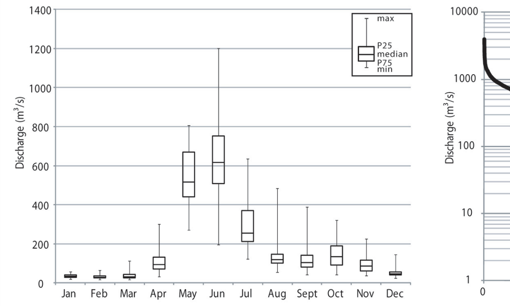
Pine River Watershed

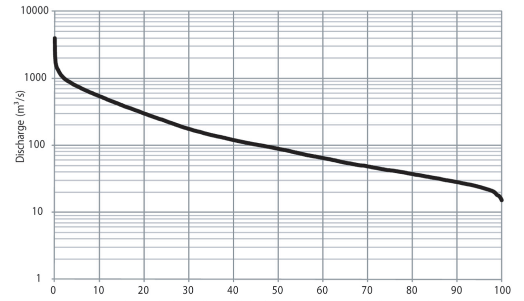
December 2010

Montney Water Project Geoscience BC

Streamflow



Pine River Mean Monthly Discharge, Water Survey of Canada 07FB001 Pine River at East Pine, 1965-2008



Pine River Flow Duration Curve, Water Survey of Canada 07FB001 Pine River at East Pine, 1965-2008

Hydrometric stations operated by the Water Survey of Canada were analyzed to identify several key parameters of flow characteristics in the study area, including:

- total annual flow volumes
- inter-annual variability
- seasonal flow volumes
- drought flows
- peak flows
- flow duration

These analyses provide information useful to understanding flow conditions in the associated watersheds such as intra-annual timing of peak flows, periods of low flow and magnitude of flood and drought flow events. Regression analyses were performed on total annual flows, drought flows and peak flows to relate flow characteristics to watershed size, and can be found in the ungauged watersheds section.

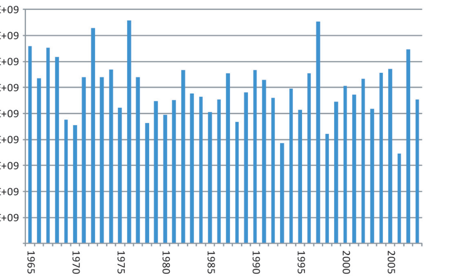
Snow melt dominates contributions to streamflow at the whole watershed scale and for larger tributaries with headwaters in the mountains, with a May/June freshet. A long-tail distribution of late summer / early fall flows suggests sustained ground water supply to base-flow. Median peak flows have the same timing for smaller watersheds (such as 07FB005) but extreme high flows on a monthly basis are found later in the summer and are due to significant summer storm events. Summer rainfall is a significant contributor to annual water volumes in lower elevation watersheds in the Pine.

Low flow years such as those in 1988 and 1992 are found at many of the stations but are not consistent comparitively or in magnitude in relation to other years.

Return Period (yr)	Q (m^3/s)
2	1358
5	1959
10	2462
25	3232
50	3919
100	4711
200	5631

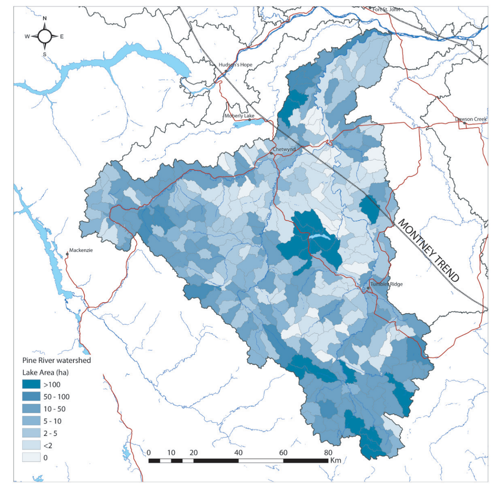
Pine River Flood Stage Predictions, based on Water Survey of Canada peak daily flow 07FB001 Pine River at East Pine, 1965-2008

Flood predictions assuming log-Pearson Type III Distributions



Pine River Total Annual Discharge, Water Survey of Canada 07FB001 Pine River at East Pine, 1965-2008

Lakes



Surface area of lakes within assessment watersheds

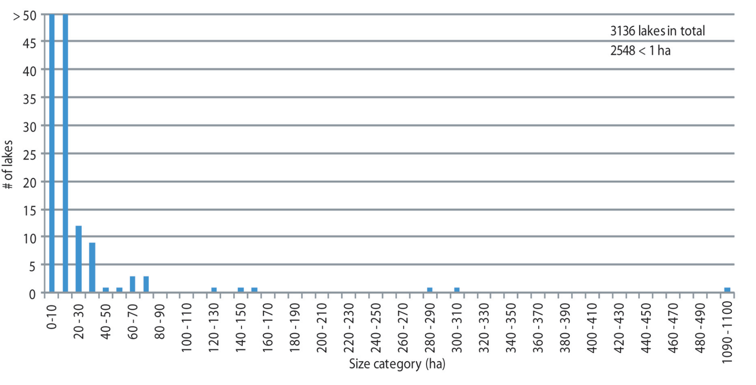
Major lakes in the Pine River watershed include Gwillim and Moose Lakes on the Gwillim River system in the centre of the watershed and Hook, Monkman and the Blue Lakes in the headwaters of the Murray River system in the Rockies. The majority of the over 3000 lakes in the watershed are very small (< 2ha). Few lakes are found near to the major drainages in the watershed.

Bathymetric maps are available for 80 lakes within the watershed including 5 lakes within the Montney play trend (Wasp, Sundance, Jackfish, Big and Stewart Lakes). These bathymetric maps have been collected by the BC Ministry of Environment and provide information such as maximum and average depths, perimeter, area and volume. All bathymetric maps are available in the database for this project.

Bathymetric Information for Lakes in Montney play area.

Lake	Area (ha)	Volume (m^3)	Mean Depth (m)	Maximum Depth (m)
Wasp Lake	67	853900	1.27	2
Sundance Lakes	9.9	195000	2	5
Jackfish Lake	41.9	1436000	3.4	5
Big Lake	71.7	3200000	4.5	10
Stewart Lake	28.3	1100000	3.8	7.5

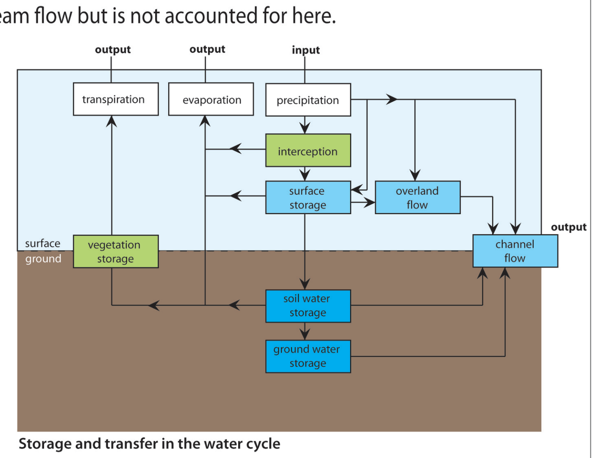
Lake Size Distribution



Water Balance

Creating a water balance for the hydrologic cycle weighs input to the system against outputs. Precipitation (rain and snowfall) are the only input to the system. Variations occur depending on when, where and at what rate precipitation occurs but for this purpose all of the water that enters the watershed leaves on an average annual basis. The three dominant processes that transport water out of the watershed are evaporation, transpiration and channel flow. Water that passes through ground water stores may take several years to exit the system. This complicates coupling water balances on a year to year basis. The relationship between ground water and surface water processes requires more in depth investigation, and in this application only considers ground water in communication with streams. Glacial meltwater may contribute to historical stream flow but is not accounted for here.

ClimateBC and ClimateWNA (see Future Climate section) are models which were used to produce mean annual precipitation maps for the watersheds. These maps were summed to calculate total volume of water input. Gauged streamflow records provide one output calculations, leaving evaporation, transpiration, and loss to groundwater (ET/GW) unknown. The Consultative Group for International Agricultural Research estimate actual evapotranspiration to be in the range of 40 - 50 cm per year.



Storage and transfer in the water cycle

The water balance calculated for the most downstream station on the Pine River (07fb001) indicates a runoff ratio of 53.1% for the watershed as a whole. Much smaller runoff percentages are found in the smaller, mid-elevation watersheds (07fb004, 005, 009) and high values for ET/GW suggest precipitation is slightly overestimated. High elevation watersheds (07fb003, 006) have very high runoff coefficients, due to the presence of barren land and de-forested areas, and precipitation, especially winter snow accumulation could be underestimated as ET/GW values are very low.

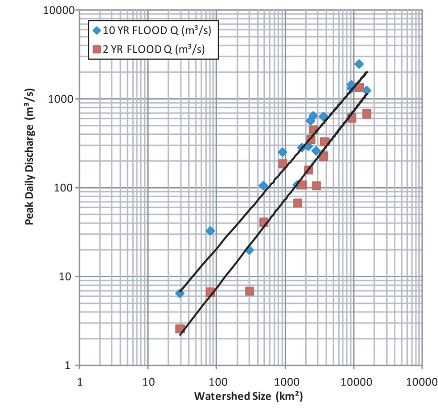
In moderately sloped, forested regions which are representative of much of the watershed, evapotranspiration has first priority for water use for most of the year. Winter snow accumulation and subsequent spring melt allows for replenishment of ground water stores as soil layers become saturated to below root growth levels.

Watershed	Station	Area (km^2)	Precip (cm/yr)	Runoff (cm/yr)	ET/GW (cm/yr)	% runoff	Precipitation 2025 (cm/yr)
Pine	07fb001	11993	92.3	49	43.3	53.1	93.4
	07fb003	2539	103.2	92.3	10.9	89.4	104.5
	07fb004	88	74.1	20	54.1	27.0	74.9
	07fb005	35	72.5	16.3	56.2	22.5	73.2
	07fb006	2364	102	76.8	25.2	75.3	103
	07fb009	503	77.4	25.5	51.9	32.9	78

Average annual water balances for gauged watersheds in the Pine River watershed
Precipitation is based on PRISM data for period 1961-1990.
Runoff is based on WSC data: 07fb001 - 1965-2008, 07fb003 - 1978-2008, 07fb004 - 1978-2008, 07fb005 - 1978-2000, 07fb006 - 1978-2008, 07fb009 - 1983-2008

Ungauged Watersheds

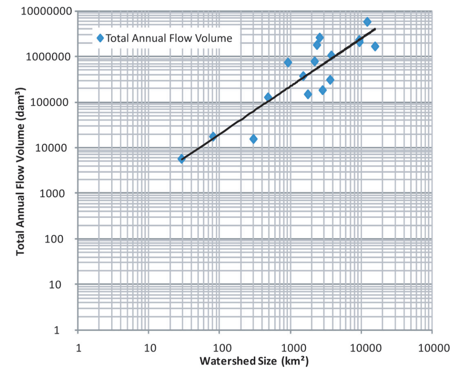
Hydrologic monitoring stations within the Peace region are in most cases located on major drainages. This leaves many watersheds without gauged hydrologic information. Using regression analysis, parameters identified at stations have been correlated with watershed size to develop sets of coefficients for estimating the same parameters in ungauged watersheds, using upstream drainage area.



Flood frequency analysis using a log-Pearson Type III distribution was conducted to determine the peak daily discharge for 17 stations in the study area. Regression analysis suggests that both the 2 and 10 year peak daily discharges are strongly correlated to watershed size. These values can thus be roughly estimated using the equation:

$Q_{Tr} = C \times A^b$ where Q is discharge in m^3/s
Tr is the return period
C and b are coefficients
A is the watershed size in square kilometres.

Flood Return Period Tr (years)	Coefficient C	Coefficient b	R^2
2	0.0752	0.9974	0.9029
10	0.318	0.9067	0.9139

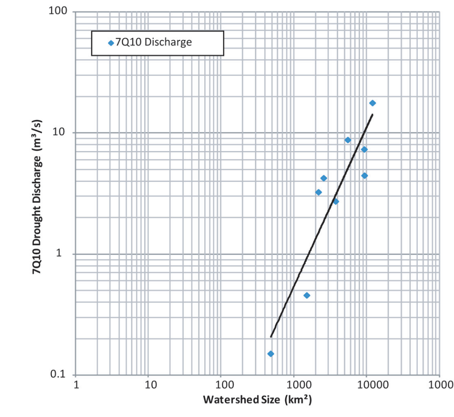


Total flow volume was calculated on a median annual basis using monthly average flow values, for stations with whole year records. Total volume of water flowing through drainages in the study area has a moderate to strong correlation with watershed size. Variation exists due to large differences in precipitation values between some of the watersheds moving from more mountainous regions to lower plains settings. Total flow can be roughly estimated using the following equation:

$V = C \times A^b$

where V is total flow volume in dam^3 ($1\ dam^3 = 1000\ m^3$)
C and b are coefficients
A is the watershed size in square kilometres.

	Coefficient C	Coefficient b	R^2
Total Flow Volume	156.97	1.05	0.8065



Low flow characteristics at monitoring stations were determined using the 7 day low flow period with 10 year recurrence interval, which is commonly used as a general indicator of drought conditions. These values were calculated for 11 stations and compared with other published values for these stations where available. No relationship was found ($R^2=0.2$) when correlating 7Q10 values with watershed size for all of the stations. Moderate to strong correlation was found when all stations other than those in the Kiskatinaw and Pouce Coupe River watersheds were considered*. This correlation used only larger watersheds as inputs as smaller drainages are seasonaly intermittent. Drought discharge can be estimated in larger (>500 km^2) watersheds in the foothills region by the following equation:

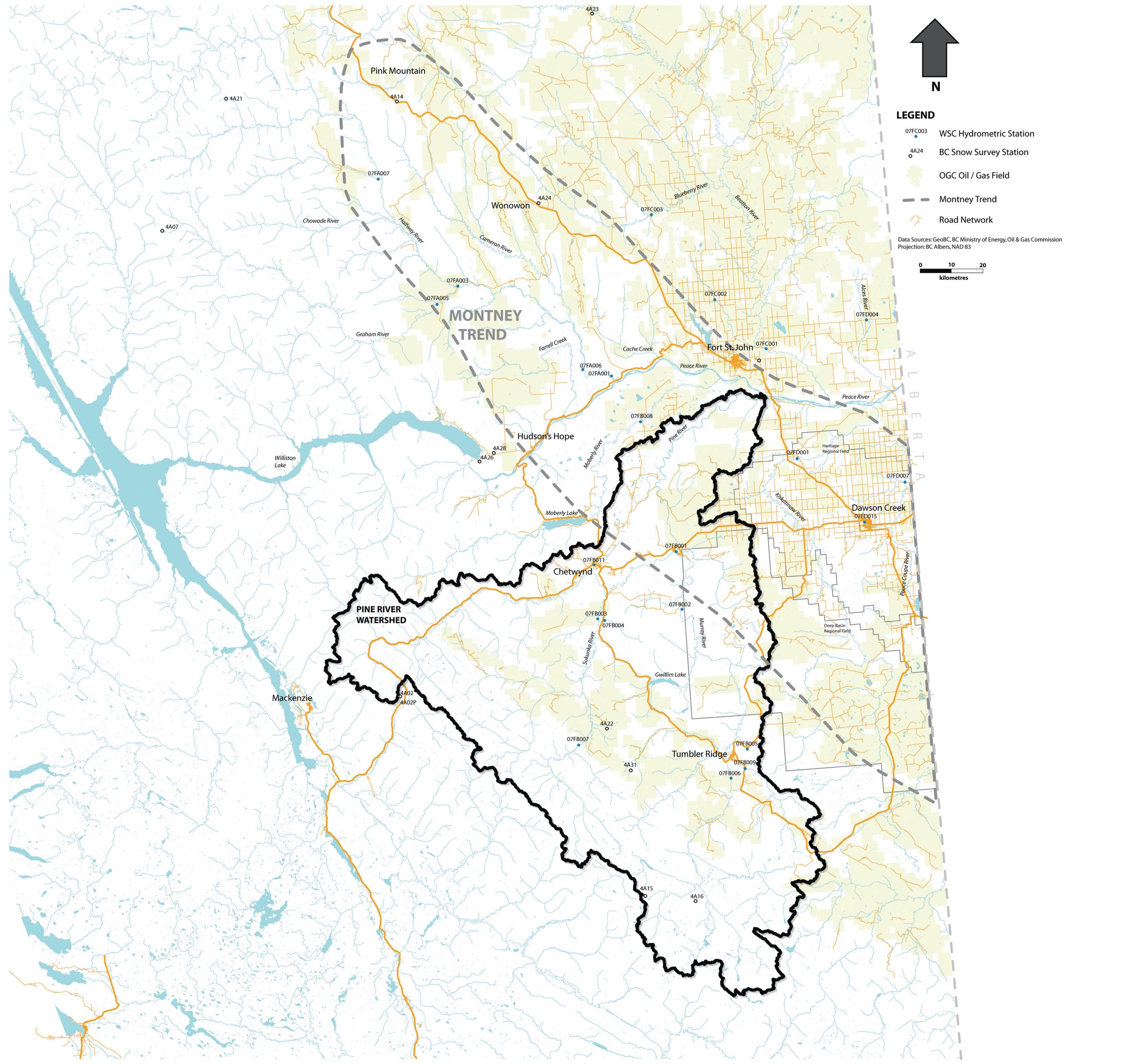
$$7Q10 = C \times A^b$$

where 7Q10 is the seven day low flow (m^3/s) with a return period of 10 years
C and b are coefficients
A is the watershed size in square kilometres.

	Coefficient C	Coefficient b	R^2
Drought Flow (7Q10)	0.00006	1.3146	0.8317

Methodology after British Columbia Streamflow Inventory, BC Ministry of Environment, 1998.

*refer to BC streamflow inventory section on Northeast Plains Low Flow zone for the Kiskatinaw and Pouce Coupe watersheds.

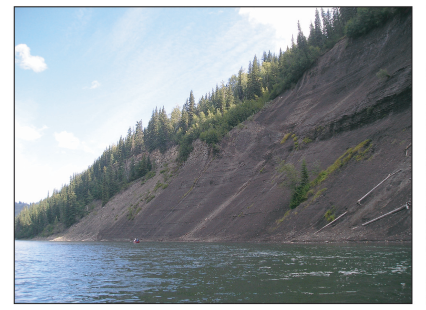
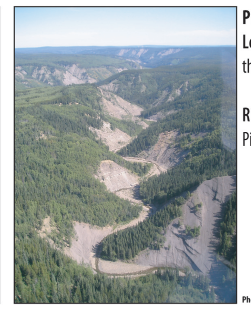


Pine River Watershed Overview

The Pine River originates in the Rocky Mountains of British Columbia and flows into the Peace River near the community of Taylor. The river drains an area roughly 12,100 km^2 in size and has a total length of 290 km. The majority of the watershed is forested and its major tributaries include the Murray, Sukunka and Wolverine Rivers. Gwillim Lake is the watershed's largest lake, located in the foothills of the Rocky Mountains.

The watershed is home to the communities of Chetwynd and Tumbler Ridge, both of which are service centres for a diverse range of industries – logging, sawmills and pulping, natural gas development, production and transportation, coal mining, wind generated power, ranching and farming. Other activities include those related to recreation and tourism. Coal mining is concentrated in the headwaters, while natural gas exploration and development activity is scattered throughout the watershed, with specific concentrations of interest in the lower portion where the Pine borders the Kiskatinaw and Moberly River watersheds.

The Pine River is the primary water source for Chetwynd, while Tumbler Ridge draws its water from wells. Within the watershed, Highways 29 and 97 intersect Chetwynd and a rail line branches off in three directions: north to Fort St. John, east to Dawson Creek and west to Prince George.

Photos:
Left: Cretaceous shales exposed along the Pine River.
Right: Deeply incised tributary in the Pine River watershed.

Photo credit: Derek Brown, Strategic West Energy Ltd.

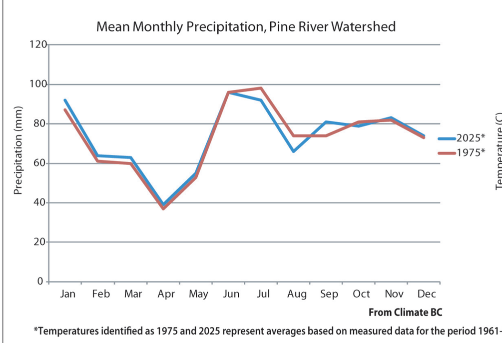
Peace Region

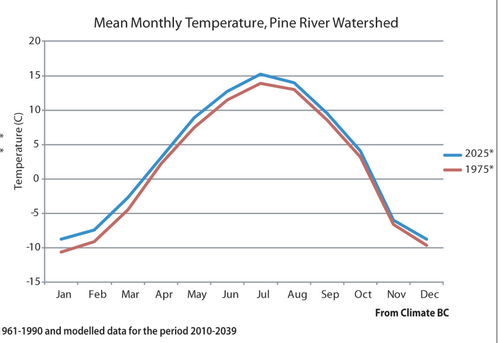
The Peace River originates in the mountains of British Columbia and forms the southwestern branch of the Mackenzie River System. From its headstreams in the Rocky Mountains the Peace River flows northeast into Alberta and eventually empties into the Slave River, which enters the Arctic Ocean through the Mackenzie basin. The Peace River's total course from the head of the Finlay is 1,923 km, and it covers a total area of 302,500 km^2. The B.C. portion of the Peace River basin covers an area of 41,600 km^2.

The largest tributaries of the Peace River basin in B.C. are the Pine, Halfway, Beatton, Moberly, and Kiskatinaw Rivers. The Peace River is influenced by BC Hydro's WAC Bennett and Peace Canyon Dams in the upper reaches of its drainage. These hydro-electric dams produce 31% of British Columbia's hydro-electric power.

The basin includes the major communities of Fort St. John, Dawson Creek, Chetwynd, Mackenzie, Tumbler Ridge, and Hudson's Hope. Much of the basin is forested with significant natural gas exploration and production in the Montney shale gas play, a northwest to southeast trending geologic zone underlying the river basin from Pink Mountain to the BC border at Dawson Creek. Agricultural production occurs near the communities of Fort St. John and Dawson Creek. Natural gas, mining, agriculture, forestry, and tourism are the basis of the local and regional economies with mining and natural gas development being the biggest employers in the region.

Climate





*Temperatures identified as 1975 and 2025 represent averages based on measured data for the period 1961-1990 and modelled data for the period 2010-2039

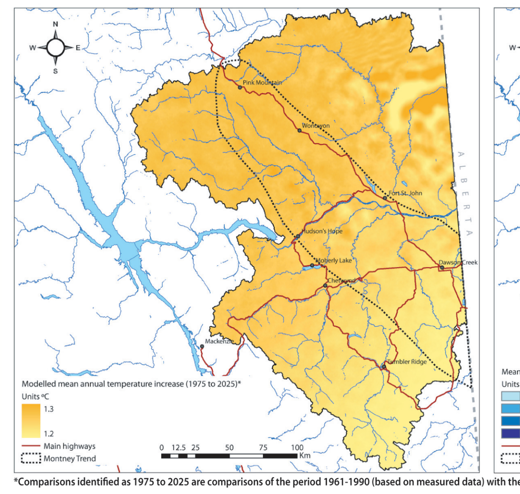
In the Pine River watershed, precipitation is reasonably consistent over the year with lows during late winter / early spring. Mountainous regions receive the majority of precipitation during the winter months while more low lying areas receive significant summer rains.

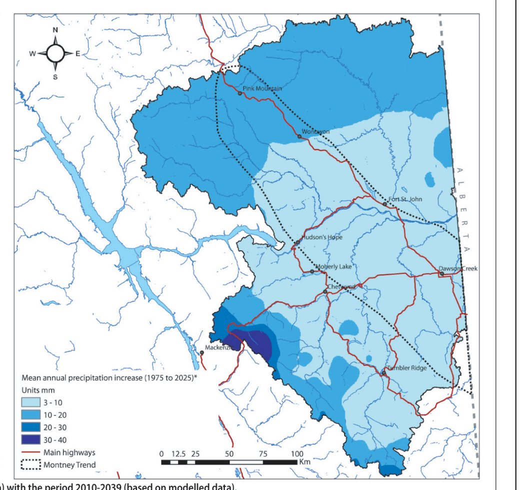
At Pine Pass, an automated snow pillow collects information on snow accumulations. Peak accumulation regularly occurs in April. Snow water equivalent (swe) is a standardized method of communicating the water volume in snow pack considering depth and density.

There are 14 other snow monitoring locations within or very near the Montney Water Project area, the majority of which are high in the mountains in the headwaters of the watersheds. Station 4A20 in the headwaters of the Murray River provides a good record of snow accumulation.

Environment Canada, and the BC Ministries of Transportation and Forests operate weather stations throughout the Peace region. Climate data from these stations is available in the database for the project.

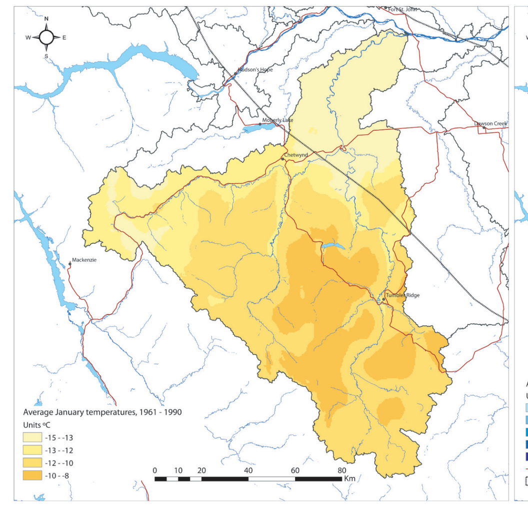
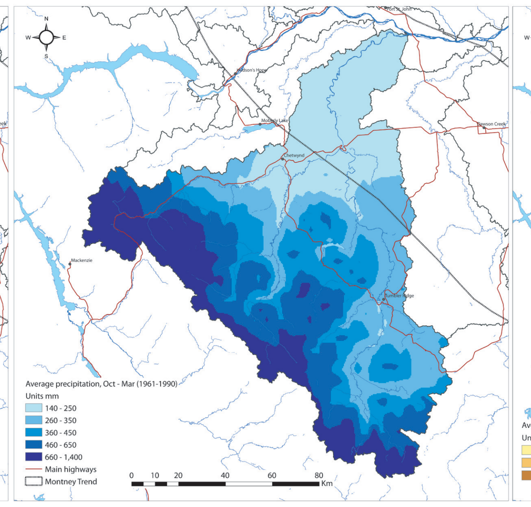
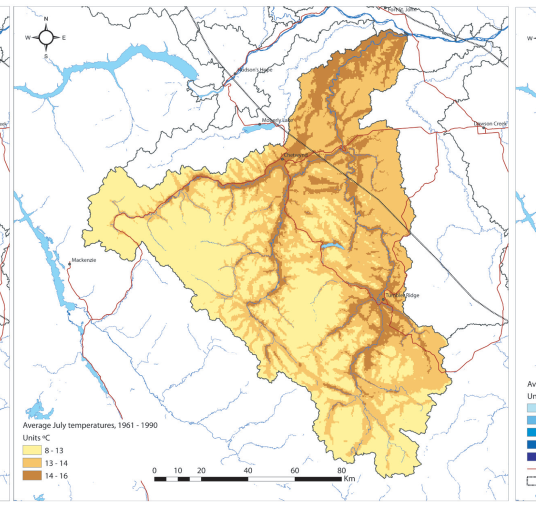
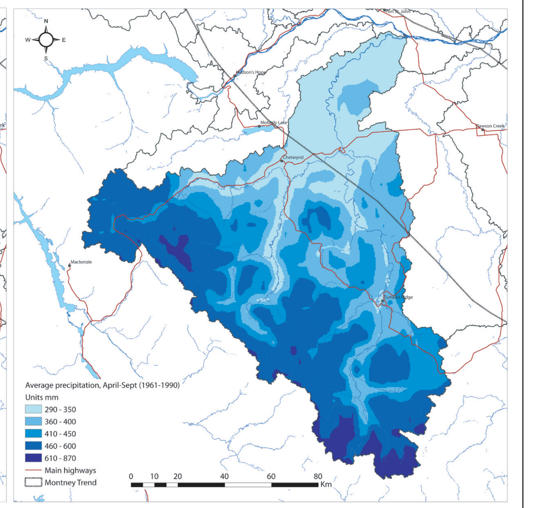
Future Climate Model (2025)





*Comparisons identified as 1975 to 2025 are comparisons of the period 1961-1990 (based on measured data) with the period 2010-2039 (based on modelled data).

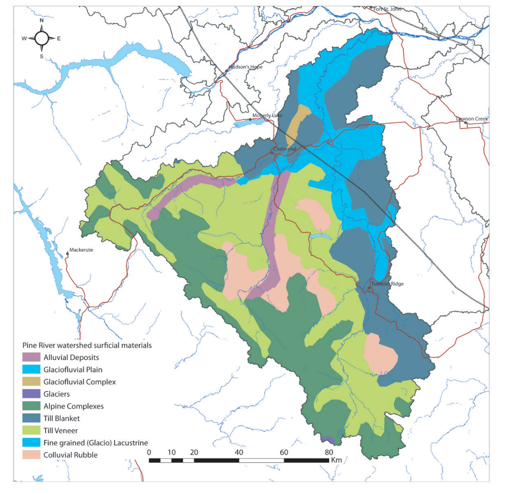
ClimateBC is a modelling program developed by researchers at the University of British Columbia in collaboration with the BC Ministry of Forests, in order to provide high resolution climate data for resource management in Western Canada. Recent updates have expanded the scope of the project to Western North America in ClimateWNA. These products are based on PRISM Climate Data developed by Oregon State University, with improved elevation related variations, additional modelled parameters, and the introduction of forward looking climate predictions based on a variety of global circulation models. The period of normals (1961-1990) has been compared with predicted values for the period 2010-2039 using the CGCM2-A2x global circulation model. Mean annual temperatures as well as mean annual precipitation is expected to increase across the Peace region. Temperature is expected to increase in a relative way, consistent across the region, while the magnitude of precipitation will vary.

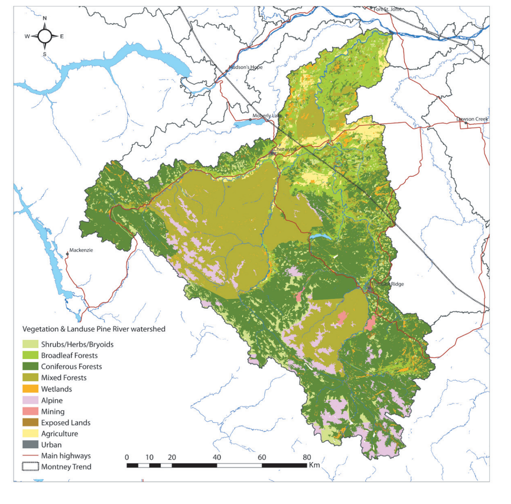





Seasonal Climate, 1961-1990 averages: **January Mean Temperature** | **Winter (Oct-Mar) precipitation** | **July Mean Temperature** | **Summer (April-Sept) precipitation**

All data from ClimateBC

Surficial Materials and Land Use





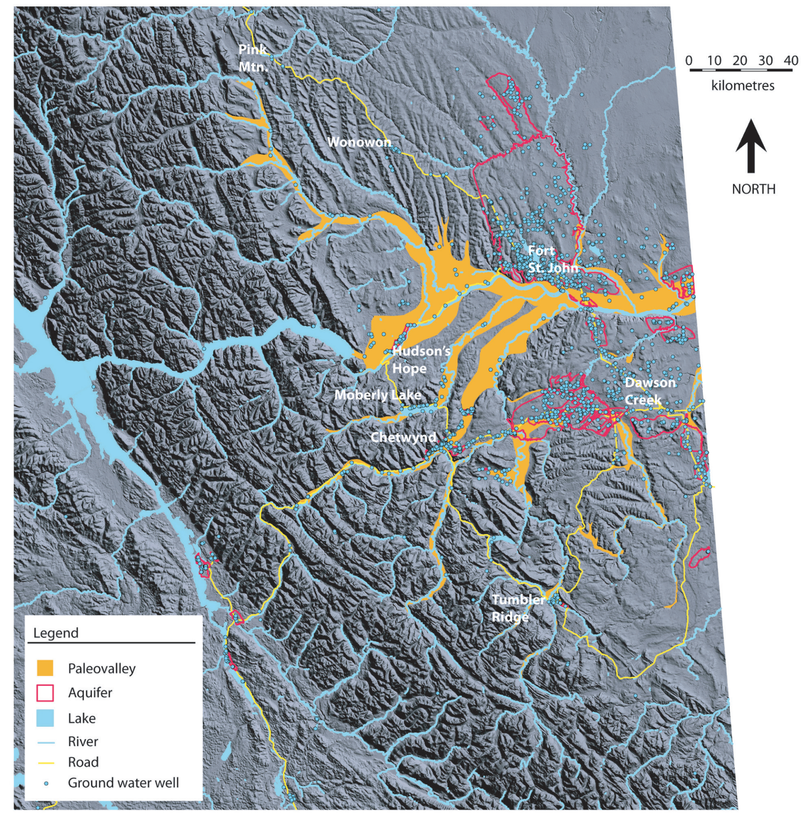
Glacial sediments are the dominant surficial material type in the Pine River watershed. The map to the left is coarse scale, national mapping at 1:5,000,000 scale. As part of the Montney Water Project more detailed mapping is being compiled into digital format. N.T.S. Map Sheets 94A and 93P will be available at 1:250,000 and 94A/SE and 93P/NE will be available at 1:50,000. Surficial material type is an important component for hydrological modelling and can provide other operational benefits such as construction aggregate resource identification.

The B.C. Ministry of Forests Vegetation Resources Inventory provides detailed stand level mapping including tree species, age and height estimates. Coverage of the Montney Water Project area is not complete. GeoBC provides Baseline Thematic Mapping, which reflects current conditions as of the date of imagery of the product (1992) which is out of date for time sensitive or transitional areas (e.g. burned, logged, etc). A third data set useful in characterizing vegetation characteristics is the Biogeoclimatic Ecosystem Classification (BEC) Program which classifies the province into zones based on forest type, moisture and temperature.

The Pine River watershed is mostly forested, with broadleaf and mixed forests in lower elevations and coniferous in the mountains. Wetlands are more prevalent in the downstream portion of the watershed. There are significant alpine areas as the watershed extends west into the Rocky Mountains. Extensive coal mining occurs near Tumbler Ridge.

Data Sources:
Surficial Materials of Canada, GSC Map 1880A
Vegetation Resources Inventory, BC Ministry of Forests and Range
Baseline Thematic Mapping, GeoBC
Freshwater Atlas, GeoBC

Ground Water and Paleovalleys



Summary of Water Well Yields for the Pine River Watershed

Aquifer	n	Minimum US GPM	Minimum L/s	Maximum US GPM	Maximum L/s	Median US GPM	Median L/s	# of Artesian
Undifferentiated	26	0.5	0.03	105.0	6.62	15.0	0.95	1
Bedrock	74	0.5	0.03	120.0	7.57	6.6	0.41	1
Unconsolidated	113	0.2	0.01	4940.0	311.67	12.0	0.76	0

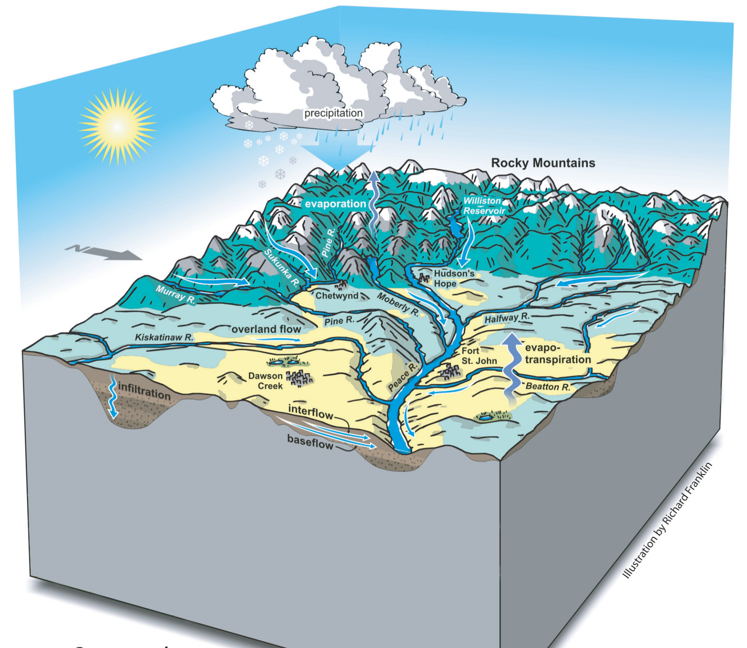
The majority of the Peace Region is covered by glacial and interglacial sediments deposited during repeated glaciations in the Quaternary Period. These sediments vary significantly in thickness. In some locations, bedrock is covered by a thin veneer of sediment or is exposed at surface. In others places, such as in pre-glacial buried paleovalleys, these sediments can be over 100 m thick. In many cases modern rivers occupy pre-glacial river valleys and the thick unconsolidated valley-fill sediments may host aquifers with significant volumes of water. Areas with thick Quaternary sediments are targets for further aquifer evaluation.

The BC Ministry of Environment maintains a database of water wells drilled in the province and delineates ground water aquifers based on this database and other geologic and hydrogeological information.

As part of the Montney Water Project, geologic analysis is being performed by the B.C. Ministry of Energy to more accurately map the thicknesses of Quaternary sediments that may have potential for hosting water. The B.C. Ministry of Environment is collecting additional water well information, which is being used to update the online water well database and refine mapping of aquifers in unconsolidated sediments and bedrock.

This map illustrates the geographic distribution of water wells, currently mapped and classified aquifers and areas that likely have thick Quaternary sediments which will be evaluated for their aquifer potential.

Data Sources:
Ground water Aquifers, B.C. Ministry of Environment
Paleovalleys, B.C. Ministry of Energy unpublished
Ground water wells, B.C. Ministry of Environment
Freshwater Atlas, GeoBC



Conceptual Diagram of Hydrologic Cycle (scale varies)

For the surface water component of the Montney Water Project, several parts of the water cycle have been assessed and described. Themes include flow characteristics in gauged watersheds, lake size distributions, climate and projected future climate, groundwater, vegetation and surficial geology characteristics, water balances and discussion of estimating conditions in ungauged watersheds. Posters have been created highlighting key aspects of these themes, in each of the major watersheds in the region. Supporting information is available in a report accompanying the poster series, and includes additional analyses, more thorough discussion, and references.

Montney Water Project Overview:

The Montney Shale Gas Play in northeast British Columbia is a world-class unconventional natural gas resource development. Operations in the Montney are moving into development drilling, which will increase the demand for water and deep sites for the disposal of fluids. Provincial, First Nations and local governments, industry, communities, and environmental groups all want to ensure that water sources are carefully managed during natural gas development. These stakeholders require detailed, scientifically-based and unbiased information about existing water resources to make appropriate policies, regulations and permit decisions as well as to support public discussion on issues related to water use.

In response to this need, Geoscience BC met with industry and government in early 2010 and began a collaboration to undertake water studies in the Montney area. The Project is designed to create a comprehensive database of surface water, ground water and deep saline aquifers in the Montney area.

Phase I of the study focuses on collecting, analyzing and interpreting available water information in the Montney region.
If required, a second phase of the study will focus research on addressing remaining data gaps. Three components of the project are as follows:

- Surface Water: Collection and presentation of data on surface water system (lakes, streams and wetlands) and processes that control availability of water (timing and amount). Analysis of these components provides insight into important aspects of the regional water cycle, including seasonal flow conditions, climate, vegetation and land use characteristics.
- Unconsolidated and shallow bedrock: Unconsolidated and shallow bedrock aquifers host a significant source of water in the Peace Region. These aquifers are best developed in areas with thick Quaternary age sediments often associated with buried paleovalleys. This component of the MWP has focused on compiling a database of available surface and subsurface data that elucidates the thickness of the unconsolidated drift and the bedrock topography. These data will be used to model and map major drift thickness trends and bedrock topography which represent high potential target areas for water in unconsolidated aquifers.
- Deep bedrock: Define and characterize candidate aquifers (water sources) and potential deep disposal zones, providing a general description and indicating the homogeneity of each aquifer. The work focuses in zones deeper than domestic water wells and in zones typically explored by the oil and gas sector, greater than 250 m below surface. Compilation of existing hydro-stratigraphic data and development of groundwater flow models for select areas will assist in the identification of regional aquifers with suitable reservoir characteristics, fluid content, and capacity to be viable source/disposal candidates.

Montney Water Project Partners:

ARC Resources Ltd. | ConocoPhillips Canada | Progress | British Columbia – The Best Place on Earth | devon | encana natural gas | Shell | Talisman Energy | scek | Geoscience BC

Geoscience BC is an industry-led, industry-focused not-for-profit society. Its mandate includes the collection, interpretation and marketing of geoscience data and expertise to promote investment in resource exploration and development in British Columbia. Geoscience BC is funded through grants from the Provincial Government and works in partnership with industry, academia, government, First Nations and communities to attract mineral and oil & gas investment to BC.

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