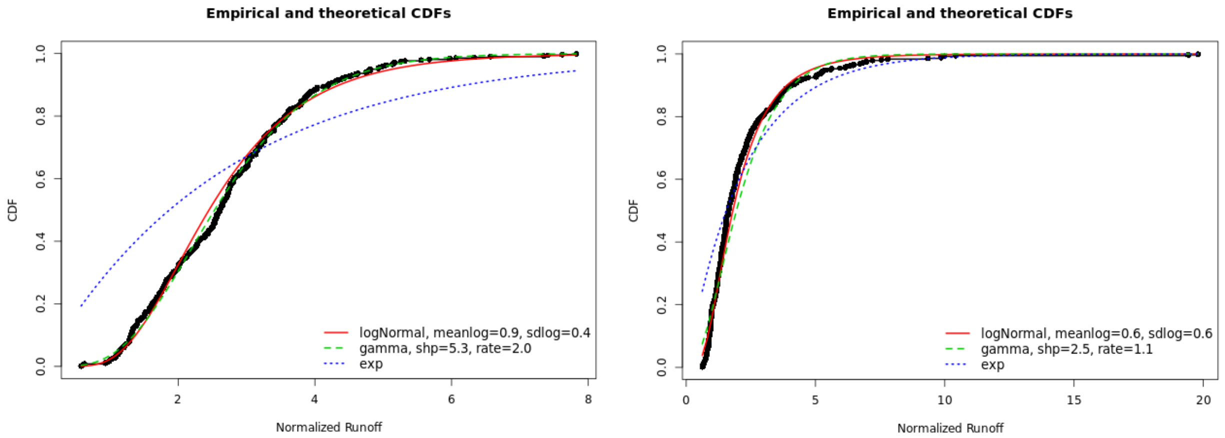


Figure 10. Log-Normal, gamma and exponential distribution derived cumulative density functions and parameters for weeks 21 (left) and 29 (right) at hydrometric station 07GJ001.

While initial investigations into a flow duration curve approach produced encouraging results, concerns existed regarding the efficacy of the methods for predicting the flow characteristics over the course of the year, and technical complexities and associated time requirements. Previous research in the prediction of flow duration curve characteristics from physical basin characteristics has been exclusively at the annual time scale, and generally exploratory in nature.

Much of the hydrologic detail exposed by flow duration curves generated from measured data is not necessary for the administration of water rights, such as peak flow characteristics. Ultimately the information required for water rights administration is the total volume of water present for the given week, and the low-flow threshold for determining environmental base flows (in this case the 80% exceedance flow). With this in mind a more simple approach was developed.

Total volume of water present for a week can be represented by the mean weekly flow in a system. Available water for licensing purposes could then be approximated by 15% of this total volume, less the volume of water at flows lower than the 80% exceedance flow. Approximating the low flows below the 80% exceedance assuming a constant flow to the 100% exceedance, should provide a reasonable approximation while partially compensating for the allocation of flow below the ecosystem base flow as flows dropped towards the 80% exceedance flow value. This small inaccuracy would be expected to be well within the model error tolerance. For a more complete review and assessment of this approach please refer to Appendix 2

Mean weekly runoff was calculated from the database of daily streamflow values. The 80% and 20% exceedance flows were extracted from ranked daily streamflows, for each week and each station.

A low flow ratio was calculated as the 80% exceedance flow related to the mean weekly flow. A high flow ratio was likewise calculated as the 20% exceedance flow related to the mean weekly flow. Exploratory analysis was conducted to determine whether the mean weekly flow, low and high flow ratios could be predicted using basin scale explanatory variables and a similar regression based approach as that used for predicting monthly flows.

The weekly modeling was conducted for weeks 14-44 (April 2 – October 31). Similarly to the monthly modeling process, basin scale variables calculated during the gauged basin analysis were used as predictors. Regression equations were developed and predictors were significance tested for mean weekly runoff, low and high flow ratios (80% and 20% exceedance flow value ratio to mean flow) for each week. For each week, the gauges selected for inclusion in the modeling had to have at least 100 days of measurements available. Between 63 and 72 gauges met the criteria for weeks 14-44.

Following the exploratory analysis, the full suite of regression equations was run through a jackknife cross-validation to determine error metrics.

For weeks 45-52 and 1-13, estimates of weekly unit runoff were generated from the results of the monthly modeling. The total volume of water modeled for each month was distributed evenly amongst the weeks of that month. No low flow and high flow ratios were generated for the winter weeks.

RESULTS

Annual

For the iterative Monte Carlo based analysis and modeling for the generation of annual runoff estimates, model performance was monitored by comparing modeled estimates for the 106 basins in the model domain with their long term mean runoff. Summary statistics generated for the overall model performance at the annual time step are provided in Table 8.

Table 8. Error metrics for annual hydrologic modeling.

Mean Error	2.6%
Median Error	-1.5%
Mean Absolute Error	16.0%
Watersheds with < 20% error	76.2%

The majority of the study area was covered by gauged watersheds. Limited coverage exists for lower elevation watersheds on the south side of the Peace River, in the Barrhead / Spruce Grove / Edmonton Region, and immediately north and southwest of Red Deer.

By count, for the 106 gauged basins, 76.2% have modeled runoff within +/-20% of the mean annual measured runoff in those watersheds. The watersheds vary greatly in size used within the model however. Inspection of the model performance by geography suggests an approximately equal magnitude of coverage by geography. Much of the study area falls within watersheds with model performance of 20% error or less (Figure 11).

The spatial distribution of watersheds with error greater than 20% exhibits clustering. Poor performance watersheds in the far northwest of the study area straddle the border with BC. Error in these watersheds is most likely due to error in the input precipitation field. In this portion of the foothills the ClimateAB climate model was found to be far superior to the ClimateWNA model but was not available west of 120deg W / BC-Alberta border.

Percent error is likely to increase where total annual runoff approaches zero due to absolute accuracy issues. In the cluster of four watersheds with significant errors immediately west of Ponoka, adjacent watersheds with greater than 20% error of opposing signs would perhaps bring in to question the accuracy of the underlying hydrologic measurements. Elevated error in small to very small watershed may also highlight the difficulties in repeatedly measuring runoff in small systems accurately. Consideration of error in all cases must consider the potential influence of error in any of the inputs, predictors and response variables used in the process.

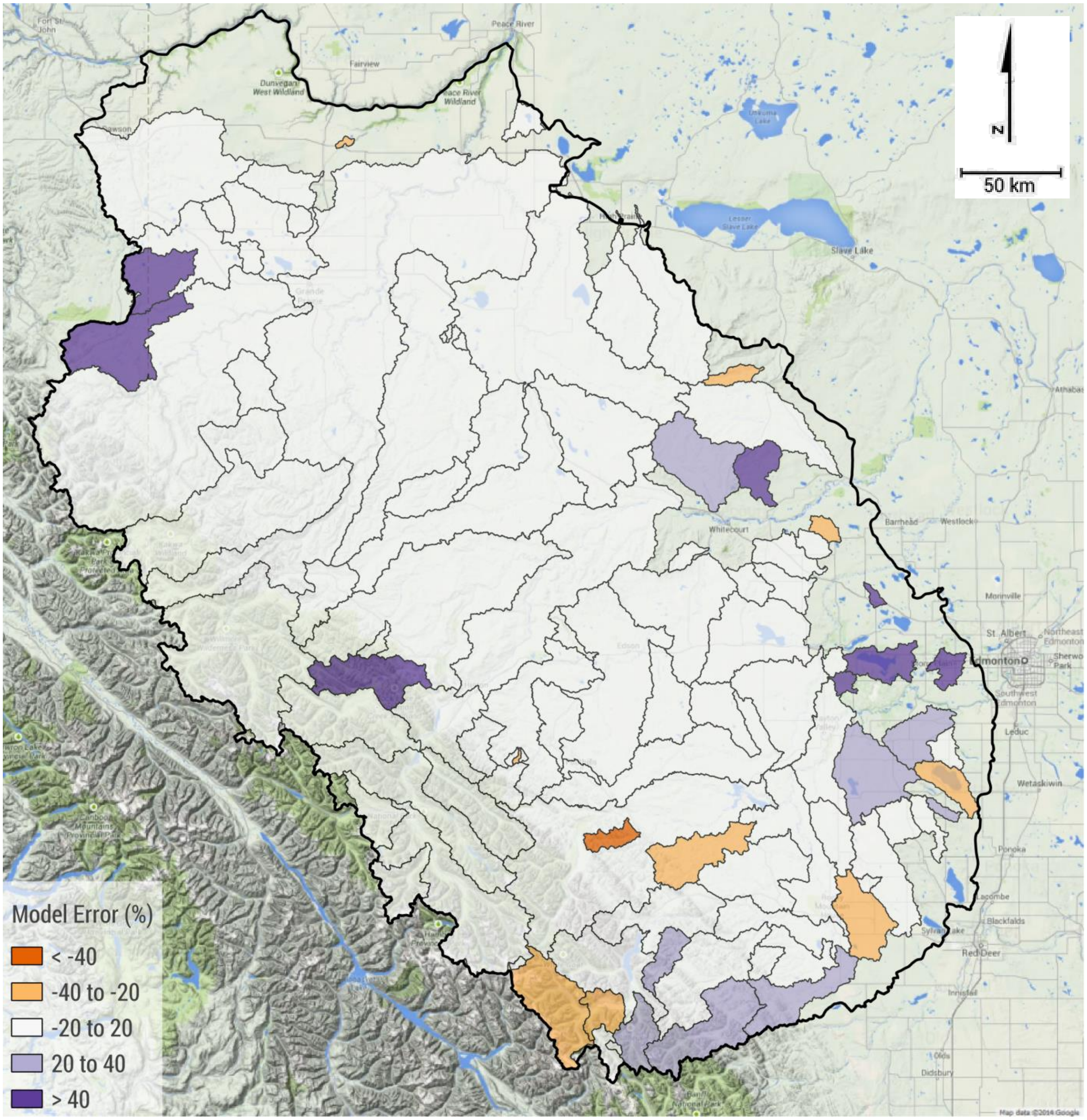


Figure 11. Gauged basins in the study area and error in the annual model.

The relationship between percent error for modeled watersheds and magnitude of annual precipitation was evaluated and is shown in Figure 12.

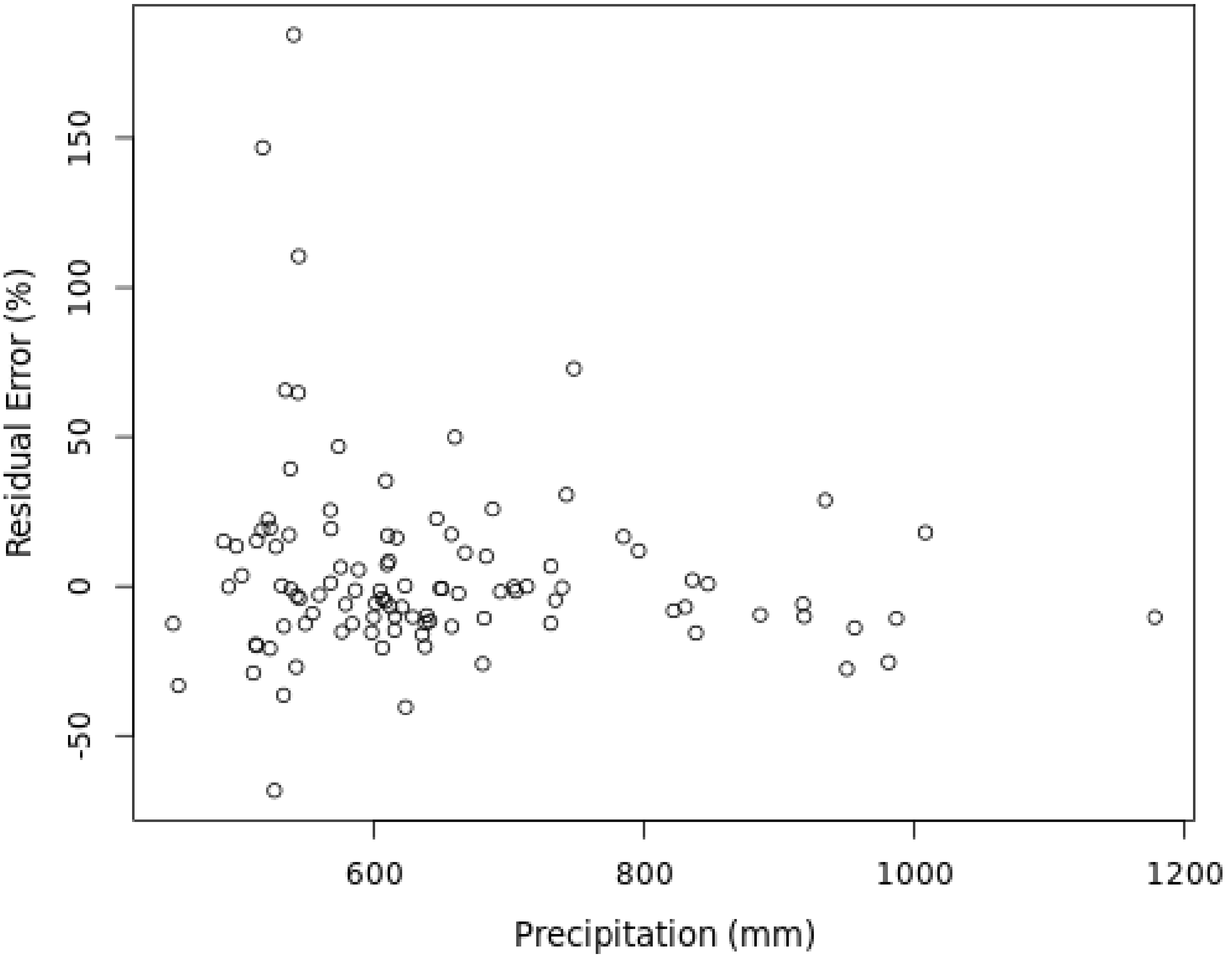


Figure 12. Residual error and basin mean annual precipitation for gauged basins used in the annual model.

Elevated percent error was observed in basins with annual precipitation around 500mm per year. While the magnitude of error expressed as unit runoff (mm) was unremarkable in comparison to other gauged basins, the generally low mean annual unit runoff values in these basins caused the error expressed as a percentage of annual runoff to appear large. Results of the water balance calculations, including annual precipitation, evapotranspiration, runoff, surface and groundwater use, and residual error are presented in Table 9.

Table 9. Water Balance Calculations.

STATION CODE	STATION NAME	PPT	ET	Q	SW USE	GW USE	ERR
05CC007	MEDICINE RIVER NEAR ECKVILLE	533.1	472.2	70.1	0.6	1.0	-10.8
05CC008	BLINDMAN RIVER NEAR BLUFFTON	559.3	458.1	103.8	0.2	0.5	-3.3
05CC009	LLOYD CREEK NEAR BLUFFTON	527.1	446.7	70.9	1.4	4.6	3.5
05CC010	BLOCK CREEK NEAR LEEDALE	544.9	479.7	67.9	0.3	0.8	-3.8
05CC013	LASTHILL CREEK NEAR ECKVILLE	532.9	482.8	78.4	0.6	1.1	-30.0
05DA006	NORTH SASKATCHEWAN RIVER AT SASKATCHEWAN CROSSING	981.1	249.9	985.6	0.0	0.0	-254.4
05DA009	NORTH SASKATCHEWAN RIVER AT WHIRLPOOL POINT	950.1	266.0	950.2	0.0	0.0	-266.2
05DB002	PRAIRIE CREEK NEAR ROCKY MOUNTAIN HOUSE	623.0	454.9	167.4	0.1	1.1	-0.5
05DB003	CLEARWATER RIVER ABOVE LIMESTONE CREEK	742.3	353.3	300.5	0.0	0.0	88.4
05DB005	PRAIRIE CREEK BELOW LICK CREEK	638.2	462.4	200.4	0.2	0.0	-24.7
05DB006	CLEARWATER RIVER NEAR DOVERCOURT	687.5	392.8	235.7	0.1	0.1	58.8
05DC001	NORTH SASKATCHEWAN RIVER NEAR ROCKY MOUNTAIN HOUSE	734.1	377.3	377.8	0.3	0.2	-21.5
05DC002	NORTH SASKATCHEWAN RIVER AT SAUNDERS	821.7	325.9	545.3	0.0	0.1	-49.7
05DC006	RAM RIVER NEAR THE MOUTH	662.6	420.4	249.9	0.0	0.0	-7.7
05DC010	NORTH SASKATCHEWAN RIVER BELOW BIGHORN PLANT	885.9	289.8	663.3	0.0	0.0	-67.2
05DA010	SILVERHORN CREEK NEAR THE MOUTH	1008.2	246.8	645.6	0.0	0.0	115.9
05DC011	NORTH RAM RIVER AT FORESTRY ROAD	646.4	427.7	179.4	0.0	0.0	39.3
05DD004	BROWN CREEK AT FORESTRY ROAD	623.6	475.2	248.7	0.0	0.0	-100.3
07AA007	SUNWAPTA RIVER AT ATHABASCA GLACIER	1178.4	113.3	1187.6	0.0	0.0	-122.5
07AC008	LITTLE BERLAND RIVER AT HIGHWAY NO. 40	704.4	375.4	335.3	0.0	0.0	-6.3
07AF003	WAMPUS CREEK NEAR HINTON	635.7	412.7	266.1	0.0	0.0	-43.1
07AF004	DEERLICK CREEK NEAR HINTON	637.7	401.4	295.6	0.0	0.0	-59.3
07AF005	EUNICE CREEK NEAR HINTON	641.2	440.5	227.3	0.0	0.0	-26.6
07GF003	WOLVERINE CREEK NEAR VALLEYVIEW	538.4	484.7	54.6	0.0	0.0	-0.9
05DE010	NORTH SASKATCHEWAN RIVER AT HIGHWAY NO. 759	693.4	399.4	302.0	0.6	0.2	-8.8
05DE911	MODESTE CREEK NEAR LINDALE	567.4	472.1	75.9	1.8	0.7	17.0
05DF004	STRAWBERRY CREEK NEAR THE MOUTH	537.9	475.3	44.9	1.0	1.2	15.4
05DF008	WEED CREEK AT THORSBY	513.2	473.0	34.9	0.5	0.6	4.2
05EA009	ATIM CREEK NEAR SPRUCE GROVE	517.6	465.8	21.0	0.3	1.0	29.5
05EA010	STURGEON RIVER NEAR MAGNOLIA BRIDGE	537.0	469.4	57.8	0.7	1.4	7.7

STATION CODE	STATION NAME	PPT	ET	Q	SW USE	GW USE	ERR	STATION CODE	STATION NAME	PPT	ET	Q	SW USE	GW USE	ERR
05DC012	BAPTISTE RIVER NEAR THE MOUTH	616.8	451.0	142.7	0.0	0.0	23.0	05FA002	PIGEON LAKE CREEK NEAR WESTEROSE	526.1	508.6	54.3	1.3	0.4	-38.5
05DD005	BRAZEAU RIVER BELOW BRAZEAU PLANT	713.2	388.6	328.8	0.0	0.0	-4.2	05FA019	PIGEON LAKE CREEK NEAR USONA	522.7	496.3	33.4	1.0	0.6	-8.4
05DD009	NORDEGG RIVER AT SUNCHILD ROAD	606.0	465.8	176.7	0.0	0.0	-36.5	05FA912	MUSKEG CREEK NEAR WESTEROSE	521.3	458.8	51.6	0.4	0.4	10.1
05DE003	WABAMUN CREEK NEAR DUFFIELD	540.6	484.2	19.8	4.3	0.8	31.5	07AA003	ROCKY RIVER AT HAWES	784.6	302.8	413.6	0.0	0.0	68.2
05DE006	NORTH SASKATCHEWAN RIVER NEAR LODGEPOLE	703.4	394.9	312.1	0.2	0.2	-4.0	07AC001	WILDHAY RIVER NEAR HINTON	748.0	375.0	216.7	0.0	0.0	156.4
05DE007	ROSE CREEK NEAR ALDER FLATS	567.9	443.7	104.2	0.1	0.9	19.1	07AC007	BERLAND RIVER NEAR THE MOUTH	657.2	423.6	200.1	0.0	0.0	33.6
05DE009	TOMAHAWK CREEK NEAR TOMAHAWK	543.9	451.9	55.8	0.1	0.2	35.9	07AD001	ATHABASCA RIVER AT ENTRANCE	837.9	306.1	632.0	0.0	0.2	-100.4
07AG007	MCLEOD RIVER NEAR ROSEVEAR	612.2	451.4	172.9	0.5	0.2	-12.9	07AD002	ATHABASCA RIVER AT HINTON	830.1	308.8	561.3	0.7	0.2	-40.9
07AH001	FREEMAN RIVER NEAR FORT ASSINIBOINE	610.0	417.0	164.0	6.0	0.1	22.9	07AE001	ATHABASCA RIVER NEAR WINDFALL	730.5	373.5	411.4	0.5	0.1	-55.1
07AH002	CHRISTMAS CREEK NEAR BLUE RIDGE	573.6	457.6	79.0	0.0	0.0	37.0	07AF002	MCLEOD RIVER ABOVE EMBARRAS RIVER	639.0	425.7	237.1	0.5	0.0	-24.3
07AH003	SAKWATAMAU RIVER NEAR WHITECOURT	608.5	417.0	141.3	4.8	0.0	45.4	07AF013	MCLEOD RIVER NEAR CADOMIN	739.9	350.3	392.1	3.5	0.0	-6.0
07BA001	PEMBINA RIVER BELOW PADDY CREEK	620.6	468.8	162.9	0.9	1.2	-13.2	07AF014	EMBARRAS RIVER NEAR WEALD	615.4	464.8	167.3	0.1	0.0	-16.9
07BA002	RAT CREEK NEAR CYNTHIA	610.8	476.8	123.7	0.0	1.3	9.0	07AF015	GREGG RIVER NEAR THE MOUTH	650.3	389.1	263.0	0.5	0.0	-2.2
07BA003	LOVETT RIVER NEAR THE MOUTH	657.4	432.1	260.3	17.5	4.9	-57.3	07AG001	MCLEOD RIVER NEAR WOLF CREEK	615.2	447.5	197.2	0.5	0.1	-30.1
07BB002	PEMBINA RIVER NEAR ENTWISTLE	608.4	469.6	145.7	0.6	1.4	-8.9	07AG003	WOLF CREEK AT HIGHWAY NO. 16A	599.6	467.1	147.6	0.1	0.0	-15.3
07BB003	LOBSTICK RIVER NEAR STYAL	576.1	498.9	90.9	0.1	0.5	-14.3	07AG004	MCLEOD RIVER NEAR WHITECOURT	604.4	459.3	147.6	0.5	0.3	-3.2

STATION CODE	STATION NAME	PPT	ET	Q	SW USE	GW USE	ERR	STATION CODE	STATION NAME	PPT	ET	Q	SW USE	GW USE	ERR
07BB004	PADDLE RIVER NEAR ROCHFORT BRIDGE	554.3	487.6	73.0	0.1	0.4	-6.8	07GD001	BEAVERLODGE RIVER NEAR BEAVERLODGE	516.7	462.6	45.0	0.4	0.2	8.6
07BB005	LITTLE PADDLE RIVER NEAR MAYERTHORPE	531.4	475.2	56.0	0.3	0.7	-0.8	07GD002	BEAVERTAIL CREEK NEAR HYTHE	533.8	464.1	41.7	0.2	0.1	27.6
07BB009	CONNOR CREEK NEAR SANGUDO	513.1	485.3	34.4	0.2	0.4	-7.2	07GD004	REDWILLOW RIVER NEAR RIO GRANDE	659.0	450.3	138.9	0.0	0.0	69.7
07BB011	PADDLE RIVER NEAR ANSELMO	567.7	487.5	79.0	0.1	0.1	1.0	07GE001	WAPITI RIVER NEAR GRANDE PRAIRIE	731.0	445.3	266.6	0.1	0.1	18.9
07BB014	COYOTE CREEK NEAR CHERHILL	544.3	473.0	33.8	0.3	1.0	36.2	07GE003	GRANDE PRAIRIE CREEK NEAR SEXSMITH	512.2	459.2	65.8	0.0	0.1	-12.9
07BB903	ROMEO CREEK ABOVE ROMEO LAKE	510.6	484.9	36.5	0.3	0.3	-11.4	07GE005	BEAR RIVER NEAR GRANDE PRAIRIE	492.2	461.3	30.8	0.2	1.0	-1.1
07BF001	EAST PRAIRIE RIVER NEAR ENILDA	584.8	439.9	164.4	0.1	0.1	-19.6	07GE006	COLQUHOUN CREEK NEAR GRANDE PRAIRIE	488.4	463.9	21.2	0.8	0.9	1.7
07BF002	WEST PRAIRIE RIVER NEAR HIGH PRAIRIE	575.4	449.0	118.3	0.2	0.1	7.9	07GE007	BEAR RIVER NEAR VALHALLA CENTRE	498.0	456.1	36.9	0.0	0.7	4.2
07FD006	SADDLE RIVER NEAR WOKING	502.1	439.6	60.2	0.2	0.0	2.1	07GF001	SIMONETTE RIVER NEAR GOODWIN	605.9	466.6	143.8	0.6	0.1	-5.2
07FD007	POUCE COUPE RIVER BELOW HENDERSON CREEK	522.8	441.2	68.2	0.1	0.1	13.2	07GF002	SPRING CREEK NEAR VALLEYVIEW	542.4	480.8	84.2	0.1	0.0	-22.7
07GA002	MUSKEG RIVER NEAR GRANDE CACHE	682.9	427.2	233.1	0.0	0.0	22.5	07GF008	DEEP VALLEY CREEK NEAR VALLEYVIEW	681.4	480.8	224.6	4.0	0.0	-28.0
07GB003	KAKWA RIVER AT HIGHWAY NO. 40	796.5	427.3	330.6	0.1	0.0	38.4	07GG001	WASKAHIGAN RIVER NEAR THE MOUTH	601.1	471.8	136.5	0.3	0.4	-7.9
07GC002	PINTO CREEK NEAR GRANDE PRAIRIE	588.6	468.4	113.9	0.0	0.0	6.2	07GG002	LITTLE SMOKY RIVER AT LITTLE SMOKY	628.7	467.8	179.1	1.2	0.6	-20.0
07GF004	SPRING CREEK (UPPER) NEAR VALLEYVIEW	549.1	481.4	77.5	0.0	0.0	-9.8	07GG003	IOSEGUN RIVER NEAR LITTLE SMOKY	586.2	446.0	141.8	0.8	0.7	-3.2
07AF010	SUNDANCE CREEK NEAR BICKERDIKE	609.4	479.4	121.2	0.0	0.0	8.8	07GH002	LITTLE SMOKY RIVER NEAR GUY	579.0	456.0	129.1	0.6	0.4	-7.1
07AG008	GROAT CREEK NEAR WHITECOURT	598.0	476.8	143.4	0.0	0.0	-22.1	07GJ001	SMOKY RIVER AT WATINO	649.2	437.9	211.1	0.9	0.2	-0.9

STATION CODE	STATION NAME	PPT	ET	Q	SW USE	GW USE	ERR
07FD910	RYCROFT SURVEY NO. 3 NEAR RYCROFT	455.1	440.7	20.9	0.1	0.0	-6.7
07GA001	SMOKY RIVER ABOVE HELLS CREEK	917.3	335.1	620.9	0.0	0.0	-38.7
07GF006	ROCKY CREEK NEAR VALLEYVIEW	542.8	490.5	53.8	0.4	0.0	-1.9
07GJ005	LALBY CREEK NEAR GIROUXVILLE	451.0	429.6	24.4	0.0	0.0	-3.0
05DA002	SIFFLEUR RIVER NEAR THE MOUTH	934.3	267.0	519.3	0.0	0.0	148.0
05DA007	MISTAYA RIVER NEAR SASKATCHEWAN CROSSING	986.8	264.7	812.6	0.0	0.0	-90.5
07AA001	MIETTE RIVER NEAR JASPER	848.1	339.9	505.5	0.0	2.5	0.1
07AA002	ATHABASCA RIVER NEAR JASPER	917.7	284.0	707.4	0.0	0.4	-74.1
07AA009	WHIRLPOOL RIVER NEAR THE MOUTH	954.5	281.9	783.9	0.0	0.0	-111.4
07AB002	SNAKE INDIAN RIVER NEAR THE MOUTH	835.8	320.1	506.8	0.0	0.0	8.8
07BJ003	SWAN RIVER NEAR SWAN HILLS	680.1	446.0	316.4	0.0	0.0	-82.2
07GB001	CUTBANK RIVER NEAR GRANDE PRAIRIE	667.6	445.8	199.4	0.0	0.0	22.4

Modeled annual runoff in the study area is generally consistent with previous research undertaken (Golder 2008, Bell (PFRA) 1994, AAFC 2013). Elevated runoff occurs in the Rocky Mountains and foothills, and at higher elevations along the drainage divide between the Smoky and Athabasca River watersheds. Swan Hills in the northeast of the study area also exhibits elevated annual runoff (Figure 13).

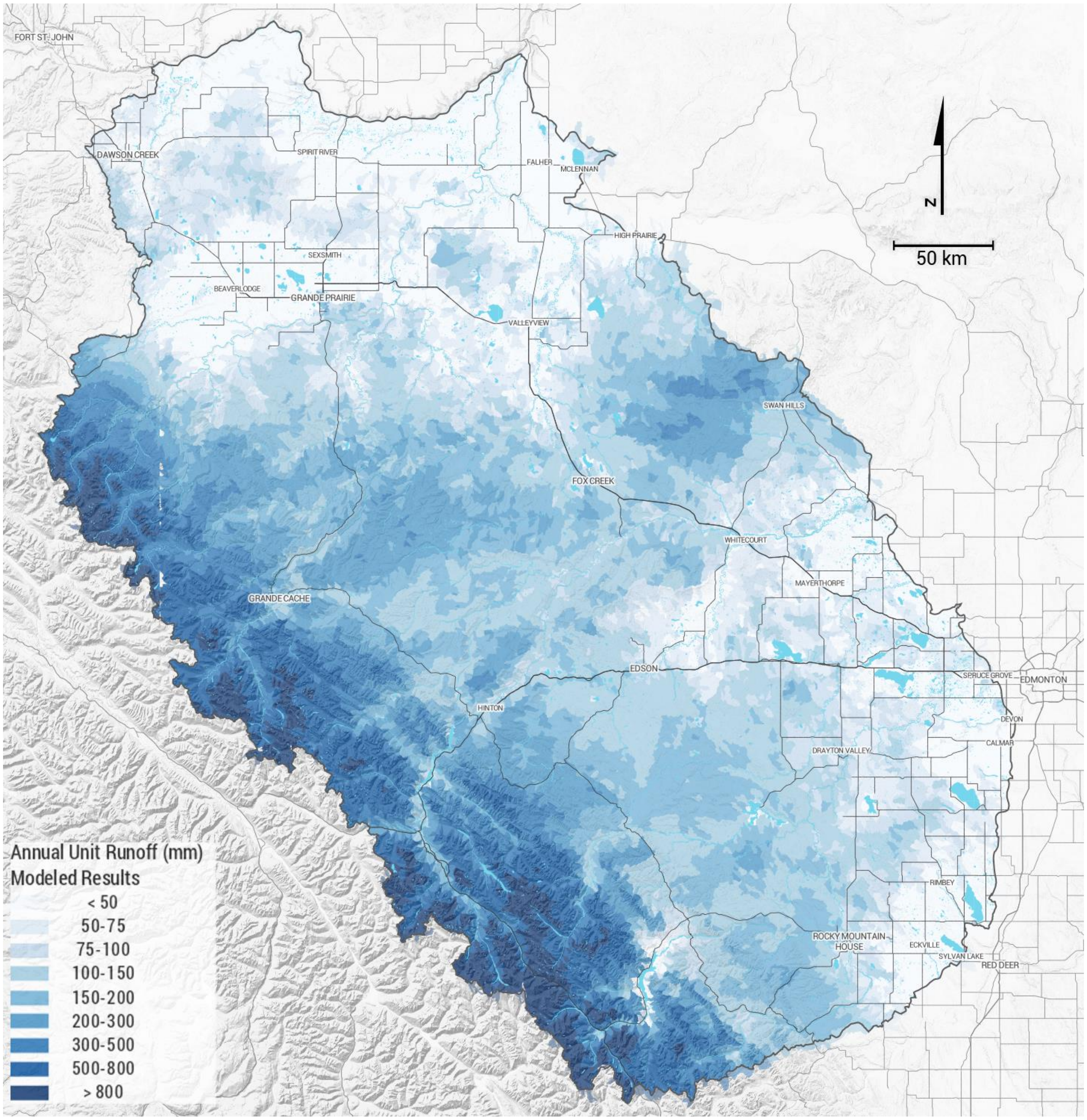


Figure 13. Modeled annual unit runoff.

Substantially greater detail is provided in sub-regional gross runoff volumes when compared to previous research, as a function of the model approach and objectives. When comparing modeled runoff to the P50 runoff from the PFRA 1994 product, approximately 2/3 of the study area is more than 20% different, as shown in Figure 14. Our analysis suggests runoff is substantially less than previous estimates in large parts of the northern portion of the study area. Our estimate suggests higher runoff values at the highest elevations in the Rocky Mountains and also a more rapid decrease moving northeast into the foothills along the Rocky Mountain front. Our estimate corresponds most closely with previous estimates of annual runoff along the drainage divide between the Smoky River and Athabasca River watersheds. In the northern and southern portions of the study area both significant positive and negative differences in magnitude are evident and interspersed. These differences are likely due to elevation driven precipitation variability in the climate drivers used for the project.

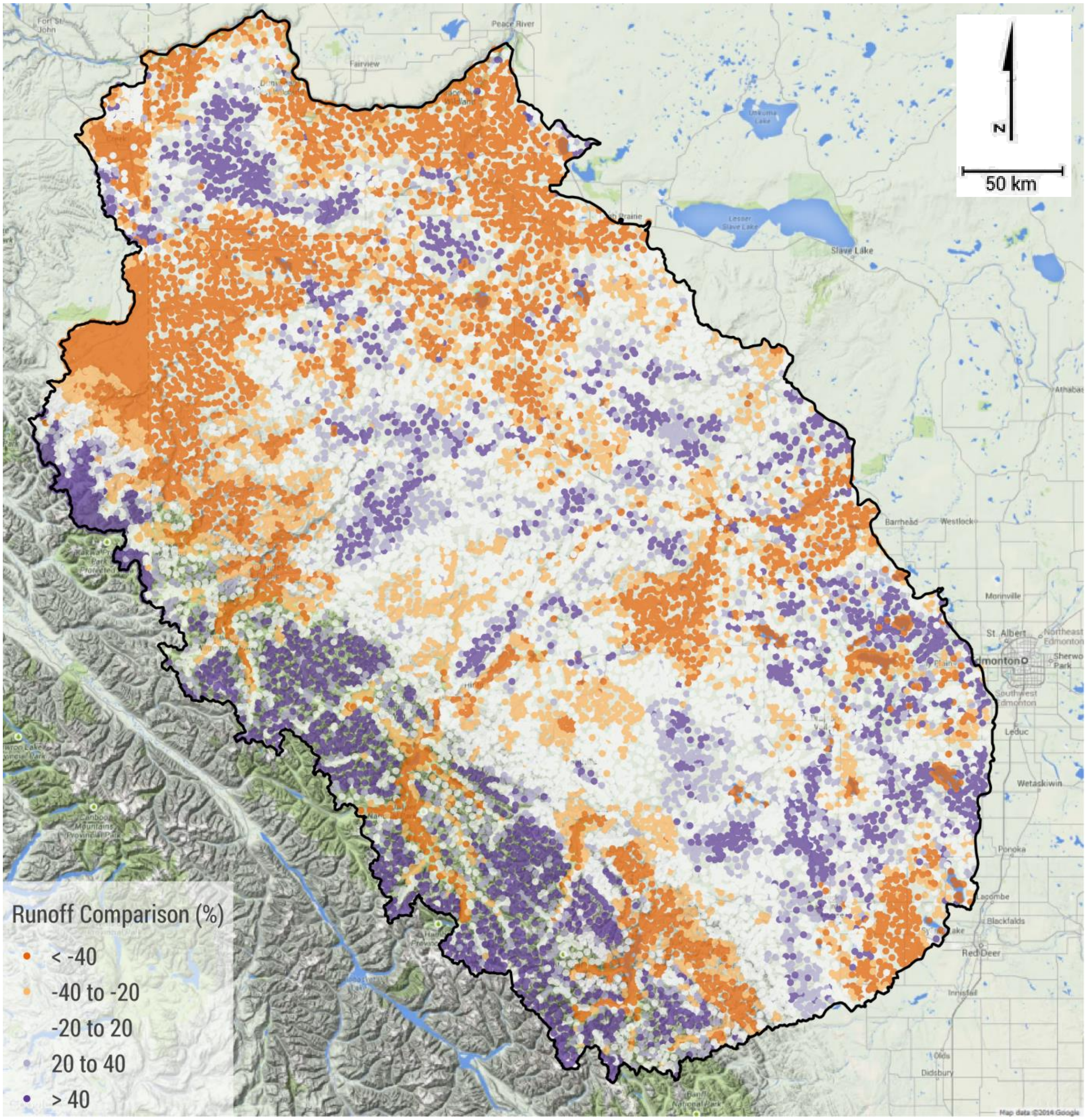


Figure 14. Comparison between annual modeled runoff and previous estimate of P50 runoff (Bell (PFRA) 1994).

The fine scale regional variation is attributed to elevation influenced variation in precipitation in the climate models used and the detailed vegetation and associated evapotranspiration values used to calibrate the hydrologic model.

Monthly

Monthly runoff was generated through the use of regression models for each month. Predictor variables were selected through an exploratory process. Regression equations developed for each model are provided in Appendix 3a.

The monthly models performed well to moderately well for most months based on residual standard error and R^2 values generated in the regression, with the exception of March and December. These months are on the threshold of seasons, exhibit substantial variation in interannual flows, and are challenging to measure effectively due to difficult conditions.

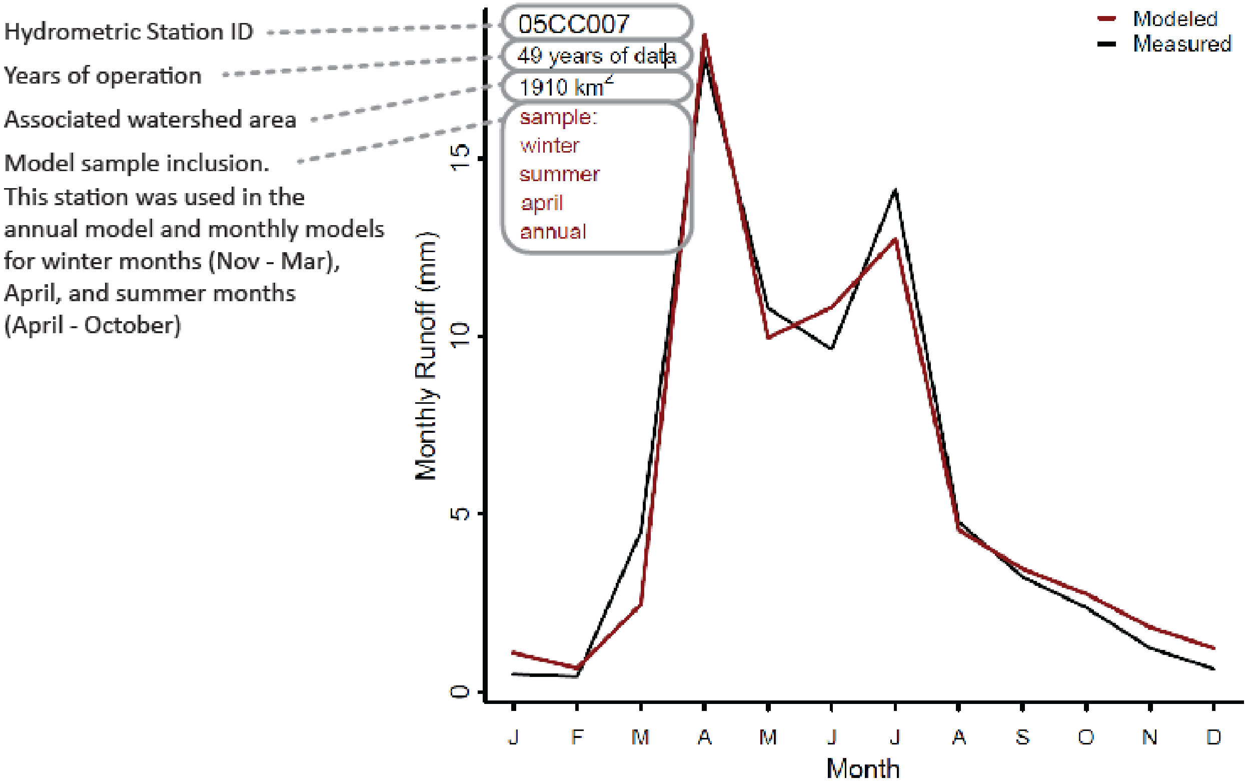
The number of significant predictors selected for each month varies. For many months, predictors included monthly and seasonal precipitation and percent precipitation. Basin centroid coordinates were significant for several months, with annual precipitation and monthly temperature significant in some cases. In some months, predictors with lower significance codes were selected for inclusion based on a subjective assessment of the influence of the specific process represented on runoff generation.

Following the exploratory process, the model regression parameters for each month were validated using a jackknife method. The validation was implemented for each month separately. Data from a single station is reserved for validation, while the regression coefficients are calculated with the remaining n-1 stations (winter: n=45, summer: n=94, April: n=86). The resulting regression is then used to make independent predictions of the validation data. Error metrics were recorded for each iteration, and then model performance statistics were generated from the results. Error metrics for individual months are shown in Table 10. Root mean square error for each individual month was acceptable. Median error was also monitored for each month and again December and March exhibited highest error values.

Table 10. Monthly modeling error metrics (RMSE = Root Mean Square Error).

Month	RMSE (% runoff)	Median Error (%)
January	0.41	-0.67
February	0.37	5.63
March	0.94	17.37
April	6.34	6.50
May	4.36	-1.67
June	3.86	-1.02
July	3.65	-1.45
August	2.88	-3.02
September	1.70	-0.84
October	1.08	-0.03
November	0.63	5.55
December	0.58	8.07

Monthly runoff was modeled as percent runoff coefficients, and then applied to runoff values determined from the annual modeling process. Monthly runoff was then plotted against measured values for visual comparison. A sample hydrograph plot is shown in Figure 15 with the full set of hydrograph comparisons provided in Appendix 4a.



Hydrometric Station ID

Years of operation

Associated watershed area

Model sample inclusion. This station was used in the annual model and monthly models for winter months (Nov - Mar), April, and summer months (April - October)

Figure 15. Comparison of modeled and measured monthly hydrograph for station 05CC007 (Medicine River near Eckville)

The fit between the predictive model and the observed measurements was quantitatively assessed using the Nash-Sutcliffe efficiency (NSE) method (Nash and Sutcliffe 1970) and Spearman's rank correlation coefficient (Spearman 1904). Metrics were calculated comparing twelve months of model predictions with 12 months of observed monthly data for 45 stations. The mean NSE and Spearman's rank was 0.89 and 0.96, respectively. Metrics were also calculated comparing 6 months of model predictions with 6 months of observed monthly data for 86 stations with data for the open water season. The NSE and Spearman's rank for this sample were 0.82 and 0.93, respectively. For both metrics, a value of 1 represents a perfect match between modeled and observed values. The NSE and Spearman's metrics are shown in Table 11.

Table 11. Nash-Sutcliffe Efficiencey (NSE) and Spearman's rank correlation coefficient for monthly time-step.

April - October

Station	NSE	Spearmans
07AC007	0.84	0.86
07AG003	0.96	0.89

January - December

Station	NSE	Spearmans
07AG003	0.98	0.97
07AG004	0.96	0.99

April - October

Station	NSE	Spearmans
07AG004	0.89	0.93
07AC008	0.86	0.96
07AD001	0.95	0.96
07AG007	0.90	0.96
07AG008	0.76	0.86
07AH001	0.97	0.96
07AH002	0.81	0.89
07AH003	0.92	1.00
07BA001	0.91	0.89
07BA002	0.95	0.89
07AD002	0.96	0.93
05EA010	0.91	1.00
07BB002	0.97	0.86
07BB003	-0.22	0.89
05DA007	0.97	0.96
07BB005	0.95	0.96
05DD009	0.86	0.86
05FA019	-1.05	0.93
07BB011	0.86	0.89
07BB014	0.81	0.89
05DB005	0.93	1.00
07BF001	0.94	1.00
07BF002	0.96	1.00
07AA001	0.71	0.93
07BJ003	0.81	0.86
07FD006	0.95	0.96
07FD007	0.82	0.96
07AA002	0.97	1.00
05DB006	0.93	0.93
07AE001	0.93	0.93
05CC010	0.86	0.96
05DE007	0.79	0.68
05DC012	0.88	0.86
07AF002	0.94	0.86
07GA001	0.87	0.96
07GA002	0.93	0.86
07GB001	0.88	0.89
07AF003	0.76	0.86
07GB003	0.70	0.89
07AF004	0.78	0.79
07GC002	0.92	1.00
07GD001	0.97	1.00
07GD002	0.89	0.93
07AF005	0.82	0.93
07GD004	0.60	0.82
07GE001	0.49	0.86
05DE009	0.92	0.93
07GE003	0.96	1.00

January - December

Station	NSE	Spearmans
07AD001	0.97	0.97
07AG007	0.96	0.99
07AD002	0.98	0.97
07BB002	0.99	0.97
07BB003	0.60	0.97
05DA007	0.98	0.97
05DD009	0.94	0.97
07BF002	0.97	0.99
07AA001	0.82	0.98
07FD007	0.90	0.98
07AA002	0.98	0.96
05DB006	0.96	0.94
07AE001	0.96	0.98
05DC012	0.95	0.97
07AF002	0.97	0.97
07GA001	0.93	0.98
07GA002	0.96	0.95
07GD001	0.98	0.97
07GD004	0.76	0.96
07GE001	0.73	0.94
05DA009	0.97	0.94
07GF001	0.96	0.99
05CC007	0.97	0.97
07GG001	0.98	0.99
07GH002	0.99	0.99
05DB002	0.91	0.99
07GJ001	0.92	0.97
05DC006	0.88	0.94
07AG001	0.92	0.97
07AG002	0.90	0.97
07BB001	0.63	0.95
07GC001	0.12	0.86
07GD003	0.77	0.95
07GE005	0.68	0.99
05DA003	0.96	0.92
05DA006	0.97	0.91
05DA010	0.89	0.91
05DB001	0.93	0.94
05DC001	0.96	0.97
05DC002	0.94	0.95
05DE001	0.94	0.97
07AA003	0.92	0.96
07AA004	0.91	0.97

April - October

Station	NSE	Spearmans
05DA009	0.95	0.89
07AF010	0.89	0.89
07GE007	0.74	1.00
07GF001	0.90	1.00
07GF002	0.68	0.93
05DE911	0.73	1.00
07GF004	0.89	1.00
05CC007	0.98	0.96
07AF013	0.96	1.00
07AF014	0.82	0.96
07AF015	0.90	0.89
07GG001	0.96	0.96
07GG002	0.93	0.96
07GG003	0.98	0.96
05DF004	0.78	1.00
07GH002	0.97	0.96
05CC008	0.83	0.96
05DB002	0.79	0.96
05CC009	0.96	1.00
07GJ001	0.82	0.86
05DC006	0.77	0.71
07AG001	0.83	0.86
07BA003	0.95	1.00
07BB004	0.90	1.00
07BB009	0.78	0.86
07GE005	0.43	1.00
07GE006	0.84	0.89
07GJ005	0.93	0.89
05CC013	0.71	0.86
05DA006	0.95	0.89
05DC001	0.93	0.96
05DC002	0.90	0.93
07AA003	0.87	0.93
07AC001	0.16	0.96

January - December

Station	NSE	Spearmans

The study area is classified as continental/microthermal by the Koppen climate classification system (Kriticos 2012). The microthermal component suggests cold winters. Accumulation of precipitation in the form of snow and associated melt is the dominant control on the timing of maximum flow in rivers in the study areas, which typically occurs in the spring. Additional peaks in runoff can be observed during the summer months in many hydrographs, and are associated with substantial summer rainfall. Areas with substantial monthly runoff can be determined by inspecting the individual monthly runoff maps included in Appendix 5.

Weekly

Weekly runoff was generated through the use of regression models for weeks 14-44. For weeks 1-13 and 45-52, weekly runoff was interpolated from monthly modeled runoff. For weeks 14-44, models were generated for average weekly runoff, and 20% and 80% exceedance values. Average weekly runoff was modeled directly while the 20% and 80% exceedance values were estimated as a ratio of weekly average runoff. In total, 93 models were created, and significant predictors were determined through exploratory analysis. Regression equations developed for each model are provided in Appendix 3b.

Robust regression parameters were developed for average runoff for all weeks after week 19. Weeks 14-19 (April 2 – May 12) in most years cover the winter break up and beginning of elevated flows, and as such flow conditions in these weeks are highly sensitive to climatic conditions in the watersheds in individual years. The R^2 and residual standard error resulting from the weekly average runoff models for these weeks were still acceptable, however.

The results of the exploratory analysis for low flow ratios identified significant predictors, with strong or very strong metrics for each weekly model produced. By estimating low flow parameters as a ratio of mean weekly flows, error associated with the absolute values estimated for low flows will inherit the error associated with the mean flow estimates also.

The high flow ratio analysis resulted in weaker regression parameters compared to the average weekly flow and low flow estimations, both in terms of identification of significant predictors and error metrics. Outside of weeks 19 to 23, weak to moderate relationships were identified. For weeks 19 to 23, R^2 values were close to zero. These weeks correspond to the time when high flows are expected across much of the study area.

The high flow ratio was not a required outcome of the modeling exercise. An attempt was made to model the parameter to allow for possible representation of a modeled weekly flow duration curve using three points, but due to the poor performance of the model results the concept was not pursued further.

The most common predictors used in the regression equations were monthly absolute and percent annual runoff, and seasonal absolute and percent annual runoff. Basin centroid coordinates, and elevation were significant in many of the equations, with monthly temperature identified in a handful of regression equations. Watershed size was tested as a predictor in all of the equations but found to be not significant.

Following the exploratory analysis, synthetic hydrographs were generated to visually compare the measured data with the results of the modeling exercise. Synthetic hydrographs were found to produce a very good fit with the observation derived hydrographs, with hydrograph shape, magnitude, timing of freshet onset, and preservation of summer peak flows preserved for a large percentage of watersheds. As suggested by the very strong regression coefficients resulting from the low flow analysis, the 80%

exceedance values calculated also closely fit with the measured data. A sample hydrograph comparison plot is shown in Figure 16. Weekly hydrograph comparisons for each gauged basin are provided in Appendix 4b.

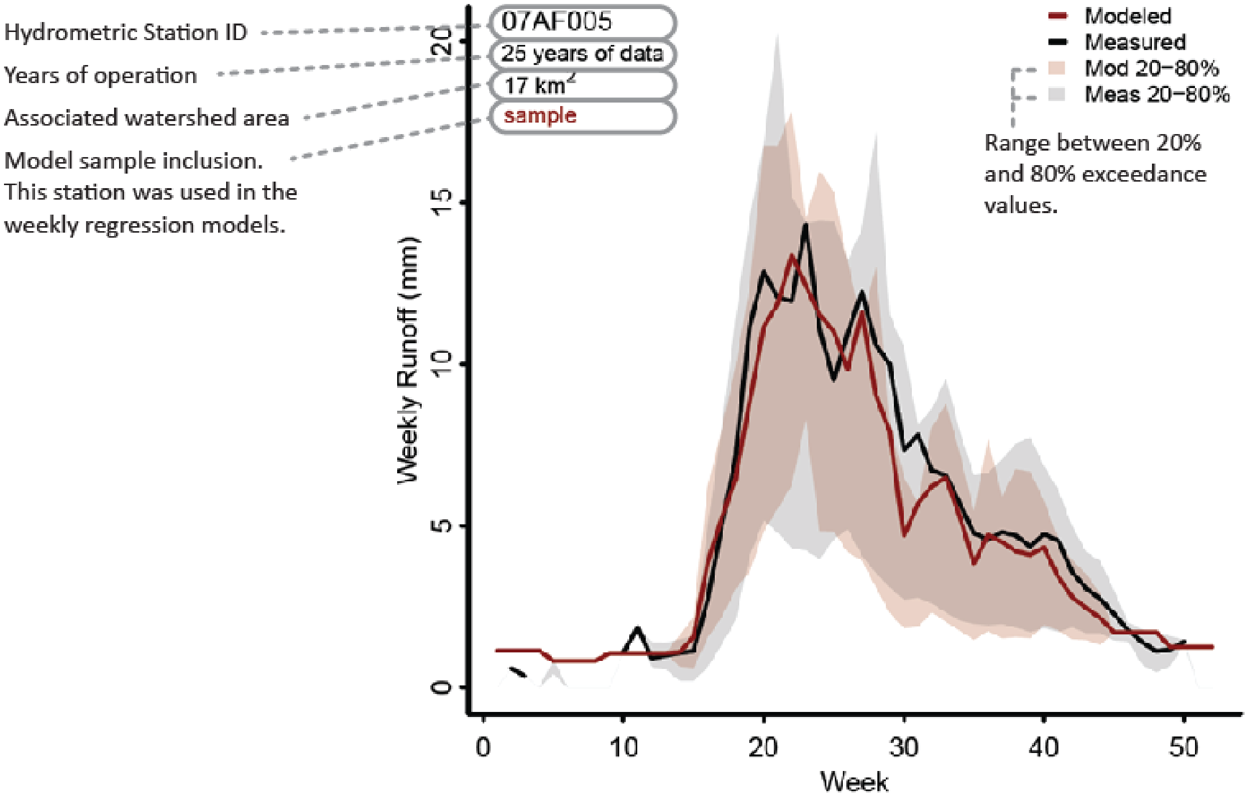


Figure 16. Comparison of modeled and measured mean weekly hydrograph for station 07AF005 (Eunice Creek near Hinton) with 20% and 80% exceedance runoff.

For some gauges used in the analysis, weekly hydrographs of mean measured runoff exhibit significant variation through the summer. One would expect a truly 'normal' hydrograph to have less extreme variation between weeks. Large flood events in the record likely skew the mean substantially in these cases. Consideration of median flows may have produced smoother shapes over these periods but would have removed the ability to conserve mass over the course of the year.

A jackknife method was used to quantify the performance of the weekly models. The validation was implemented for each month separately. Data from a single station is reserved for validation, while the regression coefficients are calculated with the remaining n-1 stations (week 14-29: n=72, week 30: n=71, week 31, 32, 36-38: n=69, week 33, 34, 39-43: n=68, week 44: n=63). The resulting regression is then used to make independent predictions of the validation data. Error metrics were recorded for each iteration and then model performance statistics were generated from the results. Model performance statistics for each week are shown in Table 12.

Table 12. Weekly modeling error metrics (RMSE = Root Mean Square Error).

		Mean Runoff (mm)		Low Flow Ratio		High Flow Ratio	
Week #	Date	RMSE	Median Error %	RMSE	Median Error %	RMSE	Median Error %
14	Apr02-Apr08	0.81	3.13	4.93	28.87	0.12	2.10
15	Apr09-Apr15	1.28	5.27	0.16	-0.44	0.09	-0.34
16	Apr16-Apr22	1.49	2.12	0.19	-1.35	0.10	-4.80
17	Apr23-Apr29	1.60	0.32	0.17	-0.12	0.08	-1.93
18	Apr30-May05	1.58	-0.49	0.20	-0.90	0.08	-0.45
19	May07-May12	1.83	-1.10	0.00	0.00	0.08	-0.04
20	May14-May19	1.99	1.23	0.20	-0.57	0.09	-0.31
21	May21-May26	1.86	-0.07	0.14	0.02	0.08	-2.53
22	May28-Jun02	2.37	-0.71	0.23	1.57	0.08	0.16
23	Jun04-Jun09	2.39	1.60	0.20	1.36	0.11	-3.26
24	Jun11-Jun16	2.48	3.15	0.21	-0.32	0.08	3.05
25	Jun18-Jun23	2.67	1.53	0.28	-1.16	0.07	0.81
26	Jun25-Jun30	2.68	3.69	0.24	2.38	0.06	-0.61
27	Jul02-Jul07	1.87	-1.40	0.20	-1.48	0.07	-0.03
28	Jul09-Jul14	1.61	-3.89	0.20	0.42	0.07	1.81
29	Jul16-Jul21	1.53	1.46	0.26	-0.29	0.07	2.34
30	Jul23-Jul28	1.86	4.40	0.23	0.65	0.08	-1.21
31	Jul30-Aug04	1.66	4.41	0.22	-0.51	0.08	-0.81
32	Aug06-Aug11	2.52	-5.89	0.25	3.74	0.08	-0.18
33	Aug13-Aug18	2.18	-0.39	0.31	-1.27	0.08	-1.41
34	Aug20-Aug25	1.94	-5.57	0.25	-0.48	0.08	0.94
35	Aug27-Sep01	1.85	-9.43	0.19	-1.72	0.09	0.98
36	Sep03-Sep08	0.92	-0.39	0.26	-1.27	0.09	2.18
37	Sep10-Sep15	0.92	-1.28	0.28	1.37	0.09	5.13
38	Sep17-Sep22	0.74	-3.39	0.30	-1.04	0.08	0.32
39	Sep24-Sep29	0.56	-3.59	0.21	0.16	0.08	1.37
40	Oct01-Oct06	0.50	-1.27	0.20	0.91	0.08	-2.52
41	Oct08-Oct13	0.47	-1.43	0.15	1.09	0.09	2.81
42	Oct15-Oct20	0.39	-0.19	0.16	0.11	0.08	-1.53
43	Oct22-Oct27	0.33	-0.72	0.13	0.07	0.08	1.09
44	Oct29-Oct31	0.28	0.24	0.14	-0.26	0.07	2.69

The Nash Sutcliffe efficiency (NSE) and Spearman rank correlation coefficient were calculated for each gauged basin used in the weekly modeling. Modeled mean weekly runoff values were compared with observed mean weekly runoff values. For the 63 stations used in each weekly model, weekly estimates of mean runoff were compared with measured mean runoff. The mean NSE and Spearman's rank metrics were 0.83 and 0.93, respectively. The NSE and Spearman's metrics are shown for each station in Table 13.

Table 13. Nash-Sutcliffe Efficiency (NSE) and Spearman's rank correlation coefficient for weekly time-step.

Station	NSE	Spearman
07AC007	0.84	0.86
07AG003	0.96	0.89

Station	NSE	Spearman
07GC002	0.92	1
07GD001	0.97	1

Station	NSE	Spearman
07AG004	0.89	0.93
07AC008	0.86	0.96
07AD001	0.95	0.96
07AG007	0.9	0.96
07AG008	0.76	0.86
07AH001	0.97	0.96
07AH002	0.81	0.89
07AH003	0.92	1
07BA001	0.91	0.89
07BA002	0.95	0.89
07AD002	0.96	0.93
05EA010	0.91	1
07BB002	0.97	0.86
07BB003	-0.22	0.89
05DA007	0.97	0.96
07BB005	0.95	0.96
05DD009	0.86	0.86
05FA019	-1.05	0.93
07BB011	0.86	0.89
07BB014	0.81	0.89
05DB005	0.93	1
07BF001	0.94	1
07BF002	0.96	1
07AA001	0.71	0.93
07BJ003	0.81	0.86
07FD006	0.95	0.96
07FD007	0.82	0.96
07AA002	0.97	1
05DB006	0.93	0.93
07AE001	0.93	0.93
05CC010	0.86	0.96
05DE007	0.79	0.68
05DC012	0.88	0.86
07AF002	0.94	0.86
07GA001	0.87	0.96
07GA002	0.93	0.86
07GB001	0.88	0.89
07AF003	0.76	0.86
07GB003	0.7	0.89
07AF004	0.78	0.79
07GD002	0.89	0.93
07AF005	0.82	0.93
07GD004	0.6	0.82
07GE001	0.49	0.86
05DE009	0.92	0.93
07GE003	0.96	1
05DA009	0.95	0.89
07AF010	0.89	0.89
07GE007	0.74	1
07GF001	0.9	1
07GF002	0.68	0.93
05DE911	0.73	1
07GF004	0.89	1
05CC007	0.98	0.96
07AF013	0.96	1
07AF014	0.82	0.96
07AF015	0.9	0.89
07GG001	0.96	0.96
07GG002	0.93	0.96
07GG003	0.98	0.96
05DF004	0.78	1
07GH002	0.97	0.96
05CC008	0.83	0.96
05DB002	0.79	0.96
05CC009	0.96	1
07GJ001	0.82	0.86
05DC006	0.77	0.71
07AG001	0.83	0.86
07BA003	0.95	1
07BB004	0.9	1
07BB009	0.78	0.86
07GE005	0.43	1
07GE006	0.84	0.89
07GJ005	0.93	0.89
05CC013	0.71	0.86
05DA006	0.95	0.89
05DC001	0.93	0.96
05DC002	0.9	0.93
07AA003	0.87	0.93
07AC001	0.16	0.96

After the validation of the weekly models, the results of the annual modeling were used to reconcile the weekly average runoff models to ensure that the sum of the individual weeks matched the total amount of water present in a year. Following the normalization of the weekly average runoff values, the low and high flow ratios were applied to generate values for the 20% and 80% exceedance values in mm.

RECONCILIATION

As the final goal of the modeling exercise is to produce a data product that represents our understanding of the regional hydrology as best as possible, several quality assurance and correction steps are required. These fall into two primary categories, (1) adjustments to rectify gross volumes of water to measured long term averages, and (2) adjustments to ensure that the range of values within the model output fall within hydrologic limits.

Following the completion of the annual modeling, residual error existed within all individual basins. As the 106 basins used in the annual modeling were deemed to be accurate measurements of hydrology, modeled annual runoff within these gauged basins was adjusted to remove all error. This was done by transforming the nested, overlapping set of watersheds into a patchwork layer of incremental watersheds. Incremental runoff generated from each watershed unit was calculated and compared with modeled runoff within the incremental unit. This process identified gauged basins where significant discrepancies existed between gauges hydrologically related. In these cases, further evaluation of the relevant gauges was conducted and selections for continued inclusion were made.

The comparison of measured incremental runoff values with modeled incremental runoff resulted in adjustment factors to be applied to the runoff in each incremental basin. These adjustment factors were applied to the incremental watersheds uniformly, effectively assuming that error in the model was evenly distributed across the watershed. This process ensures that when the modeled hydrologic data is supplied to a decision support system, that gross volumes of water estimated at locations where hydrometric stations are present will match the mean annual measured runoff exactly, and that there does not exist an excess or deficit of water in the system.

In some areas of the study area, negative annual runoff values were observed. These areas were investigated and determined to be acceptable. Areas with significant negative runoff values were associated with large bodies of water. Shallow lake evaporation is often greater than annual precipitation in areas of low or even moderate rainfall in the study area. Some areas with slight negative runoff values were found in areas with irrigated agricultural activity, also identified by the PFRA as non-contributing areas. Mean annual runoff in these areas would reasonably be expected to be close to zero, and perhaps less than zero considering significant agricultural irrigation.

The monthly runoff percentages were generated through a statistical model. In some months, measured runoff is very low and as such percentage runoff approaches zero. While conceptually impossible to have a negative percent monthly runoff in a month, this can occur in the modeled values. The sample of hydrometric stations used in the model effectively covers the range of physical characteristics in the study area. Portions of the study area are outside of the domain of variables used in the model for one or multiple variables. In cases where values in the model broke physical laws, values were adjusted after the fact to within a range of acceptable minimum values.

In most cases, the sum of the monthly runoff percentages was within a few percentage points, but not equal to, 100%. In order to ensure that 100% of the annual runoff was distributed over the course of the year, individual months associated with each discrete fundamental watershed in the study area were normalized to ensure that their monthly sums equaled 100%.

Estimates of weekly runoff were produced directly as unit runoff rather than as a percentage of longer term runoff as was done for the monthly modeling. These weekly runoff estimates determined the shape of the hydrograph. Continuity was ensured between the annual modeled runoff and sums of weekly modeled runoff by normalizing the weekly runoff values using the sum of the individual weeks and the annual runoff values. This process ensured that the sum of the weekly estimates would match the accepted total annual volume across the study area.

Following the normalization of weekly mean runoff, modeled low and high flow ratios were applied to the weekly mean flow values to produce estimates for the 20% and 80% exceedance flows.

SUMMARY

Estimates of annual, monthly and weekly surface water runoff have been generated for the project study area, covering 142,000 km^2 of west-central Alberta. The study area covers the headwaters and large portions of the Smoky, Athabasca, and North Saskatchewan River watersheds. Significant water resources exist within the study area, with very large amounts of runoff generated from the Rocky Mountains on an annual basis. Total unit runoff decreases with decreasing elevation moving northeast, but significant amounts still exist across much of the study area. Water availability in any given drainage is a function of the watershed area and unit runoff across the watershed. Across most of the study area, drainages should support substantial allocations while still ensuring the needs of the environment are met. In areas with substantial settlement and associated commercial and industrial activities, such as those in the southeastern most portions of the study area, elevated existing demands for surface water are present. Total existing use of water as a proportion of availability is still far less than many areas in southern Alberta with significant water stress.

Highest volumes of surface runoff are present in the study area during the spring and early summer, associated with warming temperatures and associated winter precipitation melt which begins earliest at low elevations, and progresses westward towards the mountains. Convective storms during the summer produce substantial volumes of runoff in areas trending perpendicular to the Rocky Mountains, in the Grande Cache / Fox Creek / Swan Hills region. In watersheds covering these areas, smaller secondary peaks in the hydrograph are typically seen in July to September. The hydrology within any given stream or river in the region is significantly more dependent on the characteristics of the entire watershed providing runoff to it, than on the characteristics in its immediate vicinity.

The accuracy of the modeling work completed is quite good. Results compare favourably with previous work undertaken in northeast British Columbia in support of the development of the NorthEast Water Tool (NEWT). As such the modeling work completed in west-central Alberta should be of suitable quality and accuracy to support the development of a similar decision support tool in west-central Alberta.

DISCUSSION AND RECOMMENDATIONS

The hydrologic modeling work completed in year 2 of the WCAB project effectively synthesized and processed a large amount of hydrologic and other data to produce estimates of surface runoff at annual, monthly and weekly time steps across the study area. Model calibration and validation statistics suggest the modeled estimates provide a robust estimate of hydrologic conditions for normal, or average years. The detailed spatial estimates of runoff generation across the study area make a significant contribution to the understanding of regional hydrology. These estimates were made possible by the availability of high resolution, high quality data products, in particular those representing climate and land cover. These products more accurately represent phenomena including elevation influenced precipitation patterns, and climate and vegetation controls on evapotranspiration. The net result of these factors can be broadly summarized as suggesting runoff generation to be lower at lower elevations, and higher at higher elevations, than previously estimated. The objective of the modeling process was to create a useful, regional product suitable for reference when evaluating water resources or water resource applications.

In all cases, the level of effort put into evaluation of a particular water source should be concomitant with the size, scope and details of any proposed use or the needs of the particular evaluation. The entire modeling process relies on the use of measured, field based observations of stream flow and continued collection of this data is essential to achieve continuous improvements in the management of surface water resources. Specific attention should be devoted to monitoring winter flows in the region if significant and/or growing demand for winter water withdrawals is expected. Spatial gaps in the hydrometric network also exist. Elevated demand for water is expected to be associated with increased hydraulic fracturing activity in the Montney and Duvernay Plays. These plays are found in bands parallel to the Rockies (Figure 1). Limited hydrometric data is available for lower elevation watersheds along the Peace River (both in BC and Alberta), and medium sized (500-1500 km^2) watersheds along the main stem of the Smoky River from the confluence with the Kakwa to Watino. Similarly, medium sized watersheds along the foothills to plains transition from Drayton Valley to Grande Prairie could be better represented. Limited hydrometric data exists for the Swan Hills, north of Whitecourt. Our modeling and the hydrometric data that does exist suggests increased runoff in this area, and drainages originating here flowing into areas of anticipated demand for water would benefit from hydrometric gauging.

In order to generate the highest value from the work undertaken, a decision support system should be developed to provide estimates of surface water resources leveraging the modeled data produced. The

Northeast[22] and Northwest[23] Water Tools in British Columbia are two examples of hydrologic decision support systems providing information on water resources in support of surface water resource management. The modeling products generated by this project have been specifically tailored to support the development of a similar tool. If a tool is developed in Alberta, it should be made publically available. The tool should endeavour to provide hydrologic estimates in a clear and straight-forward manner suitable for a range of potential users including subject matter experts and concerned public stakeholders. The focus of such a tool should be exposing the ability to query and understand surface water resources and existing allocations in a watershed context.

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[22] http://geoweb.bcogc.ca/apps/newt/newt.html

[23] http://www.bcwatertool.ca/nwwt/

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