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Desktop Watershed Characterization Resources and Methods for British Columbia

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Dave Reid. View of the Coldwater River next to the Coquihalla Highway, summer of 2023.

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EXECUTIVE SUMMARY

A desktop watershed characterization is often a first step in gathering knowledge about a watershed. The primary objective of a watershed characterization is to provide context surrounding how the watershed functions and what stressors may be actively (or historically) influencing watershed processes and dynamics through space and time. In contrast to a *watershed assessment*, a characterization is broader in scope and is not indicator-based.

Over the past decade, a wide array of new tools and resources have become available to support watershed characterizations. This document provides an update and expansion on a previous report titled: *Desktop watershed characterization methods for British Columbia* (Pike and Wilford, 2013).

The availability of information is constantly improving, and this 2024 report provides an updated, comprehensive list of publicly available resources, data sources and information to better understand watersheds in British Columbia. In addition to a list of resources, this report contains a summary of relevant questions to ask during the process of developing a watershed characterization, with key resources tied to the questions to enable users to most easily locate and connect different tools to objectives. The report concludes with an example characterization which works through nearly all the characterization items described below.

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ACRONYMS

AFN	Assembly of First Nations
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
BC CDC	BC Conservation Data Centre
BCSEE	BC Species and Ecosystems Explorer
BEC	Biogeoclimatic Ecosystem Classification
CABIN	Canadian Aquatic Biomonitoring Network
CCCS	Canadian Centre for Climate Services
DEM	Digital Elevation Model
EFN	Environmental Flow Needs
EMS	Environmental Monitoring System
ENSO	*El-Niño* Southern Oscillation
EOSDIS	Earth Observing System Data and Information System
FIDQ	Fisheries Inventory Data Query
FTP	File Transfer Page
GCM	General Circulation Model
GIS	Geographical Information System
IDF	Intensity-duration-frequency
LiDAR	Light Detection and Ranging
MAD	Mean Annual Discharge
MAFF	Ministry of Agriculture, Food, and Fisheries
MASL	Meters Above Sea Level
NASA	National Aeronautics and Space Administration
NRCan	National Resources Canada
NTS	National Topographic System
PAVICS	Power Analytics and Visualization for Climate Science
PCIC	Pacific Climate Impacts Consortium
PDO	Pacific Decadal Oscillation
PRISM	Panchromatic Remote-sensing Instrument for Stereo Mapping
SEI	Sensitive Ecosystems Inventory
SSP	Shared Socioeconomic Pathway
SWE	Snow Water Equivalent

1. INTRODUCTION

Understanding the formative processes, pressures, histories, and values present in a watershed can be a difficult task. In British Columbia (B.C.) it is not uncommon for most watersheds to have a complex history of interacting disturbances, recoveries, and cumulative effects that may affect a wide range of key processes. Similarly, there is often significant spatial and temporal variability in many natural watershed processes across the hydrologic regions of British Columbia. The challenge for examining and describing watershed processes and function, therefore, lies in obtaining this contextual understanding for a watershed of interest.

A desktop watershed characterization (Pike and Wilford, 2013) is often a first step in gathering watershed knowledge and aims to support the gathering and synthesis of as much information as possible about a watershed. The primary objective is to provide context surrounding how the watershed operates and what stressors may be actively (or historically) influencing watershed processes and dynamics. A watershed characterization is often a component of, and starting point for, many other watershed analysis methodologies. For example, forest management-based watershed assessments, water balance analysis, habitat evaluations and even hydrologic modelling all use common information that an initial, desktop watershed characterization can provide. It is important to distinguish that a watershed characterization is different from a watershed assessment. An assessment is primarily indicator-based and focused on specific sub-components of watershed dynamics, such as hydrology or geomorphology usually pertaining to a specific land-use sector. Examples of these indicator-based approaches include the coastal watershed assessment procedure (Province of B.C., 1995) and the channel assessment procedure (Province of B.C., 1996). Another example is the current joint professional guidance for conducting watershed assessment and management of hydrologic and geomorphic risk in the B.C. forest sector (see: Engineers and Geoscientists British Columbia website). Thus, conducting a characterization does not replace these methods of watershed assessment or other water analyses, but rather, the watershed characterization can be considered a common first step in developing a better understanding of a watershed. Desktop watershed characterizations conducted in advance of fieldwork also allow for strategic planning of field activities and/or monitoring projects, thereby increasing efficiency and reducing costs.

This document updates information and resources found in the report "Desktop Watershed Characterization Methods for British Columbia" (Pike and Wilford, 2013). This update also considers additional topics not covered in the 2013 report, such as climate change, aquatic ecology, groundwater, geology/geomorphology, and cultural values. The purpose of this report is to highlight current tools and sources of watershed information [Section 2], provide a template of potential disturbance drivers to consider in relation to different information sources, and ultimately create a list of questions that can be used to characterize a watershed depending on primary characterization objectives [Section 3]. The report also, by way of example [Section 4], demonstrates how the template and resources can be used to generate a better understanding of the Clinton Creek watershed.

This document is intended for anyone who wishes to use a desktop approach to initially characterize a watershed. It is important to note that some of the featured desktop methods may not work at certain mapped scales, and some datasets may be limited in coverage in some areas of the province. This report does not include a summary of Indigenous knowledge sources or Indigenous-derived approaches to watershed characterizations. The techniques featured are intended to be a first-order approximation of watershed characterization and should not displace the need for more precise information where and when required.

2. ONLINE RESOURCES

There are many open access desktop tools and information resources available for watershed characterization in B.C. This section provides an overview on accessing information sources. Resources discussed include the following categories: reports, spatial data resources, climate and climate change information, surface water (hydrometric), groundwater data and aquifer information, water licences, permits and demand (use), fish and aquatic habitat, terrestrial ecological information, water quality information, geomorphic and geologic information, historical watershed disturbances, land titles, land use information, and socio-cultural values.

2.1 Data Sources

2.1.1 Reports

Existing reports and other publications provide important insights into the characteristics of a watershed and may offer information about past projects in the area. Reports may include prior watershed characterizations or information on specific watershed attributes, compiled to support a permit application or as part of an investigation. A list of potential sources of reports is provided in Table 2.1, together with suggested search terms (e.g., location of interest) that can assist in identifying available resources.

EcoCat: The Ecological Reports Catalogue is maintained by the Province of B.C. and represents a large repository for reports and related files such as maps, datasets and published inventories on ecological activities in B.C. Report topics range in scope from aquatic species and habitats, terrestrial species and habitats, floodplain mapping, reservoirs, groundwater and vegetation. A collection of watershed assessments can be accessed in EcoCat by selecting "*Advanced Search*," then scrolling to the bottom of the page under "*Water Information*," clicking "*Watershed Assessment Studies*." Reports can also be searched spatially by selecting the "*Search for reports using a map*" on the main page. More detailed instructions on how to access watershed assessments in EcoCat are provided by Carver (2008).

Additional water-related reports and research projects include the Water Science Series, which is a repository of scientific reports that relate to the understanding and management of B.C.'s water resources, and the Watershed Research page, which hosts documents pertaining to multiple long-term watershed studies, such as the Upper Penticton Creek Watershed Experiment and the Carnation Creek Watershed Experiment. The summary index for *Streamline Watershed Management Bulletin* (see URL links in the left hand margin), provides access to all back issues of Streamline and the watershed centric information published between 1996 and 2013.

Wider-ranging in topic and encompassing government publications from across Canada, the Government of Canada Publications portal searches their catalogue of hundreds of thousands of publications, most of which are accessible in digital format.

Geosciences BC, which generates independent, publicly available, geoscience research and data about B.C.'s minerals, energy, and water resources, provides a search function on their website for projects and reports and can filter specifically for water-related resources queries.

EPICBC contains resources related to past environmental assessments across B.C. Environmental assessment locations are available via a map selection tool, while projects and associated documentation are searchable within an associated list. Reports connected with projects often contain detailed information pertinent to watershed characterizations.

Forest stewardship plans (FSPs) are map-based, landscape-level plans of potential forest development activities that are intended to take place in a watershed or other planned area. FSPs can be an informative source of historic/current land cover, habitat, surface hydrology, and other physical features of a watershed, which can provide indications of potential future disturbance from forest-related activity. The FSP Tracking System accepts and tracks Forest Stewardship Plans submitted electronically to the B.C. Ministry of Forests. Users external to government (including major licensees, woodlot licensees, community forest agreement holders, and pulpwood agreement holders) can access the FSP Tracking System but need to have a BCeID (user ID). To obtain a user ID, a user must complete the BCeID Enrollment Process. Alternately, some FSPs are available online without having to go through the FSP Tracking System and instead through a webpage search (e.g., Google). A search is best achieved by knowing the Time Supply Area (TSA), Tree Farm Licence (TFL) and/or Community Forest Agreement (CFA), for the watershed of interest.

Lastly, academic information found through sites such as Google Scholar and ResearchGate, and other scholarly journals provide comprehensive general searches for any study location. Google search is particularly useful to find grey literature, such as reports, pamphlets, and personal blogs, which can provide links to additional information on the study area or contact information for researchers who have conducted research in the past. It is important to note that Google has added *Artificial Intelligence (AI) results* to their searches, and as such, it is recommended that users explore (verify) the sources that were used to generate the AI results. Google Scholar typically only provides links to peer-reviewed journal articles which may or may not be open access.

Table 2.1: Resources for exploring past reports and characterizations.

Data Source	Website	Search Terms
EcoCat: *The Ecological Reports Catalogue*	https://a100.gov.bc.ca/pub/acat/public/welcome.do	Location
EPIC	https://projects.eao.gov.bc.ca/	Location, project type (e.g., 'mine")
Forest Stewardship Plans	Forest Stewardship Plans - Province of British Columbia (gov.bc.ca)	Location, TSA, or TFL of interest
Geoscience BC	https://www.geosciencebc.com/our-research/	Location or topic of interest
Google/Google Scholar	https://scholar.google.com	Location or topic of interest
Government of Canada Publications	https://publications.gc.ca/site/eng/home.html	Location or topic of interest
Streamline Index	https://confluence-jwsm.ca/index.php/jwsm/article/view/45	Location, topic of interest
Water Science Series	https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-science-data/water-science-series	Topic of interest
Watershed Research	https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-science-data/watershed-research	Location, topic of interest

2.1.2 Spatial Data Resources - Vector and Mixed Data

There are several information sources available providing access to Provincial or Federal datasets in a spatial (e.g., mapped) format. Spatial data comes in two data forms: raster and vector. Vector data includes points, lines, and polygons represented by a series of coordinates. Vector data is typically provided as shapefiles or KML files (e.g., road networks, park areas, or station locations). In contrast, raster images use pixels to represent spatial data for an area are typically provided as *.tiff* files. Raster data is discussed in Section 2.1.3. This section focuses on vector data resources. Table 2.2 contains a list of vector-focused or mixed (i.e., raster and vector) spatial data resources.

Table 2.2: Vector and mixed spatial data resources.

Data Source	Website	Data Type	Search Terms, if applicable
BC Map Services (from BC Data Catalogue)	https://www2.gov.bc.ca/gov/content/data/geographic-data-services/web-based-mapping/map-services	Basemap data	Location and variable of interest
GeoGratis	http://geogratis.gc.ca/index.html	Vector and raster	Location
iMapBC	https://maps.gov.bc.ca/ess/hm/imap4m/	Vector and raster	Variable of interest (e.g. 'aquifer'; location
MapPlace	https://www2.gov.bc.ca/gov/content/industry/mineral-exploration-mining/british-columbia-geological-survey/mapplace	Basemap data	Location

The Province of B.C. hosts several repositories of spatial data useful for a wide range of purposes. The B.C. Data Catalogue is the most comprehensive database containing land use information in the province. iMapBC is an online application that allows users to access and visualize information stored in the BC Data Catalogue. Data layers can be viewed in this online application as well as exported and saved to view in Google Earth (see Webmap library layers below). Links for data layers in the B.C. Data Catalogue accessed with iMapBC are provided in the "*Metadata URL*". A user manual and frequently asked questions (FAQ) document are available for iMapBC. The B.C. Data Catalogue can be accessed directly (without iMapBC) allowing users to search for and download spatial information.

The B.C. Webmap Library is an example of a downloadable dataset in the B.C. Data Catalogue. The webmap library is particularly useful because it is a *KML* file that is user friendly and intended to be opened and used in Google Earth. The files contain key spatial data layers including freshwater and marine information, soil and geological information, and land-use that users can easily navigate and view within the Google Earth interface.

Provincial spatial data is also available from the BC Map Services page which provides links to the BC Geographic Warehouse Map Web Service, the BC Imagery Web Map Services, and the BC Base Mapping Tiles Services. Other map-based search portals include MapPlace, catered specifically towards geoscience and mineral resource data and maps in B.C.

GeoGratis is the main repository of spatial data for the Government of Canada. The GeoGratis landing page provides access to: i) the Open Government Search tool, which uses keywords to search Natural Resources Canada products; ii) the Geospatial Product Index, a map tool that allows users to search

imagery, raster, vector and elevation data from across Canada; iii) the Toporama Interactive Map, which allows users to navigate, measure, draw on and ultimately download data from several key basemaps layers (both raster and vector); and, iv) the Geospatial Data Extraction tool, which allows users to select and download spatial data based on areas of interest defined using locations such as street addresses, city/town names, postal codes, geographical features (e.g., lakes, mountains, etc.), and National Topographic System (NTS) map grid numbers.

2.1.3 Spatial Data Resources – Raster-Based, Remote Sensing and Physiographic Data

Remotely sensed data consists of imagery collected from aircraft and satellites, and subsequent products derived from this imagery. Access to satellite imagery at high spatial and temporal resolutions has become more readily available in the last decade. While data from many satellites remain proprietary and can only be accessed for a fee, there are many sources of high-quality spatial data that are free for use (also known as free optical satellite imagery, or FOSI) and can form the basis for advanced spatial analysis of a watershed. Remotely sensed data is typically in raster format. Imagery, such as air photos and satellite images, are key examples of raster data. A list of remote sensing and physiographic data is provided in Table 2.3.

Table 2.3: List of resources for accessing remotely sensed and topographic data.

Data Source	Website	Data Type	Search Terms (if applicable)
Air Photo Viewer	https://a100.gov.bc.ca/ext/mtec/public/products/airPhoto	Air photos	Date and location
Copernicus Data Space Ecosystem	https://dataspace.copernicus.eu/	Satellite imagery	Date and location
Earthdata Search	https://search.earthdata.nasa.gov/search	Satellite imagery	Location
Earth Explorer	https://earthexplorer.usgs.gov/	Vector and raster	Location
GeoGratis	http://geogratis.gc.ca/index.html	Satellite imagery, vector and raster	Location
Google Earth/ Google Earth Timelapse	https://earth.google.com/web/	Satellite imagery	Location
LiDAR Data Portal	https://governmentofbc.maps.arcgis.com/apps/MapSeries/index.html?appid=d06b37979b0c4709b7fcf2a1ed458e03	LiDAR point clouds	DEM, point cloud, and location
Planet Explorer	https://www.planet.com/	Satellite imagery	Date and location

The Province of B.C. provides access to freely available LiDAR data (light detection and ranging data) that covers select portions of the province (with plans to have all of B.C. flown by the end of the decade). Instructions and information about the LiDAR data are available from this link, but often a GIS software program is required for processing and analyzing the LiDAR data.

Air photos dating back to as early as the 1940s are available for British Columbia. Air photos can be viewed and ordered from the Air Photo Viewer or opened in Google Earth. Air photos can also be searched online through the BC Gov Imagery Finder. Additionally, physical copies of air photos showing a watershed of interest may be available at municipal archives and/or university libraries (e.g., the University of British Columbia, Geographic Information Centre, and the University of Northern British

Columbia, Geoffrey R. Weller Library Air Photo Collection). Air photos are useful to show spatial disturbances, recovery and often changes in stream channels over time. Depending on borrowing policies and procedures, which may include a fee, air photos can also be scanned for use.

GeoGratis is an excellent source for physiographic information and is the main repository of spatial data for the Government of Canada. Of key interest within GeoGratis are the Toporama Interactive Map. This tool contains features that allow users to navigate, measure, draw on, and ultimately download data from several key basemap layers (both raster and vector). The Geospatial Data Extraction tool allows users to select and download digital elevation models (DEMs) as raster files, along with other vector data for a given area of interest.

Spatial data applicable to B.C. is also available on other governmental platforms from around the world. From the United States, NASA and the USGS host Earthdata Search and EarthExplorer, respectively. Earthdata Search provides access to more than 33,000 Earth observation data collections from NASA's EOSDIS, as well as from other U.S. and international partner agencies. Data includes imagery from satellites such as Sentinel, ASTER and CRYOSAT, among many others. Instructions on how to use Earthdata Search are available here. EarthExplorer also provides access to imagery from global satellites, such as Landsat and Sentinel, as well as to aerial imagery that extends up into southern parts of B.C. Sentinel imagery can be viewed via the Copernicus Browser and the Sentinel Hub EO Browser (sentinel-hub.com). Sentinel data can also be directly downloaded via Copernicus Data Space Ecosystem.

Planet Labs is a privately-owned company that provides high-frequency, high-resolution global satellite imagery. While an account is required to access the Planet Explorer web-based mapping system, free accounts are provided to some sectors (e.g., research sectors) through their contact page.

2.1.4 Climate Data

Climate data consists of precipitation, temperature, and other meteorological data collected at climate stations or derived from remotely sensed information. Several public-sector agencies have long-term networks of stations installed around the province, and where station coverage is limited, several gridded datasets of modelled historical climate data are available. Several sources for historical climate data for the Province of B.C. are listed in Table 2.4. An additional source of data is the Canada Water Resources Association (CWRA) GreyJay Project website where an up-to-date list of links to climate and hydrological data for Canada in maintained.

The Government of Canada runs a national network of climate stations, many of which are in B.C. Climate data available from these stations include air temperature, precipitation, relative humidity, windspeed and direction, and derived statistics such as degree-days, monthly summaries, averages, extremes, and climate normals.

Pacific Climate Impacts Consortium's (PCIC) Data Portal provides access to a wide range of climate data, including BC Station data, as well as gridded data discussed below. Station data are from a wide range of sources, including the B.C. Ministry of Agriculture and Food, B.C. Ministry of Environment & Climate Change Strategy, Metro Vancouver, and others and are available for download through the BC Station Data Web App. The PCIC's, *BC Station tool* also provides access to data from climate stations maintained by BC Hydro and the B.C. Ministry of Transportation and Infrastructure.

Snow survey data is collected by the B.C. Ministry of Environment & Climate Change Strategy. Snow survey summaries are provided by the BC River Forecast Centre (Ministry of Water Land and Resource Stewardship). Data provided includes that from automated snow weather stations (snow water equivalent, snow depth, cumulative snowfall and ambient temperature) and manual snow survey sites.

A map of all snow data collection sites, as well as data for download, is available through the Snow Survey Stations Interactive Map.

Spatial data showing the location of all climate stations and snow surveys (automated and manual) are also available to view and download on iMapBC. The spatial data for the datasets discussed above are found under the "*Air and Climate*" and the "*Fresh Water and Marine > Snow Surveys*" layers. Frequently collected free optical satellite imagery (FOSI) may also be helpful for estimating spatial snow coverage (i.e., snow cover extent at different points in time).

In addition to point data from climate stations, several organizations provide gridded historical/re-analyzed climate data that cover the province. These datasets are developed either through interpolating station data or calibrating numerical models (often forecasting models) using climate station data. PCICs Data Portal provides access to two gridded historical climate data sets: Daily Gridded Meteorological Datasets and PRISM Climatology and Monthly Timeseries. ERA5-Land, and Daymet are global datasets that include B.C. at 9 km x hourly and 1 km x daily resolutions, respectively.

Table 2.4: B.C. Climate data and tools.

Data Source	Website	Data Type	Search Terms (if applicable)
BC Hydro Hydrometeorological Data	https://www.bchydro.com/energy-in-bc/operations/transmission-reservoir-data/hydrometeorologic-data.html	Various weather and hydrological	Location
ClimateBC	https://climatebc.ca	Gridded data products	Location, climate scenario
Daymet	https://daymet.ornl.gov/	Gridded data products	Location
ERA5-Land	https://www.ecmwf.int/en/era5-land	Gridded data products	Location
Canadian Forest Fire Weather Index (FWI)	https://cwfis.cfs.nrcan.gc.ca/background/summary/fwi	Weather index	Location
FarmWest Evaporation estimator	https://farmwest.com/climate/calculators/evapotranspiration/	Evaporation data	Location
Government of Canada's Historical Climate Data	https://climate.weather.gc.ca/	Various historical climate data	Historical data, monthly climate summaries
iMapBC	https://maps.gov.bc.ca/ess/hm/imap4m/	Weather station locations	Climate, monitoring, weather
PCIC's Data Portal	https://www.pacificclimate.org/data	Various historical climate data	Station data, gridded datasets
Snow Survey Data	https://governmentofbc.maps.arcgis.com/apps/webappviewer/index.html?id=c15768bf73494f5da04b1aac6793bd2e	Snow depth and SWE	Location

ClimateBC provides access to historical climate data derived from downscaled PRISM 1971-2000 gridded monthly climate normal data at scale-free point locations (instead of grid averages) within B.C. Access to over 200 monthly, seasonal, and annual climate variables are available using a standalone MS Windows application or alternately a web-based map application. Downscaled point location data may be useful to assess climate characteristics in areas with limited or absent meteorological station coverage, while gridded data may be useful to assess spatial variations in climate variables (e.g., elevation differences in temperature and precipitation across a mountainous terrain). In some cases, obtaining information on evaporation rates can be useful (e.g., for water balance modelling). Modelled estimates of daily evaporation are available for many locations via the Farmwest Evaporation Estimator.

The Canadian Forest Fire Weather Index (FWI) system is a means of understanding current weather conditions and is based on consecutive daily observations of temperature, relative humidity, wind speed, and 24-hour precipitation.

2.1.5 Climate Change Information

Projected changes in normal and extreme future air temperature and precipitation are often a critical component of a watershed characterization. Information on how climate variables will change in the future under a range of climate change scenarios is available from sources outlined in Table 2.5.

Table 2.5: Climate change information.

Data Source	Website	Data Type	Search Terms (if applicable)
B.C. Data Catalogue – Glacier extent	Current: https://catalogue.data.gov.bc.ca/dataset/glaciers Historic: https://catalogue.data.gov.bc.ca/dataset/historical-glaciers	Glacier extent (various)	Location
Canadian Centre for Climate Services Climate Data Portals	https://www.canada.ca/en/environment-climate-change/services/climate-change/canadian-centre-climate-services/display-download.html	Climate change projection (raster)	Location and variable
Canadian Climate Atlas	https://climateatlas.ca/map/canada/annual_precip_2060_85#	Climate change projection (various)	Location, climate change scenario
ClimateBC	http://climatebc.ca/	Climate change projection (raster)	Location, BEC zone, SSP
ClimateData.ca	www.climatedata.ca	Climate change projection	Community or region
IDF_CC Tool	https://www.idf-cc-uwo.ca/home	Map data with attributes	Location or Station ID
PCIC Climate Analysis Tools	https://pacificclimate.org/analysis-tools	Climate change projection (raster)	Region or Station ID
University of British Columbia Clarke et al. (2015)	https://www.unbc.ca/office-research-and-innovation/supplementary-data-unbc-publications	Glacier extent (various)	Location and climate projection scenario

A variety of climate change models and projections that correspond to different emissions scenarios and timeframes are available. Projections are developed via General Circulation Models (GCMs), which explore process interactions between the atmosphere, ocean, cryosphere, biosphere, and land surface (IPCC, 2022). Most GCM outputs are associated with the Coupled Model Intercomparison Project (CMIP), which has published a series of climate projections since the 1990s. Historically, each scenario was labelled as a "Representative Concentration Pathway" (RCP) effectively representing future scenarios with increasing radiative forcings (in Wm^{-2}) from RCP2.6 through RCP8.5. The most current suite of projections included in CMIP6 introduce the term "SSP", which stands for "shared socioeconomic pathways". SSPs correspond to different emissions scenarios leading to a range of global temperature change targets. To evaluate climate change at smaller spatial scales, more regional approaches can be taken, including the use of statistical downscaling. Typically, many model simulations are run and the median value is used as a representation of expected change. Generating projections in this way is referred to as "ensemble forecasting". Given uncertainty in model projections, information is often presented for discrete time periods (e.g., 2040-2070). A high-level overview of projected changes to B.C.'s climate can also be found in Spittlehouse (2008). A summary of climate change effects on watershed processes in B.C. can be found in (Pike et al., 2010).

At the provincial level, in addition to historical climate change datasets, both ClimateBC and PCIC provide future climate variables for a range of emissions scenarios and global climate models (GCMs). Projected climate data from ClimateBC is available for download for individual site locations using the online map or a standalone Microsoft Windows application.

PCIC provides access to statistically downscaled climate scenario data at a gridded resolution of 300 arc-seconds (which is approximately 10 km). Data from two climate models (CanDCS-U5 and CanDCS-U6) are available through interactive map interfaces linked through PCIC's data portal. In addition to the gridded climate projection data, PCIC also supports two climate change analysis tools: Plan2Adapt and PCIC Climate Explorer. The Plan2Adapt tool is a user-friendly tool that generates maps, plots, and data describing how climate change may manifest and impact different regions in B.C. The PCIC Climate Explorer has a more complex user interface and a greater number of configurable variables designed to provide climate change data to engineers and other scientists. Tutorials for using the PCIC Climate Explorer are provided on the tool's website.

The Canadian Centre for Climate Services (CCCS), run by the Government of Canada, provides a suite of climate data platforms to help visualize, explore, and work with climate projection data. The Climate Atlas of Canada provides large-scale gridded climate projections and climate change summaries. This spatial tool includes videos highlighting real stories of climate change that support climate action. The ClimateData.ca tool provides climate data at annual, monthly, or daily model outputs for 10 km grids across Canada and is geared towards scientists, municipal planners, and engineers. The Power Analytics and Visualization for Climate Science (PAVICS) project is an advanced climate tool created for expert users and is intended to streamline climate scientist workflow. The platform allows for access to multiple datasets, climate data analysis, and the capacity to run hydrological models. In addition to these three tools, CCCS also provides access to a climate data viewer and a climate data extraction tool.

The IDF CC Tool allows users to update rainfall intensity-duration-frequency curves under changing climate conditions for gauged Environment Canada weather station locations as well as ungauged locations through the use of grided datasets.

For information about changes to glaciers because of climate warming and change, several resources are available. The B.C. Data Catalogue provides current (2021) and historic mapped extents of glaciers in the province, available in multi-part polygon datasets in various file extensions, including .shp, which can be opened in Google Earth or ArcGIS. When current and historic data sets are compared, a user can

understand loss of glacier extent over time for a watershed of interest. For a more advanced understanding of glacial extent loss, the University of Northern British Columbia (UNBC) houses supplemental material for a publication by Clarke et al. (2015) that projects the extent of deglaciation of western Canada in the twenty-first century.

2.1.6 Surface Water (Hydrometric)

Characterizing surface waters often involves accessing a range of hydrometric and other data sources describing water quantities within or withdrawn from a surface water body (e.g., surface water flow, water allocations), timing, and location within a watershed. Information may be presented spatially or as a time series, or as a static report in the case of scanned water licences. A list of resources available for accessing surface water - hydrometric data for B.C. is found in Table 2.6.

The Province of BC's Hydrology Program webpage provides a comprehensive overview of the range of surface water data collected at the provincial level. This page provides links to flow data, both integrated data from the Water Survey of Canada (WSC), as well as non-integrated flow data collected by provincial staff and third parties and presented in the Real-time Water Data tool. Other tools linked on this page include the BC Streamflow Inventory, which provides regional analyses of surface flows, and the BC Extreme Flood Project, which summarizes extreme events for engineering design purposes through regional flood frequency analysis, regional precipitation analysis, and probable maximum precipitation. Lastly, this page provides links to other sites related to the Provincial Hydrology Program such as regulatory and educational documents.

Table 2.6: Surface water (hydrometric) data, modelled data, and summary information.

Data Source	Website	Data Type	Search Terms (if applicable)
B.C. Hydro Hydrometeorological Data	https://www.bchydro.com/energy-in-bc/operations/transmission-reservoir-data/hydrometeorologic-data.html	Various	Location
B.C. Hydrology Program	https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-science-data/water-data-tools/provincial-hydrology-program	Hydrometric and guidelines	Location, data type
B.C. Streamflow Inventory	https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-science-data/water-data-tools/provincial-hydrology-program/resources/streamflow-inventory	Summary report	Region or site of interest
B.C. Water Resources Atlas	https://maps.gov.bc.ca/ess/hm/wrbc/	Various	Hydrometric, watershed, station, streams
B.C. Water Tool	https://www.bcwatertool.ca/	Modelled hydrometric and licensing	Location, data type
Environmental Reporting BC	https://www.env.gov.bc.ca/soe/indicators/climate-change/rivers.html	Climate change effects on streamflow	Location, station ID

Table 2.6 continued: Surface water (hydrometric) data, modelled data, and summary information.

Data Source	Website	Data Type	Search Terms (if applicable)
Floodplain Mapping BC	https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/drought-flooding-dikes-dams/integrated-flood-hazard-management/governance/flood-hazard-land-use-management/floodplain-mapping/floodplain-maps-by-region	Floodplain maps	Floodplain, region of interest
iMapBC	https://maps.gov.bc.ca/ess/hm/imap4m/	Vector data	Hydrometric, watershed, station, streams, network
PCIC Station Hydrologic Model Output	https://pacificclimate.org/data/station-hydrologic-model-output	Hydrometric time series data	Station ID
Real-time Water Data Tool (Aquarius Time-Series database)	https://aqrt.nrs.gov.bc.ca/	Surface water data from monitoring stations across the province	Location, station ID
River Forecast Centre: Current Streamflow Conditions and Flood Forecast Modeling; Drought	https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/drought-flooding-dikes-dams/river-forecast-centre	Current conditions and forecasts - hydrometric	Forecast, location
U.S. Geological Survey National Water Information System	https://maps.waterdata.usgs.gov/mapper/index.html	Hydrometric data in boundary watersheds	Location of interest
Water Survey of Canada Real-Time Hydrometric Data	https://wateroffice.ec.gc.ca/mainmenu/real_time_data_index_e.html	Historical and real-time streamflow	Station ID, location of interest

In addition to the Province's Hydrology Program webpage, several other resources are available that summarize hydrologic and hydrometric resources for BC. The BC Water Resources Atlas is an online mapping platform for visualizing and downloading water resource data in B.C., such as the location of dams, flood protection, watersheds, aquifers, and water wells. Similarly, iMapBC provides visualization and download links to water resource data, found under the "*Base Maps > Freshwater Atlas*" and "*Fresh Water and Marine*" layers. Lastly, the Fisheries Inventory Data Queries page provides access to multiple query tools, the Watershed Dictionary Query, the Single Waterbody Query, and the Multiple Waterbodies Query, all of which allow fisheries and hydrometric attribute data pertaining to specific waterbodies to be located and summarized. This tool is particularly useful in relation to querying data about a waterbody pertaining to fish and fish habitat.

The Water Survey of Canada (WSC) has historical and real-time streamflow data. WSC stations can be located using either the station search bar or a map search function. Hydrologic data may be visualized on the WSC website or downloaded in a range of formats. For watersheds that extend into the U.S., the U.S. Geological Survey has multiple streamflow gauges along the border.

The BC Water Tool is a platform that displays the location of monitoring stations around the province and provides direct links for data download at each monitoring site. Further, it provides on-the-fly watershed discharge modelling and reporting for any selected point over more than two-thirds of B.C., including the Kootenay-Boundary regional area, the Cariboo regional area, and most parts of northern BC (Northeast Water Tool, Northwest Water Tool, and Omineca Water Tool). Note that values present in summary reports mainly correspond to modelled flow data when gauge data is not available.

Though not typically part of a watershed characterization, flood and climate change streamflow forecast modelling is available for the province. The B.C. River Forecast Centre provides short-term forecasted flow data from several models, including the CLEVER model, the WARNS model, and the COFFEE model. Further, forecasted low streamflow conditions can be accessed through the Drought Information Portal. Additional forecasting resources provided by the Province of B.C. includes an Environmental Reporting BC report on the long-term change in timing and volume of river flow in B.C., as well as floodplain maps delineating the extent of a 200-year flood for all regions in B.C. Climate change projections of streamflow in B.C. are also available through the Pacific Climate Impacts Consortium (PCIC). Simulated data is available for 190 locations in B.C. corresponding to WSC stations, and some U.S. Geological Survey gauges in the Peace, Fraser, and Columbia watersheds. Modelled historical streamflow for 1945-2012 is available based on PCIC's gridded meteorological data for northwest North America (PNWNAmet), while projected streamflow data up to 2099 is available for 12 combinations between six GCMs for RCP 4.5 and 8.5 emissions scenarios.

2.1.7 Groundwater Data and Aquifer Information

Groundwater and surface waters are often intrinsically connected in a watershed and understanding groundwater and aquifer attributes is often a central objective of a watershed characterization. Groundwater data may pertain to monitoring locations (i.e., well descriptions), groundwater levels, estimated groundwater yields, groundwater licences, or the properties and extent of the aquifers (where they have been mapped) through which groundwater flows. There is also significant crossover between the data sources available for surface water and groundwater (see list of groundwater data sources in Table 2.7).

Groundwater level monitoring data is available for several aquifers in B.C. through the Provincial Groundwater Observation Well Network (PGOWN). The Groundwater Level Monitoring Data map provides access to this PGOWN data using an interactive map or by browsing a list of active observation wells. The Groundwater Well and Aquifers Search provides access to information about the location of registered water wells, including details on well construction, well depth, geology (if logged), type of water use, etc. In addition, aquifer fact sheets provide aquifer characteristics such as depth, geology, recharge mechanisms and mapped aquifer extents. These can be accessed via the Groundwater Well and Aquifer Search (GWELLS). The Real-Time Water Data Tool (Aquarius Time-Series database) also provides download links to groundwater data, collected by a range of parties, across the province. Similar results may be found via the Community Watersheds Query, which focuses on community-held water licences.

The BC Water Resources Atlas and iMapBC are useful web-based mapping applications; the BC Water Resources Atlas shows the locations of mapped aquifers and registered water wells, while iMapBC has groundwater-related spatial data layers in both the "*Freshwater Atlas*" (Freshwater and Marine) and "*Mining and Petroleum*" layers. The Province of B.C. has also compiled an in-depth report about long-term trends in groundwater levels in B.C., which is available through the Environmental Reporting BC website.

The Real-Time Water Data Tool (Aquarius Time-Series database) is the province's primary repository of continuous surface, groundwater and snow data from monitoring stations across the province. The browser-based information and data presentation system that allows timely access to snow and water monitoring data. The interactive map-based tool displays locations of monitoring stations, allows for the export of data, and creation and viewing of charts and reports.

Table 2.7: Groundwater data and aquifer information.

Data Source	Website	Data Type	Search Terms (if applicable)
Aquifer fact sheets	https://apps.nrs.gov.bc.ca/gwells/aquifers	Summaries of aquifer attributes	Location
BC Water Resources Atlas	https://maps.gov.bc.ca/ess/hm/wrbc/	Vector and groundwater hydrometrics	Aquifer, wells, water quality, licensing
Environmental Reporting BC	https://www.env.gov.bc.ca/soe/indicators/water/groundwater-levels.html	Groundwater hydrometrics and statistics	Location
Groundwater Level Monitoring Data	https://governmentofbc.maps.arcgis.com/apps/webappviewer/index.html?id=b53cb0bf3f6848e79d66ffd09b74f00d	Hydrometric	Location
Groundwater Well and Aquifers Search	https://apps.nrs.gov.bc.ca/gwells/	Registered water well records and aquifer attributes	Location
iMapBC	https://maps.gov.bc.ca/ess/hm/imap4m/	Various	Aquifer, wells, water quality, licensing, monitoring
Real-time Water Data Tool (Aquarius Time-Series database)	https://aqrt.nrs.gov.bc.ca/	Groundwater data from monitoring stations across the province	Location, station ID

2.1.8 Water Licences, Permits and Demand (Use)

Information on water demand, water use, and permits/licences are typically a central component of a watershed characterization. This information may be inferred from existing water licences and discharge authorizations, applications, and other sources. Licences typically provide information on the location and volume of water allocated within a watershed, and the nature of the water allocation (e.g., for industrial, irrigation, waterworks purposes). Wastewater discharge authorizations provide information regarding permitted discharges into the receiving environment. A summary of resources for accessing this information is shown in Table 2.8

The B.C. Agriculture Water Calculator helps agriculture water users in B.C. estimate the annual irrigation or livestock water demand for a farm. Irrigation water demand estimates are based on the geographic location of the farm, as well as its soil type, crop type and type of irrigation. Livestock water demand estimates are made for a given number and type of animals.

Table 2.8: Water licence and permit Information.

Data Source	Website	Data type	Search terms (if applicable)
Authorization Management System (AMS)	https://j200.gov.bc.ca/pub/ams/Default.aspx?PossePresentation=DocumentSearch	Written report	Location, authorization number, company or person, and type of industry
B.C. Agriculture Water Calculator	https://bcwatercalculator.ca/agriculture/welcome	Water use estimates	Location
B.C. Drought Monitoring	https://droughtportal.gov.bc.ca/pages/drought-map	Drought level overview for each major basin in B.C.	Location
B.C. Water Reservations	https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-licensing-rights/water-reservations	Written report	Order in Council number, reservation point code, and site
B.C. Water Tool	https://www.bcwatertool.ca/	Hydrometric and licensing	Location
B.C. Water Allocation Notations	https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-licensing-rights/water-allocation-notations	Written report	Location, point code
Community Watershed Tool	https://www.env.gov.bc.ca/wsd/data_searches/comm_watersheds/index.html	Community-held water licence information	Location
iMapBC	https://maps.gov.bc.ca/ess/hm/imap4m/	Permit and licence spatial data	Licence, permit, well
Scanned water licence permits	https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-licensing-rights/water-licences-approvals/water-rights-databases	Scanned historical water licence documents	Location
Water Licence Query Tool	https://j200.gov.bc.ca/pub/ams/Default.aspx?PossePresentation=AMSPublic&PosseObjectDef=o_ATIS_DocumentSearch&PosseMenuName=WS_Main	Water licence information	Location
Water Sustainability Act temporary protection orders	https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/drought-flooding-dikes-dams/drought-information/wsa-tpo	Written report	Watershed, order type, effective date, date expired or repealed

The Water Licence Query Tool provides information on groundwater and surface water licences and applications. Copies of water licences can also be found via the query tool or a Scanned Water Licences webpage. Mapped locations of water licences, registered groundwater wells and discharge permits are available via multiple layers in iMapBC. Limited attribute data is available alongside the mapped licence locations. The Community Watershed Tool provides information about community-held water licences in B.C. for drinking water purposes.

The B.C. Water Tool can also be used for exploring and finding data about water resources across parts of B.C. (where available), including water licences and hydrometric information. This should be considered a secondary resource, and licences should be cross-referenced against the primary resources listed above.

There are several resources that can provide information regarding drought conditions, allocation reservations and/or use restrictions that may be in place for the watershed of interest including: B.C. Drought Monitoring; B.C. Water Allocation Notations; B.C. Water Reservations; and, *Water Sustainability Act* temporary protection orders. Additionally, the Authorization Management System (AMS) stores all documentation for waste discharge authorizations.

2.1.9 Fish and Aquatic Habitat

Often, a watershed characterization will require information on fish, aquatic habitat and ecology (Table 2.9). The BC Species and Ecosystems Explorer (BCSEE) offers a range of searching options to access information for over 22,000 plants, animals, and ecological communities across BC. The Habitat Wizard, a map-based tool, allows users to spatially query fish, wildlife and ecosystem data from Provincial datasets. The B.C. Conservation Data Centre runs an online map of known locations of species and ecological communities at risk. This data on threatened ecosystems can be further supplemented by information from the Sensitive Ecosystems Inventory Project. Finally, iMapBC provides a wide range of spatial ecosystem and habitat-related data under the layers: "*Fish Wildlife and Plant Species*"; "*Forest Grasslands and Wetlands*"; "*Fresh Water and Marine*"; "*Parks Recreation and Tourism*"'; and, "*Obstacles to Fish Passage*". Note that the dataset "*Obstacles to Fish Passage*" in iMapBC includes points ranging from permanent actual barriers to seasonal barriers and non-barriers. As a result, an iMapBC user should pair the "*Obstacles to Fish Passage*" data with data on fish distribution to better understand the habitat situation in the watershed of interest.

Data pertaining to fish communities across the province, particularly for salmonids can be located from several sources. The Fisheries Inventory Data Queries (FIDQ) page can be queried by individual waterbody or stream, or for the entirety of a watershed providing access to a range of data including fish stocking, fish species, and fish inventory data. The Salmon Watershed Program's website links to numerous scientific and technical documents, as well as baseline data sets relevant to Pacific salmon populations and freshwater and estuarine habitats. The website also supports the Pacific Salmon Explorer tool which displays information on the status of salmon and their habitats across B.C. More information is also available via the BC Web Map Library available on the BC Data Catalogue. The Hatcheries and Spawning Channels website contains information about hatcheries that incubate, rear and release salmon to live alongside wild Pacific salmon.

The Canadian Aquatic Biomonitoring Network (CABIN) provides a map-based platform to access data from CABIN sites across B.C. CABIN specifically collects data on benthic macroinvertebrates to assess the ecological health of streams. The information available for CABIN sites includes on-site images (including streambed substrate) and a range of other watershed-specific data.

Table 2.9: Fish and aquatic habitat information.

Data Source	Website	Data Type	Search Terms (if applicable)
BC Species and Ecosystems Explorer	https://a100.gov.bc.ca/pub/eswp/	Attributes by species/ ecosystem	Species, region of interest
Canadian Aquatic Biomonitoring Network (CABIN) Sites Map	https://www.canada.ca/en/environment-climate-change/services/canadian-aquatic-biomonitoring-network.html	Spatial and attribute data	Location, species of interest
B.C. Conservation Data Centre	http://maps.gov.bc.ca/ess/hm/cdc/	Spatial data	Species and ecosystems at risk
Fisheries Inventory Data Queries (FIDQ)	https://www2.gov.bc.ca/gov/content/environment/plants-animals-ecosystems/fish/fish-and-fish-habitat-data-information/search-fish-fish-habitat-data-information/fisheries-inventory-data-queries	Spatial and attribute	Location, species of interest
Habitat Wizard	https://maps.gov.bc.ca/ess/hm/habwiz/	Spatial data	Fish, fisheries, species of interest
Hatcheries and Spawning Channels	https://www.pac.dfo-mpo.gc.ca/sep-pmvs/hatcheries-ecloseries/index-eng.html	Spatial data	Location, hatchery name
iMapBC	https://maps.gov.bc.ca/ess/hm/imap4m/	Spatial data	Fish, fisheries, species of interest
Salmon Watersheds Project	https://salmonwatersheds.ca/	Spatial data and attributes	Location, species of interest
Sensitive Ecosystems Inventory (SEI) Project Boundaries	https://catalogue.data.gov.bc.ca/dataset/sensitive-ecosystems-inventory-sei-project-boundaries	Spatial data	Location

2.1.10 Terrestrial Ecological Information

Watersheds across B.C. support a diverse range of habitats and ecosystems largely because of B.C.'s varied watershed characteristics. Often, a characterization will include information on those terrestrial ecological values. A list of information resources for obtaining information on ecological attributes in watersheds is shown in Table 2.10.

Maps provided by the Biogeoclimatic Ecosystem Classification (BEC) Program provide high-level information about the distribution and range of ecosystems across B.C. The BC Species and Ecosystems Explorer (BCSEE), Habitat Wizard, the B.C. Conservation Data Centre, information from the Sensitive Ecosystems Inventory Project, and iMapBC as covered above for fish related queries, can be used to query the existence of terrestrial information.

Forest cover data for the province is available through the Vegetation Resource Inventory (VRI) dataset. This dataset not only describes where a given vegetation resource (i.e., timber volume, tree species) is located but also how much of that given resource is within an inventory unit. Historical data is available annually from 2002 to 2018, and a more limited dataset is available for 2022. Pre-made maps of VRI data, including species groups, age classes, and height classes are also available to view and download. Stand characteristics include growth projections and harvest date, among other attributes. For those who are interested, the Province provides information about old growth definition and values.

Table 2.10: Terrestrial ecological information.

Data Source	Website	Data type	Search terms (if applicable)
B.C. Species and Ecosystems Explorer	https://a100.gov.bc.ca/pub/eswp/	Attributes by species/ ecosystem	Location, species
B.C. Vegetation Resource Inventory (VRI)	https://open.canada.ca/data/en/dataset/02dba161-fdb7-48ae-a4bb-bd6ef017c36d	Spatial and attribute data	Location
Biogeoclimatic Ecosystem Classification (BEC) Program	https://www.for.gov.bc.ca/hre/becweb/index.html	Spatial and attribute data	Zone or region of interest
B.C. Conservation Data Center	http://maps.gov.bc.ca/ess/hm/cdc/	Vector data	Species and ecosystems at risk
Habitat Wizard	https://maps.gov.bc.ca/ess/hm/habwiz/	Spatial data	Species of interest
iMapBC	https://maps.gov.bc.ca/ess/hm/imap4m/	Spatial data	Plant, ecosystem, forest, mammal, biodiversity
Sensitive Ecosystems Inventory (SEI) Project Boundaries	https://catalogue.data.gov.bc.ca/dataset/sensitive-ecosystems-inventory-sei-project-boundaries	Vector data	Location, species

2.1.11 Water Quality Information

The quality of surface and groundwaters is often a central concern within watersheds, given water's importance for human and ecological requirements. Water quality is the chemical, physical, and biological characteristics of water, sediment and biota with respect to a particular (designated) use. In B.C., our designated uses include drinking water, aquatic life, wildlife, agriculture/ range, recreation, and industrial water supplies. Understanding water quality drivers and stressors is a key component of watershed characterizations. A list of water quality information resources in B.C. is shown in Table 2.11.

Water quality monitoring reports can be found on the B.C. Water Quality Monitoring documents webpage as well as from the Water Quality Objectives Reports webpage. Here one can find information on water quality monitoring and assessment documents organized by region. Water quality data for the province can be downloaded from the Surface Water Quality Monitoring Sites Interactive Map. This map shows all federal and provincial water quality monitoring sites within B.C. and allows access to water quality sample reports for most sites. While this map includes data from the B.C. Lake Monitoring Network, this program supports its own B.C. Lake Monitoring Portal.

On a routine basis, water samples are collected from the provincial network and analyzed for water quality parameters such as nutrients, metals and general water chemistry. Water quality sampling and analysis at prescribed locations is also a typical requirement for certain types of provincial permit holders (e.g., discharge permits). These results are publicly available in the Environmental Monitoring System (EMS) database. This data is also available via ShinyREMS, a web app for interacting with EMS data. Note that the EMS database is expected to be replaced by the Environmental Monitoring Data System (EnMoDS) in the future and depending on read date of this publication, the reader may have to

refer to the latter (new database) in absence of locating EMS. Water quality data at select hydrometric stations are also available from the Canada-BC Water Quality Monitoring Program. The Real-Time Water Data Tool (Aquarius Time-Series database), a resource that was previously listed in this report, also provides water quality data for the province based on samples from monitoring stations.

Table 2.11: Water quality data and information.

Data Source	Website	Data type	Search terms (if applicable)
B.C. EMS/ShinyREMS	https://github.com/bcgov/shinyrems	Water quality	Location, water quality parameter
B.C. Lake Monitoring Portal	https://governmentofbc.maps.arcgis.com/apps/MapSeries/index.html?appid=a5ffb1bcffad4407b387292f2e55899f	Water quality	
Canada-BC Water Quality Monitoring Program	https://governmentofbc.maps.arcgis.com/apps/MapSeries/index.html?appid=85991363447e4c73991e418dd98133ca	Water quality at hydrometric stations	Location
Real-time Water Data Tool (Aquarius Time-Series database)	https://aqrt.nrs.gov.bc.ca/	Water quality data	Location, station ID
Surface Water Monitoring Sites Interactive Map	https://www2.gov.bc.ca/gov/content/environment/research-monitoring-reporting/monitoring/tools-databases/surface-water-monitoring-sites	Spatial and attribute	Location
Water Quality Monitoring Documents	https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-quality/water-quality-monitoring/water-quality-monitoring-documents	Reports	Location
Water Quality Objectives Reports	https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-quality/water-quality-objectives	Reports	Water quality parameter

2.1.12 Geomorphic and Geologic Information

Geomorphic processes are the redistribution of mineral sediment through a landscape and are fundamental to watershed form and function. Common geomorphic processes in B.C. watersheds include landslides, debris flows, and stream channel erosion and deposition processes. Similarly, the surface and underlying bedrock geology provide control on the geomorphic processes in the system, as well as the availability and behaviour of groundwater. Geomorphic and geological data are usually spatial in nature, with features represented as mapped items. Table 2.12 provides links to data and information about geology and geomorphology in B.C.

GEOSCAN provides access to all the scientific publications from Natural Resources Canada (NRCan). This includes Geological Survey of Canada publications, National Atlas maps, topographic maps, records on mining, materials, energy, and more. For B.C. specifically, the B.C. Digital Geology webpage hosts province-wide digital coverage of British Columbia's bedrock geology, with maps ranging in scale from 1:50,000 to 1:250,000. MapPlace is a geospatial web services suite that allows users to visualize, search, and download geoscience and mineral resource data and maps. The B.C. Geological Survey website

provides links to a range of geology-related materials including maps, publications, assessment reports, and mineral inventories. Lastly, *Below BC*, a non-profit society, hosts an Interactive Geology Map which allows users to explore the geology around B.C. as well as geological specimens (i.e., minerals, rocks, fossils, etc.) from different areas around the province.

Information about surficial materials can be accessed through three primary datasets. First, the B.C. Soil Information Finder Tool is an interactive mapping application that provides access to soil survey maps, soil attributes, and agriculture capability mapping. Layers include *Soil Mapping Project Boundaries* and *BC Soil Survey Polygons*, which include descriptions of soil type and links to soil survey reports for each polygon. The second source for surficial material information is the Terrain Mapping (TER) Polygon dataset, wherein the province is divided into units according to surficial materials, landforms, and geomorphological processes using the Terrain Classification System for B.C. Lastly, surface geology maps created by the BC Geological Survey, the Geological Survey of Canada, and Geoscience B.C. are available to download.

Stream sediment-related data can be accessed from the *Sediment Data Search* managed by Environment Canada. This webpage provides access to in-stream sediment transport data collected at Water Survey of Canada stations. Data types include instantaneous, loads, and concentration, which allow for estimates of sediment movement within a watershed to be evaluated. Note that the most datasets collected in B.C. range up to 1992.

Table 2.12: Geomorphic and geological information.

Data Source	Website	Data type	Search terms (if applicable)
B.C. Digital Geology	https://www2.gov.bc.ca/gov/content/industry/mineral-exploration-mining/british-columbia-geological-survey/geology/bcdigitalgeology	Spatial geology data	Location
B.C. Geological Survey	https://www2.gov.bc.ca/gov/content/industry/mineral-exploration-mining/british-columbia-geological-survey	Reports and spatial data	Location
BC Soil Information Finder Tool	https://www2.gov.bc.ca/gov/content/environment/air-land-water/land/soil/soil-information-finder	Spatial data with attributes	Location
GEOSCAN	https://geoscan.nrcan.gc.ca/starweb/geoscan/servlet.starweb?path=geoscan/geoscan_e.web#?	Various	Location, hazard, erosion
Interactive Geology Map	https://bbcga.com/bc-interactive-map/	Spatial	Mineral type, geology
MapPlace	https://www2.gov.bc.ca/gov/content/industry/mineral-exploration-mining/british-columbia-geological-survey/mapplace	Spatial data with attributes	Surficial geology, ice flow, geology
Sediment Data Search	https://wateroffice.ec.gc.ca/search/sediment_e.html	Sediment transport data	Location, station ID
Surficial Geology Maps of BC	https://www2.gov.bc.ca/gov/content/industry/mineral-exploration-mining/british-columbia-geological-survey/geology/surficialmapping	Maps	Location
Terrain Mapping (TER) Polygon Attributes	https://open.canada.ca/data/en/dataset/caf1ad28-9bd9-4b41-b2f8-928fff115855	Vector data with attributes	Location

2.1.13 Historical Watershed Disturbances

Historical watershed disturbances can include natural or human-driven events that change the land surface cover characteristics and composition. In B.C., watershed characterization typically include descriptions of changes in forested landscape such as forest cover / composition from agents such as wildfire, forestry activities, or forest pests. Data pertaining to watershed disturbances are usually spatial in nature but may be in raster or vector form. Several resources exist that provide data about historical watershed disturbances (Table 2.13) but mostly focus on forest landscape changes due to the prevalence of forests and changes in watersheds. Note that a broad list of stressors behind disturbances that may influence watersheds is found in Table 3.13.

The Terrain Mapping (TER) Polygon dataset is a good starting point for evaluating historical watershed disturbances. In addition to providing polygons that divide the province into areas of similar surficial materials, landforms, and geomorphological processes, the TER dataset provides information about slope stability class and the surface erosion potential, both of which help evaluate past and future disturbance potential. Terrain stability is evaluated according to the guidelines laid out in the Mapping and Assessing Terrain Stability Guidebook.

Data pertaining to forest resources inventory also provides information to evaluate watershed disturbances. Data collected and presented in the Aerial Overview Surveys dataset, includes spatial information about patterns of disturbance across the forested land base. Data collected from aerial surveys since 1999, and associated maps, are available for download on an FTP site. iMap BC (via the BC data warehouse) contains polygons corresponding to wildfire, forest pest, and logging-related disturbances, usually up to the current year. Finally, the Vegetation Resource Inventory datasets contain records of disturbance type and disturbance date for vegetation polygons across B.C.

Table 2.13: Historical watershed disturbances information.

Data Source	Website	Data Type	Search Terms (if applicable)
Aerial Overview Surveys	https://www2.gov.bc.ca/gov/content/industry/forestry/managing-our-forest-resources/forest-health/aerial-overview-surveys	Spatial	Location
BC Vegetation Resource Inventory (VRI)	https://open.canada.ca/data/en/dataset/02dba161-fdb7-48ae-a4bb-bd6ef017c36d	Vector data with attributes	Location
First Peoples' Map of B.C. (fpcc.ca)	https://maps.fpcc.ca/	Map visualization	Places, people, languages and grants
Google Earth Timelapse	https://earthengine.google.com/timelapse/	Map visualization	Location
iMapBC	https://maps.gov.bc.ca/ess/hm/imap4m/	Vector data	Harvest areas, pine beetle and other pest infestations, wildfire, windthrow
Terrain Mapping (TER) Polygons	https://open.canada.ca/data/en/dataset/caf1ad28-9bd9-4b41-b2f8-928fff115855	Vector data	Location

For information about potential future disturbances to a watershed, including planned forestry openings and roads, and expected frequency of fire hazard, information resources include Forest Operations Map and viewing the BEC Natural Disturbance Type Classes layer and/or the Fire Threat Rating layer in iMapBC.

2.1.14 Land Titles

Information on land titles, and property boundaries / ownership attributes of a watershed can be gathered from Provincial and third-party data sources. Typically, this information clarifies whom in a watershed may have information and interest in a watershed characterization study as well as subsequent work. An overview of available resources associated with land territories, titles, and ownership is outlined in Table 2.14.

Information pertaining to land ownership is available via the B.C. Land Title and Survey website (see ParcelMap BC), the BC data catalogue (ParcelMap BC) and within iMapBC. This information is helpful for distinguishing between public and private land, locating lot boundaries, and for identifying property holder information if contact is required. Other types of land use titles, such as mineral titles, can be located within iMapBC and the B.C. Data Warehouse.

Multiple resources are available for outlining traditional territories, treaty lands, and reserve lands across B.C. High-level information on traditional territory boundaries for B.C. First Nations is available via the British Columbia Assembly of First Nations (AFN), which can serve as a starting point for exploring resources held by First Nations across B.C. Spatial data on language groups and community locations is available via the First Peoples' Map of B.C. (fpcc.ca). The province hosts a webpage called First Nations A-Z listing, a map and list-based means of locating and contacting First Nations communities across the province. Several spatial layers associated with treaty lands and resource agreements are also available within iMapBC.

Table 2.14: Land territories, title, and ownership information sources.

Data Source	Website	Data type	Search terms (if applicable)
B.C. Land Title and Survey	https://ltsa.ca/	Spatial, land boundaries	Location
First Nations A-Z Listing	https://www2.gov.bc.ca/gov/content/environment/natural-resource-stewardship/consulting-with-first-nations/first-nations-negotiations/first-nations-a-z-listing	Spatial data with attributes	First Nation, Region of interest
First Nations in BC Interactive Map	https://www.bcafn.ca/first-nations-bc/interactive-map	Spatial data	Region or community
First Peoples' Map of B.C.	https://maps.fpcc.ca/	Spatial data with attributes	Language, communities, arts, heritage
iMapBC	https://maps.gov.bc.ca/ess/hm/imap4m/	Spatial data	Treaty, territory, ownership, title
Native Land Digital	https://native-land.ca/	Spatial data	Location

2.1.15 Land Use Information

Land use is a broad category incorporating residential, industrial, or other human-related activities. Examples of common land uses include forestry, agriculture, residential / urban areas, recreational, and industrial uses. Data corresponding to land use is primarily spatial though time series information is available for change detection. Remotely sensed data is the most common source of information on land use. Data sources and online resources to access land use information are shown in Table 2.15.

Land use within individual watersheds can be explored in iMapBC by navigating the following layers in iMapBC: "*Administrative Boundaries*", "*Agriculture*", "*Forest Grassland and Wetlands*", "*Land Ownership and Status*", "*Land Use Permits*", "*Mining and Petroleum*", "*Parks Recreation and Tourism*", and "*Transportation*". Information layers from the BC Data Catalogue (accessed using iMapBC or directly from the catalogue) can also be exported and saved by a user for use within Google Earth.

There are many additional sources of spatial data that may provide insight into watershed land use. As previously discussed, the following resources contain information on land use: BC Vegetation Resources Inventory, the Sensitive Ecosystems Inventory, Environmental Assessment Office Project Information Centre (EPIC), Community Watersheds Query, and the Water Licence Search.

Table 2.15: Land use information.

Data Source	Website	Data Type	Search Terms (if applicable)
BC Vegetation Resource Inventory (VRI)	https://catalogue.data.gov.bc.ca/group/vegetation-resource-inventory	Vector with attribute	Location
BC Agricultural Land Use Inventory	https://www2.gov.bc.ca/gov/content/industry/agriculture-seafood/agricultural-land-and-environment/agricultural-land-use-inventories	Spatial	Location
B.C. Land Title and Survey	https://ltsa.ca/	Spatial – land boundaries	Location
Community Watershed Tool	https://www.env.gov.bc.ca/wsd/data_searches/comm_watersheds/index.html	Spatial	Location
Digital Road Atlas	https://www2.gov.bc.ca/gov/content/data/geographic-data-services/topographic-data/roads	Vector	Location
Environmental Assessment Office Project Information Centre (EPIC)	https://www.projects.eao.gov.bc.ca/projects	Location of where EAs have occurred	Location, project type
iMapBC	https://maps.gov.bc.ca/ess/hm/imap4m/	Vector	Industry, land use
Sensitive Ecosystems Inventory (SEI) Project Boundaries	https://catalogue.data.gov.bc.ca/dataset/sensitive-ecosystems-inventory-sei-project-boundaries	Vector	Location
Water Licence Search	https://j200.gov.bc.ca/pub/ams/Default.aspx?PossePresentation=AMSPublic&PosseObjectDef=o_ATIS_DocumentSearch&PosseMenuName=WS_Main	Licence attributes	Location

2.1.16 Socio-Cultural Values

Many watersheds throughout B.C. contain numerous sites of high cultural values, including sites of significance to First Nations. While this information is important to every watershed characterization, such knowledge is often proprietary and may not be publicly available. Other values of interest in a watershed characterization may include recreational areas, historical locations or other areas. Knowledge of who may have history within a watershed is important when undertaking a watershed characterization. Data in this category is almost exclusively spatial in nature, and typically vector-based. A summary of resources associated with socio-cultural values is shown in Table 2.16. While information may not be publicly available, we strongly encourage those undertaking a watershed characterization to identify and contact any relevant governments, communities or organizations within the area of interest to inquire about additional information.

Provincially managed recreation sites, such as campgrounds or day-use areas, are found at the Recreation Sites and Trails BC website. Sites can be searched or viewed via an interactive map. General information on provincial and national park locations, or other protected areas, can be found in iMapBC. Finally, Trailforks provides a detailed list of cycling, hiking, and other recreation trails globally with good coverage in British Columbia. Note that information from Trailforks cannot be exported for use in other data viewer platforms (e.g., Google Earth).

Table 2.16: Social and cultural values information.

Data Source	Website	Data Type	Search Terms (if applicable)
Community Forest Agreements (CFAs)	https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/forestry/timber-tenures/community-forest-agreements/community_forest_key_map.pdf	Spatial data	Name of CFS
First Nations A-Z Listing	https://www2.gov.bc.ca/gov/content/environment/natural-resource-stewardship/consulting-with-first-nations/first-nations-negotiations/first-nations-a-z-listing	Spatial data with attributes	First Nation, Region of interest
iMapBC	https://maps.gov.bc.ca/ess/hm/imap4m/	Vector data with attributes	Archaeology, First Nation, Historic, Fossil
Recreation sites and trails BC	http://www.sitesandtrailsbc.ca/	Spatial data with attributes	Location
TrailForks	https://www.trailforks.com/	Spatial data with attributes	Location

2.2 Methods and Tools for Data Display and Analysis

2.2.1 Mapping and Spatial Data Tools

There are a variety of desktop, spatial tools available for watershed characterization. These tools are summarized in Table 2.17 and focus on those that are freely available. However, we note that many other proprietary tools are widely used for watershed characterizations.

Spatial data and mapping resources serve both as portals for accessing and downloading spatial data, as well as platforms for viewing and interacting with a range of spatial data, including specific analyses. Key

examples of these include Earth Explorer which displays imagery from a wide range of sources and MapPlace which maps a range of geological-based data for B.C. As described previously, iMapBC is an online application that allows users to access and visualize information stored in the BC Data Catalogue, the most comprehensive database containing land use information in the province. iMapBC contains tools built into the online application (found under the 'Sketch' tab) to allow users to annotate and measure distances on maps, and export information if desired.

Google Earth Pro, is one of the most widely used, free tools for spatial data display and analysis. Many agencies produce spatial datasets that are available for download as either a KML or KMZ file, both of which are used in Google Earth and Google Earth Pro. Spatial data for a region of interest can be added to the application or built-in base maps and datasets can also be used and explored. While Google Earth Pro does have the capacity for certain types of spatial analysis (e.g., measuring distances, uploading points from CSV files), the Earth Point website provides additional useful tools that allow for the integration between Google Earth Pro and other spatial datasets. For B.C. focused watershed characterization, information layers are available from the BC Data Catalogue and can be downloaded in a variety of different file formats (e.g., csv, kmz, .shp) and online server formats (e.g., ESRI REST, WMS). Data can be used in Google Earth and/or other applications such as ArcGIS for more advanced geospatial analysis.

QGIS is an open-source geographic information system. QGIS is freely available for download and has a great deal of documentation and training materials available. Key features of the software include the ability to load and display spatial data, conduct spatial analyses, and produce high-quality maps for export. For even more advanced spatial analysis, GeoDa, a free and open-source software tool, allows the exploration and modelling of spatial information.

Table 2.17: Mapping and spatial data tools.

Data Source	Website	Run by
Earth Point	https://www.earthpoint.us/	Earth Point
Earth Explorer	https://earthexplorer.usgs.gov/	US Geological Survey
GeoDa	https://geodacenter.github.io/	University of Chicago
Google Earth Pro	https://www.google.com/earth/versions/	Google
iMapBC	https://maps.gov.bc.ca/ess/hm/imap4m/	Province of B.C.
MapPlace	https://www2.gov.bc.ca/gov/content/industry/mineral-exploration-mining/british-columbia-geological-survey/mapplace	Province of B.C.
QGIS	https://www.qgis.org/en/site/	QGIS Development Team

2.2.2 Spatial Data Methods

Working with spatial data often requires different software and approaches than are typically used for time series or statistical data. As described previously, spatial data comes primarily in two forms: vector and raster. Vector data is a geographical representation of the world using geometric objects including points, lines, and polygons. Vector data is used to represent features like watershed boundaries or channel networks. Raster data is data stored in a matrix of pixels organized into rows and columns. Raster data is commonly encountered while dealing with climate change projection data, terrain features, or satellite imagery. An important distinction between vector and raster data is how attributes

are displayed. An attribute might be, for example, a watershed area or temperature at a point. With vector data, discrete features have a single set of attributes. Attributes such as name or area might be associated with a particular watershed. With raster data, each pixel corresponds to a single value. While guidance towards meeting specific objectives with spatial data is beyond the scope of this report, a basic overview can be found in, for example, this guide.

Often, a user might wish to delineate a watershed upstream of a point of interest along a stream channel network as part of a watershed characterization. While many pre-derived watershed boundaries are available, a different boundary may be desired if a point of interest falls within a delineated watershed. In this case, the user will need to delineate a watershed using elevation data. This is most easily done from a contour map, where the high point of land is traced upstream from a starting location along a channel. Details of these methods can be found here. This process can be done in Google Earth, iMapBC, from a paper map, or in a GIS program, such as ArcGIS or QGIS. Automated methods can be applied using a DEM and a point of interest, either through programming environments (e.g., R or Python) or in a GIS program. A variety of tutorials for this process can be found online.

2.2.3 Time-Series Data Analysis and Display

Time series (sometimes called continuous time series) data corresponds to data (variable) that is collected regularly over time. Time series data is useful for examining trends or changes through time. Examples of time series data might include climate, water level/discharge, water quality or any other variable that is tracked over time. Time series data may be collected at any time interval: for example, a common interval for streamflow data is “daily”, while information on watershed disturbance (e.g., burned area) is usually presented as annual values. Meteorological data is most commonly available in hourly, daily, monthly, and annual time steps. Many data sources include a display of time series data, but occasionally this functionality is not a central feature, or a separate application may be needed to generate time series figures. A summary of tools that can be used to display and analyze time-series water data is found in Table 2.18.

There are several free tools available to process, visualize, and analyze time series data. LibreOffice, a successor to OpenOffice, is an open-source alternative to the widely used Microsoft Office, and hosts much of the same capabilities as its proprietary counterpart. From LibreOffice, Calc is the spreadsheet application that supports a range of data files including CSV, XLS, and XLSX. Google also provides access to free spreadsheets and supports Google Looker Studio, which allows for the creation of data reports, visualization and dashboards to be easily created. For those who have access to Microsoft Excel, spreadsheets developed in the FASST-X tool available on GITHUB, provide a user-friendly means to generate times series data analysis and figures of Water Survey Canada streamflow data. If more in-depth analysis of time series data is required, then common spreadsheet software can serve to display data and generate figures.

Table 2.18: List of resources for displaying time-series data.

Data Source	Website	Managed by
FASST-X	https://github.com/bcgov/FASSTX	Province of BC
Google Data Studio	https://datastudio.google.com/	Google
LibreOffice	https://www.libreoffice.org/	The Document Foundation

2.2.4 Data Download and Analysis using R Programming Language

Programming-based data analysis is also a popular option, and examples of using the *R* programming language for data science (R packages) for watershed characterization applications are shown in Table 2.19. Using various R packages, data pertaining to watershed characterizations can be imported, viewed, and downloaded. The Province of B.C. has developed numerous packages aiding in the access of environmental time series and spatial data, and additional third-party packages are also available. These packages are summarized in Table 2.19. Note that several packages also have associated web app (Shiny) interfaces (e.g., ShinyREMS).

Table 2.19: List of R packages useful in watershed characterization in B.C.

Package	Purpose	Author
arcpullr	Allows for R users to read in datasets available via ESRI REST servers, such as those published by the River Forecast Centre on the BC Data Catalogue	Frater and Driscoll
bcmaps	Allows for exploration and import of data, particularly maps, available through the BC Data Catalogue. Imports various spatial layers as *sf* objects. This package is an extension of the bcdata package and provides simplified commands to access common datasets.	Province of B.C.
bcdata	Allows for exploration and import of data available from the BC Data Catalogue.	Province of B.C.
elevatr	Access raster elevation data	U.S. EPA
fasstR	provides various functions to tidy and screen daily stream discharge data, calculate and visualize various summary statistics and metrics, and compute annual trending and volume frequency analyses.	Province of B.C.
rems	Downloads, filters, and imports data from BC EMS. See ShinyREMS for an interactive app.	Province of B.C.
tidyhydat	Access historical and real-time hydrometric data from WSC stations. See this introduction to tidyhydat by the B.C. Government package for learning more.	rOpenSci
weathercan	Download and access historical climate and weather data from Environment Canada stations	rOpenSci

3. WATERSHED CHARACTERIZATION QUESTIONS AND OBJECTIVES

This section presents examples (templates) of common questions designed to guide the identification of key sections to include in a desktop watershed characterization. The questions are meant to help guide the investigation as well as identify supporting resources (information sources, tools). The underlying objectives of the questions and data metrics (data analyses) used to address the questions are also presented. The first three themes are common across all watershed characterizations; i) determining the boundaries of the watershed and its physical setting (physiography); ii) locating and compiling prior reports / literature, and iii) generating a map of the watershed. The remaining questions for each template presented below will vary in importance and inclusion based on the overall objective(s) of the watershed characterization. These templates include: i) watershed climate (current conditions); ii) climate change projections; iii) surface water; iv) groundwater; v) water demand/supply pressures; vi)

water quality; vii) fish and aquatic ecology; viii) terrestrial ecology; ix) geology and geomorphology; x) watershed disturbance; xi) traditional territories, land titles, and ownership; xii) land use; and xiii) socio-cultural values.

3.1 Question Templates by Theme

3.1.1 Watershed Area of Interest and Basic Physiography

Defining the watershed area of interest is a first step in undertaking a watershed characterization. Questions related to watershed location and physiography are shown in Table 3.1. Once the area of interest is known, the spatial extent of the watershed can ensure that all relevant data are included. Often, a stream or point along a channel network can be used to guide the identification of the watershed boundary. A variety of methods are available for delineating a watershed, and many pre-delineated watersheds are available via the Freshwater Atlas (or iMapBC). Helpful spatial layers include "*named watersheds*" and "*FWA Stream Networks*", though many options are available. Topographic data from GeoGratis can help with evaluating watershed relief and elevation. An alternative and often convenient option to view the FWA Watersheds layer is to use the BC Water Tool, which spans more than two-thirds of the province.

Table 3.1: Questions related to defining watershed boundaries and watershed physiography.

Question	Purpose	Metrics	Resources
What are the coordinates of the watershed outlet?	Understand general physical setting	Latitude, longitude	iMap B.C. Freshwater Atlas Google Earth BC Water Tool
Where are the watershed boundaries and in what part of the province is the watershed located.	Understand setting and extent for consideration of other data sources	Coordinates of vertices	iMap B.C. Freshwater Atlas BC Water Tool
What is the area of the watershed?	Understand general physical setting and scale of system	km^2	iMap B.C. Freshwater Atlas BC Water Tool
What is the median elevation of the watershed?	Relevant for climate and hydrological regime and understanding general setting	m	GeoGratis BC Water Tool
What is the topographic relief (elevation range) and mean aspect of the watershed?	Relevant for climate and hydrological regime and geomorphic processes	m, degrees or cardinal direction	GeoGratis BC Water Tool
What river system does this watershed drain into?	Understand general physical setting. Understand potential downstream effects outside watershed of interest	River system name	iMap B.C. Freshwater Atlas BC Water Tool
What are the major tributaries in the watershed?	Understand if the watershed has distinct catchment areas that exert influence on downstream areas	Tributary names (if available) and/or geographic location(s)	iMap B.C. Freshwater Atlas BC Water Tool

3.1.2 Searching for Existing Literature and Previous Reports

Following the definition of watershed location, a next step is a search for existing documents pertaining to the watershed or region of interest. These reports may be previous characterizations, watershed assessments, or general studies ranging in topic from environmental impact assessments, or sensitive habitat inventory studies. A summary of guiding questions related to literature searches is shown in Table 3.2.

There are many databases that contain information on watersheds in British Columbia. The Ecological Reports Catalogue (EcoCat) is a good starting point. As of 2022, several thousand entries regarding British Columbia watersheds are available. Additionally, a web search (e.g., Google) may reveal additional reports not hosted on EcoCat. Common topics available via EcoCat include watershed assessments, terrain assessments, and general ecological studies. Detailed instructions on how to access watershed assessments in EcoCat are provided by Carver. (2008). GeoGratis, from Natural Resources Canada, provides an online database that allows users to spatially search for maps, data, and publications. Google and Google Scholar, and university thesis repositories (per academic institution's website) are also helpful resources to check for publications associated with a watershed of interest. Additionally, local stewardship and conservation groups, and/or First Nations may be sources for pertinent watershed information such as maps, data, and publications. Specific information on existing literature search options can also be found in Section 2.1.1

Table 3.2: Questions related to searching for existing literature / previous reports.

Question	Purpose	Metrics	Resources
Have any studies occurred in this watershed?	Learn about what data and findings might exist	Where, when and what	The Ecological Reports Catalogue (EcoCat) Google Scholar
Have any watershed assessments been conducted?	Learn about what data and findings might exist; characterization may not be necessary	Where, when and what	The Ecological Reports Catalogue (EcoCat) Google Scholar
Have any Environmental Impact Assessments occurred in this watershed?	Learn about what data and findings might exist	Where, when and what	EPIC
When was the last study, assessment, or EIA completed?	Provides context for relevance of the report	Year or Date	The Ecological Reports Catalogue (EcoCat) Google Scholar EPIC
Is data associated with past studies available?	Privately collected data may be available	Yes/No	The Ecological Reports Catalogue (EcoCat) Google Scholar EPIC

3.1.3 Base Map Generation

Following a literature search, generation of a watershed map may be desirable to visualize the physical structure of the watershed, as well as the distribution of infrastructure, monitoring stations, or any other sites of interest. The level of detail and map complexity will depend on the objectives of the characterization. For example, a basic evaluation may only require the use of Google Earth and its embedded tools to generate a map. However, a more complex characterization may involve downloading and displaying spatial data from several sources. In this case, the use of GIS software, such as QGIS, may be required.

A watershed base map may be detailed or simple, but will typically include the following physiographic elements:

1. Watershed boundaries;
2. Key water features, such as lakes, wetlands, and stream networks. Glaciers are helpful to include if the data is available, and;
3. Topographic information, either contours or a hillshade map.
4. Relevant infrastructure and data collection sites, such as:
    - Road networks, urban areas, or land type designations;
    - Property boundaries and parkland, and;
    - Locations of data collection or monitoring features, such as hydrometric or climate stations.

Other metrics may need to be displayed depending on the specific objectives of the characterization.

Typically, any map generated should be large enough to easily interpret key features. Occasionally, multiple maps showing different portions of a single watershed may be required. Maps in digital form are most helpful, as it is often convenient to make measurements on-screen (e.g., via Google Earth). Figure 3.1 and Figure 3.2 show two examples of watershed maps. Figure 3.1 shows the most basic map generated within iMapBC using information from the B.C. Data Warehouse and that can still provide reasonably helpful information. Figure 3.2 is a more detailed map with additional underlying data and watershed features.

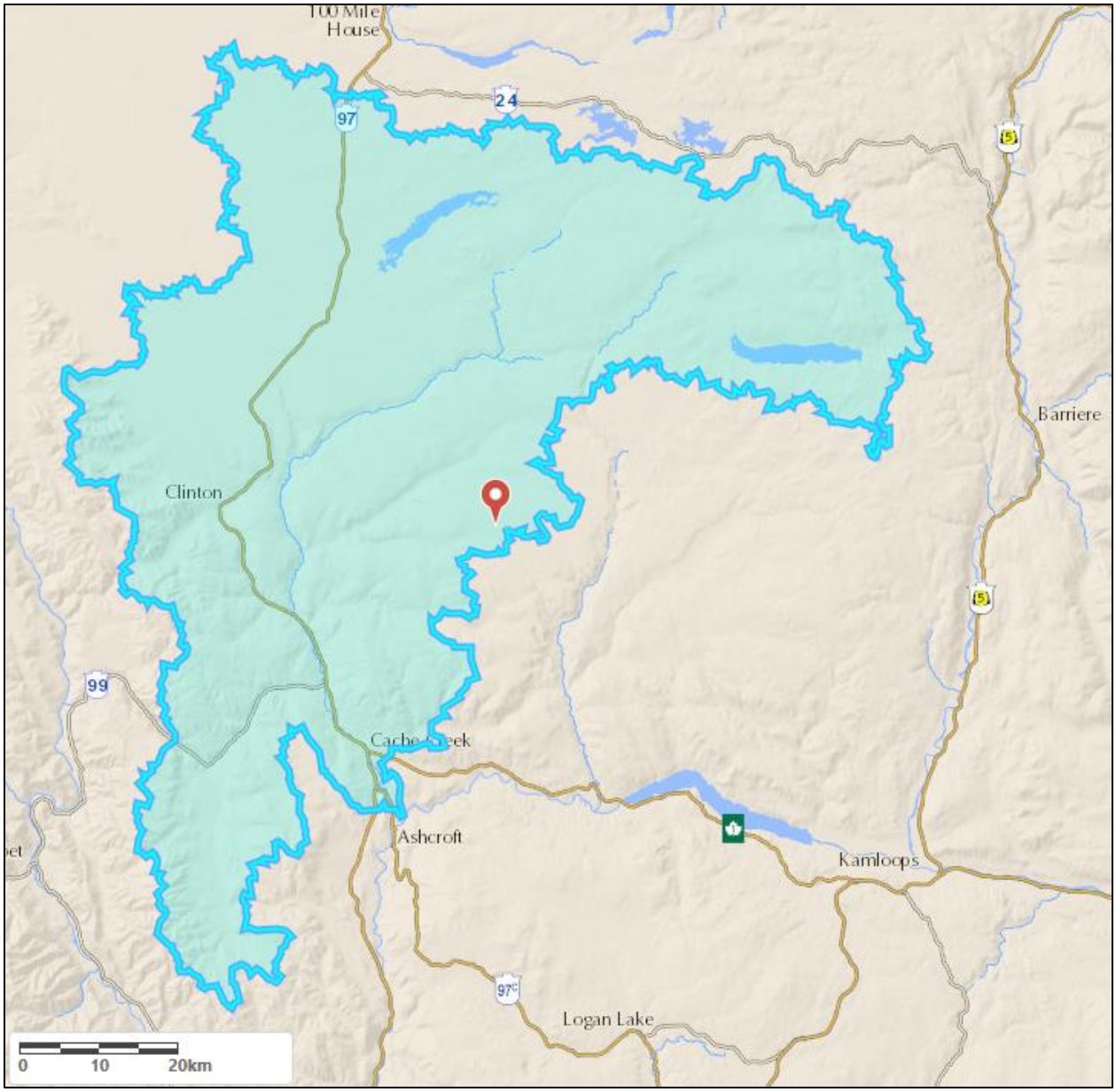


Figure 3.1: Example of a basic watershed map generated using information downloaded and displayed within the BC Data Warehouse using iMapBC. The "Named Watersheds" layer was used to demarcate the watershed boundary. Location: Bonaparte River, B.C.

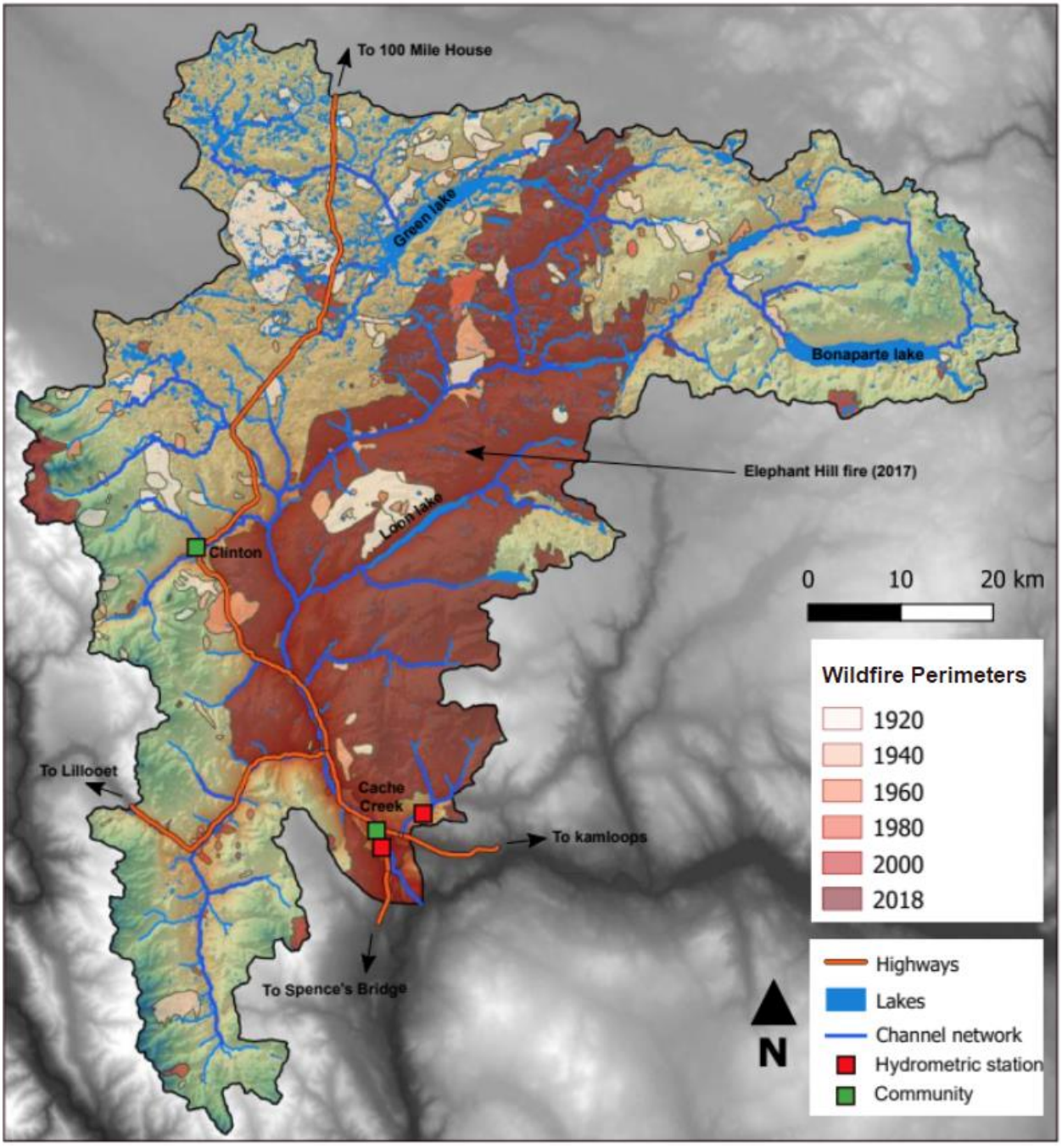


Figure 3.2: Example of a detailed watershed map generated using public data and the QGIS geographic information systems software. Location: Bonaparte River, B.C.

3.1.4 Watershed Climate (current/historical conditions)

A critical factor during most watershed characterizations is a sound understanding of the driving watershed climate in context of historical observations. Climate data is readily available at many monitoring locations from a number of sources (see Section 2.1.4), while information on climate change projections for a number of future emissions scenarios also span the province (see Section 2.1.5). Often, including a basic figure containing present and historical climate information provides important context for drivers and stressors of water (Figure 3.3).

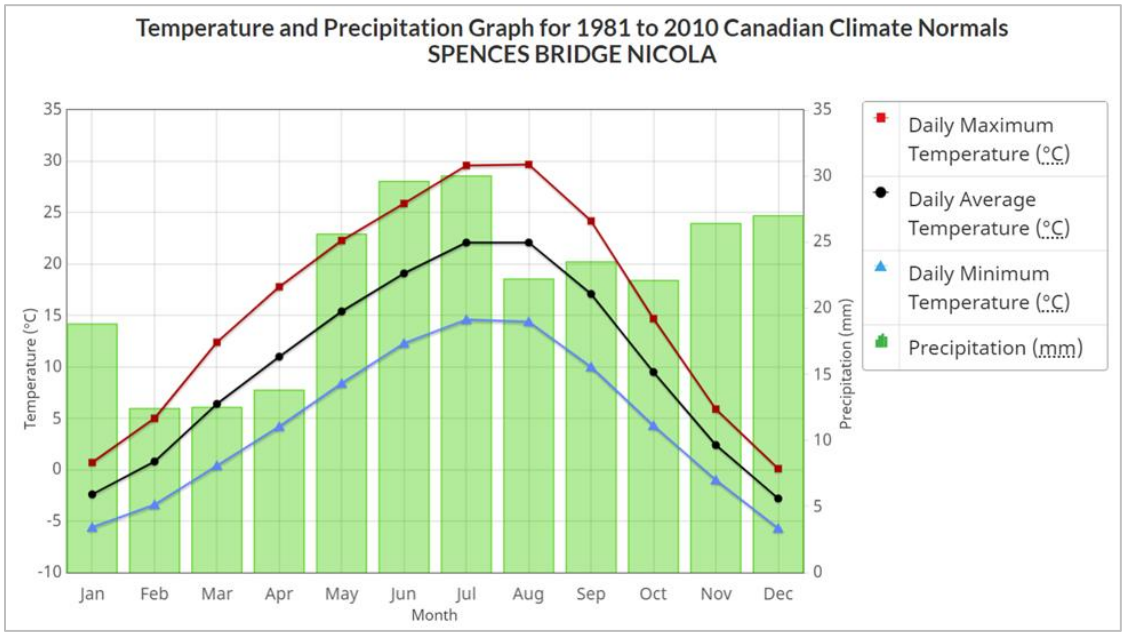


Figure 3.3: Climate summary data available from Environment Canada for Spences Bridge, B.C. Source: EC Climate Normals and Averages website, accessed June 4, 2024.

Basic climate summary information is useful to collect for the watershed of interest as it is often critical for interpreting and identifying the hydrological regime of the area. Understanding projected changes to regional climate is equally important, as these changes can profoundly impact the hydrological regime of an area (Pike et al., 2010). Table 3.3 highlights common questions relevant to historical and contemporary climate information, while Table 3.4 pertains to understanding projected changes in climate.

3.1.5 Climate Change Projections Summary

Typically, a watershed characterization will include information on how climate change will affect air temperatures and precipitation. These changes also translate to water stresses for various land uses and values under study. Table 3.4 provides questions, metrics, and resources helpful for understanding projected changes in climate. It is noted that only a limited set of questions and resources is provided. For example, even when annual precipitation is not expected to change there could be seasonal shifts in the amount of precipitation (e.g., drier summers versus wetter winters) as well as form of precipitation resulting from mean temperature changes (Figure 3.4) that can impact water resources (e.g., higher flood flows, and lower summertime flows). General information about climate models and emissions scenarios to help inform a user's understanding on which apply when looking at forecasted information is available here.

Table 3.3: Questions related to watershed climate.

Question	Purpose	Metrics	Resources
What is the total annual precipitation of the watershed?	Helpful for general understanding of watershed hydrology	mm/yr	Environment Canada PCIC Data Portal ClimateBC BC Hydro Hydrometeorological Data
What is the seasonal distribution of precipitation?	Helpful for defining watershed hydrology and likely flow characteristics in the absence of flow data	mm/month, split into rain and snow	Environment Canada PCIC Data Portal ClimateBC
How variable is precipitation year-to-year?	Helpful for understanding variability in conditions (wet versus dry cycles).	mm/yr	Environment Canada PCIC Data Portal ClimateBC BC Hydro Hydrometeorological Data
Is precipitation likely to be variable across the watershed?	Helpful for understanding spatial variability in conditions.	mm/yr	PCIC Data Portal ClimateBC
How much precipitation falls as rain vs. snow?	Helpful for defining watershed hydrology flood regime (rain versus snowmelt versus mixed)	mm/yr	Environment Canada PCIC Data Portal ClimateBC Snow Survey Data
What depth of snowpack is present in the watershed and when does it typically melt?	Helpful for understanding the role of snow in the hydrology of the watershed	Change in snow depth over season (m)	Snow Survey Data
What is the mean annual temperature?	Helpful for general understanding of physiographic environment	°C	Environment Canada PCIC Data Portal ClimateBC
What is the seasonal distribution of temperature?	Helpful for general understanding of the physiographic environment	°C	Environment Canada PCIC Data Portal ClimateBC
How variable is mean annual temperature year to year?	Helpful for general understanding of the physiographic environment	°C	Environment Canada PCIC Data Portal ClimateBC
How have precipitation and temperature changed historically in the watershed?	May indicate larger scale variability in climatological factors, and/or effects of climate change	Change in °C, change in mm/yr over time. Change in % precip as snow.	Environment Canada ClimateBC
What weather stations exist or have existed in the watershed?	Helpful for a general understanding of physiographic environment, and potentially snowpack	Names of stations	Environment Canada PCIC Data Portal
What is the mean annual evapotranspiration?	Helpful for assessing water surplus in watershed (precipitation minus evapotranspiration)	mm/yr	Farmwest Evapotranspiration Calculator ClimateBC

Table 3.4: Questions related to climate change projections for a watershed of interest.

Question	Purpose	Metrics	Resources
What are the projected changes in total precipitation in the watershed?	Understand future changes to watershed hydrology	Change in mm/yr for rain and snow	ClimateBC PCIC Climate Analysis Tools Canadian Centre for Climate Services Climate Data Portal ClimateData.ca Climate Atlas of Canada
What are the projected changes in winter and summer temperature?	Understand future changes to watershed hydrology, including risks of summer low flows and changes to snowmelt timing	Change in temperature (°C) averaged over season of interest	ClimateBC PCIC Climate Analysis Tools ClimateData.ca Climate Atlas of Canada
How are snow amounts expected to change in the region?	Understand future changes to watershed hydrology and general hydrological regime	Change in snow depth (m) and/or snow water equivalent (mm)	PCIC Climate Analysis Tools ClimateBC
Are there glaciers in the watershed?	Understand future changes to watershed hydrology and general hydrological regime	Ice area (km^2) or volume (m^3) if available. Area as % of watershed area	iMapBC GLIMS
Is the region prone to wildfire or are wildfires likely to become more common?	Understand future changes to watershed hydrology and risks of downstream flooding or channel instability	% or area of watershed that is forested, summer temperatures and precipitation	ClimateBC PCIC Climate Analysis Tools Wildland Urban Interface Risk Class Maps iMapBC

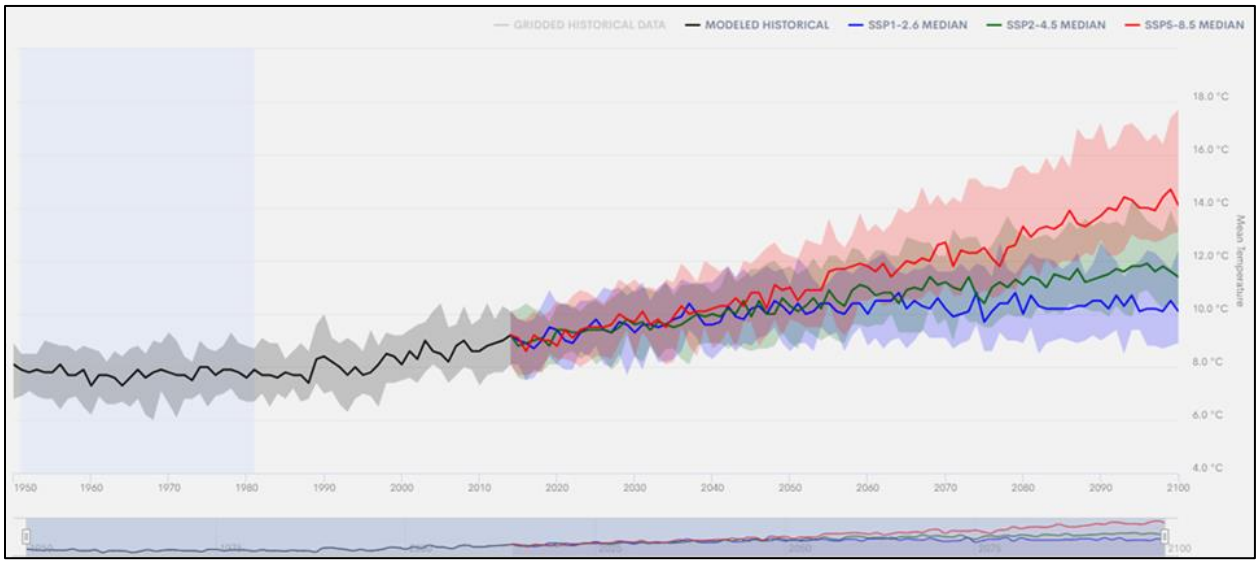


Figure 3.4: Example climate change projections for Cache Creek, B.C. Source: ClimateData.

3.1.6 Surface Water

Often, a visual summary of an annual hydrograph within the watershed is required. As described in Section 2.1.6, several resources are available to generate such a figure. For example, a time series showing the median flow conditions for a given year in relation to historical flow variability is informative for a range of purposes. An example of such a figure, generated for the *Bonaparte River near Cache Creek (Station 08LF002),* is shown in Figure 3.5.

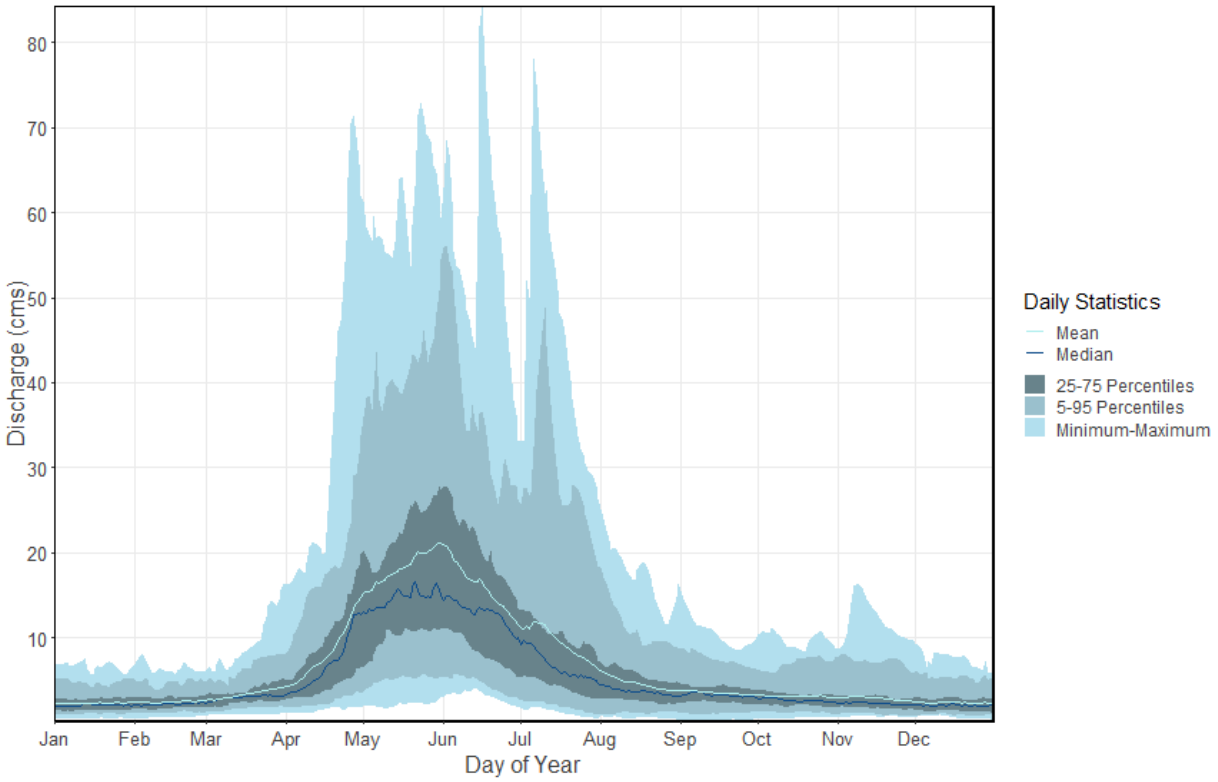


Figure 3.5: Annual hydrographs for the Bonaparte River near Cache Creek (Station 08LF002) collapsed onto a single figure, generated via fasstr R Package. cms = m^3/s

The following questions and associated metrics listed in Table 3.5 can assist in describing the hydrology and drainage characteristics of a watershed. Note that it may not be possible to answer all questions for every watershed using desktop-derived data. However, it is a useful process to follow as any outstanding questions can be used to guide future field investigations. Surface water demand may also impact streamflow characteristics and is captured in Section 3.1.8. A further overview of how various disturbance drivers may impact streamflow is provided in Section 3.1.13 (Table 3.13). Within B.C., there are many differing hydrologic regimes (See: Eaton and Moore 2010). For some watersheds, the variability and duration between low flows to high flows can result in a statistical skew in calculated hydrologic summary statistics. In instances of skew, use of mean statistics may not be the best measure of central tendency. In such cases, medians are usually a better choice for central tendency investigation as are percentiles in the expression of what is normally observed and what is outside of a normal percentile range. It is beyond the scope of this report to discuss hydrologic summary statistics further, but the authors refer the reader to Helsel et al. (2020). A brief overview of methods that may be helpful for users interacting with hydrological data can be found in Section 2.2.2.

Table 3.5: Questions, metrics and resources related to watershed surface water.

Question	Purpose	Metrics	Data / Resources
What is the mean annual discharge (MAD)?	Characterize streamflow magnitude	m^3/s	Water Survey of Canada B.C. Water Tool
What is the median streamflow on each day of the year?	Characterize streamflow magnitude and pattern	m^3/s	Water Survey of Canada
What is the lowest expected discharge observed once every 5 and 10 years?	Characterize streamflow magnitude	m^3/s	Water Survey of Canada
Is there a historical trend in MAD?	Characterize change in streamflow	m^3/s over time	Water Survey of Canada
When do the highest flows occur?	An indicator of different hydrological regimes (rain dominated, snowmelt dominated, etc.)	Average date of annual peak flow	Water Survey of Canada B.C. Water Tool
What is the seasonality of flow? Do low flows occur only in specific seasons or at any time during the year?	Implications for water allocations, aquatic habitat conditions	Hydrograph shape, average date of minimum and maximum streamflow	Water Survey of Canada B.C. Water Tool
Are there any flood warnings and/or advisories in the watershed?	Understanding of current flooding risk	Advisory and warning levels (3 levels; high streamflow advisory, flood watch; and flood warning)	B.C. River Forecast Center
Has a flood frequency analysis been undertaken in the watershed?	Understanding of future flooding risk	Flood magnitudes associated with various return periods (e.g., 1:10, 1:50 yr)	B.C. Extreme Flood Project
What is the expected hydrologic regime (rain, snow, hybrid, glacial) of the area?	Important for understanding impacts of landcover change and climate change on watershed hydrology, especially flood flows and low flows	Timing of peak flows, number of high flow events per year	Water Survey of Canada Environment Canada Historical Climate Data
Does the watershed contain any lakes, wetlands, or glaciers?	Can indicate water sources during dry conditions	Lake or glacier area (km^2) and/or volume (m^3)	iMapBC GeoGratis B.C. Water Tool
What is the role of wetlands, lakes, dams/diversions, glaciers, in shaping daily and/or seasonal discharge?	General understanding of watershed hydrology	Lake and glacier area as a percentage of watershed area (%), wetland area and proximity to stream network	iMapBC GeoGratis B.C. Water Tool

Table 3.5 continued: Questions, metrics and resources related to watershed surface water.

Question	Purpose	Metrics	Data / Resources
Is the water system regulated or natural?	Important for interpreting patterns in streamflow data	Presence of dams and regulation control features	Water Survey of Canada B.C. Water Tool
Are any diversions present (list numbers/types)?	Important for interpreting patterns in streamflow data	Presence of withdrawals, diversions	B.C. Water Tool B.C. Surface Water Licence Search
What is the pattern of streamflow? Does streamflow ever become spatially intermittent along the channel profile? Have zero-flow conditions been measured in the watershed?	Implications for water allocations, aquatic habitat conditions, general characterization of hydrological conditions.	Presence of 0 flow in flow data series, disconnected channel areas Visible on map if stream wide enough	Google Earth Pro B.C. Air Photo Viewer Water Survey of Canada
Are drainage diversions, roads, ditches or other impervious surfaces affecting runoff patterns and timing?	Implications for explaining patterns in streamflow particularly flood events in small streams	Shape of unit hydrograph, presence of turbidity near road crossings	Google Earth Pro iMapBC GeoGratis
Does the stream network freeze in the winter?	Implications for water allocations, aquatic habitat conditions	Presence of ice in imagery, 0 flow in winter identified from streamflow data	Google Earth Pro EO Browser Water Survey of Canada

3.1.7 Groundwater

Numerous resources pertinent to groundwater characterization are available for watersheds in B.C. In many instances, information on groundwater, such as existing licences or water quality, is critical to obtain should future industrial, agricultural, or other water use be planned. Common questions, metrics, and associated resources helpful for characterizing groundwater are shown in Table 3.6. More specific questions regarding groundwater use and demand are provided in Section 3.1.8. A brief overview of methods that may be helpful for users interacting with hydrological or other time series data can be found in Section 2.2.2.

Table 3.6: Questions, metrics, and resources related to watershed groundwater.

Question	Purpose	Metrics	Resources
What groundwater wells exist in the watershed?	Indicator of existing water allocation, % allocation	Number of wells, well allocation	GWELLS – Groundwater Wells and Aquifers Search B.C. Water Tool iMapBC
What aquifer(s) underlay the area of interest? Are aquifers confined or unconfined?	To provide an indication of potential risk to groundwater from surface contamination, and the hydraulic connectivity of groundwater to surface water	Aquifer vulnerability ranking Aquifer presence/ mapped	GWELLS - Groundwater Wells and Aquifers Search iMapBC
Is groundwater the dominant water source for streams during dry periods?	May provide information on surface water impacts from groundwater withdrawals during dry conditions	Stream water temperature close to mean annual temperature (GW temp proxy) in absence of lakes Rate of baseflow recession, presence of alternative water sources	iMapBC GeoGratis Water Survey of Canada ClimateBC
What groundwater monitoring occurs in the watershed?	Helpful for learning about real-time data availability relevant to groundwater characterization	Presence of monitoring stations, type of data monitored	Real-Time Water Data Tool
Have trends in groundwater level been observed over time?	Helpful for understanding how groundwater levels may have changes in response to water use	Change in elevation	Provincial Groundwater Observation Well Network Environmental Reporting B.C.

3.1.8 Water Demand / Supply Pressures

Several resources pertinent to water licences and permitting are available for watersheds in B.C. Information on water licences and permits is helpful for understanding current water use and potential implications of future water use. Common questions, metrics, and associated resources associated with water licensing and permitting are shown in Table 3.7. The "*Groundwater Wells and Aquifers*" search and associated map box can provide an indication of the number of groundwater and surface water users and types of use in the watershed, including an estimate of well yield (where provided). Links to licence documents are also available. The BC Water Tool only considers surface water allocations.

Table 3.7: Questions, metrics, and resources related to water demand and impacts.

Question	Purpose	Metrics	Resources
What surface or groundwater water licences exist in the watershed?	Characterize potential surface water and groundwater use	Number and flow allocation of licences	B.C. Water Licence Query iMapBC Scanned Water Licences BC Water Tool
Is the watershed a Community Watershed?	Provides information on special considerations needed for the watershed	Presence/absence	Community Watershed Tool
Are water use allocation reservations or restrictions in place in the watershed? Have orders curtailing water use even been applied to the watershed?	Indication of whether low stream flows possibly impact groundwater availability, for groundwater-surface water connected systems; and an Indicator of whether water use has been restricted during times of water scarcity, and what form such restrictions take	Water use status	B.C. Drought Monitoring B.C. Water Allocation Notations B.C. Water Reservations *Water Sustainability Act* temporary protection orders iMapBC
Are major industrial or agricultural water users present in the watershed?	Indicator of potential groundwater or surface water demand.	Water withdrawals/allocations by industry	B.C. Water Tool iMapBC GeoGratis B.C. Agriculture Water Use Calculator
When was the last water use licence approved and/or the most recent priority date?	Indicator on whether surface water and/or groundwater is full recorded	Date of water use approval	Groundwater Wells and Aquifers Search (GWELLS)
How many wells exist in the watershed?	Indicator of potential groundwater use	Number of wells, types of use and well yield	Groundwater Wells and Aquifers Search (GWELLS)
What volume and/or fraction of surface water is allocated within the system?	Indicator of remaining capacity for allocation	Volume/year, water withdrawals/ allocations by licence	iMapBC BC Water Tool
How does allocation timing relate to streamflow availability?	Indicator of possible consequences of present allocations or future allocations	Allocation timing relative to streamflow	Authorization Management System B.C. Water Tool

3.1.9 Water Quality

Water quality data and information can provide insight into the state of disturbance within a watershed and to the habitat conditions for a variety of aquatic organisms. Table 3.8 summarizes several key questions and metrics helpful for characterizing water quality. A further overview of how various disturbance drivers may impact water quality is provided in Section 3.1.13 (Table 3.13).

Table 3.8: Questions related to watershed water quality.

Question	Purpose	Metrics	Resources
Are high levels of sediment/ turbidity often observed?	Indicates potential problems for water treatment, potential effects of land cover disturbance, and possible sediment input to streams	SSC (mg/L), TSS, NTU	Surface Water Monitoring Sites Interactive Map BC EMS Sediment Data Search
What is the stream water temperature in summer?	Provides an indication of suitability for habitat for aquatic species; and an indication of groundwater potential	Temperature (°C) during summer months	Water Survey of Canada Real-Time Water Data Tool (Aquarius Time-Series database)
What is the pH of surface and groundwater?	General water quality indicator, may indicate contamination	pH	Surface Water Monitoring Sites Interactive Map B.C. EMS
What is the electrical conductivity of surface and groundwater?	General water quality indicator, may indicate contamination	Microsiemens per centimetre (µS/cm)	Surface Water Monitoring Sites Interactive Map B.C. EMS shinyREMS
Have algae blooms been observed?	General water quality may indicate contamination, especially from agricultural runoff.	Chlorophyll a concentrations (µg/L), pH	B.C. EMS Google Earth Pro Sentinel Hub
Are major industrial or agricultural water users present in the watershed?	Indicator of potential groundwater or surface water contamination. See Table 3.13 for further discussion.	Types of land use activities	iMapBC GeoGratis
Are there any discharge permits approved in the watershed?	Indicator of potential water quality impacts from effluent discharge	Types and number of permits	Authorization Management System
Are there any registered contaminated sites in the watershed?	Compare site locations and issues to vulnerable receptors (aquifers, streams)	Site locations and number	B.C. Contaminated Sites Registry
Have any chemical water quality metrics been observed outside of guidelines?	Helpful for understanding full suite of water quality problems within a watershed	Comparison of water quality data to specific guidelines	B.C. EMS shinyREMS Water Quality Objectives Reports

3.1.10 Fish and Aquatic Ecology

Many watersheds in B.C. contain complex aquatic ecosystems and highly valued fish. To better understand what fish species and aquatic habitat attributes are present in a watershed, and what hazards are projected to impact fish populations due to watershed disturbances such as climate change and wildfires, numerous resources are available. Key questions, metrics, and resources are listed below in Table 3.9.

Table 3.9: Questions related to fish and aquatic ecology.

Question	Purpose	Metrics	Resources
What fish species (including resident and migratory species) are present in the watershed?	Key consideration for effects of changes in streamflow or water quality	Presence/absence by species type; abundance by species type	iMapBC FIDQ
Have federally or provincially listed endangered or at-risk species been identified in the watershed?	Key consideration for effects of changes in streamflow or water quality, and for general changes to land cover	Presence/absence by species	B.C. Conservation Data Centre Interactive Map Government of Canada Species at Risk
Is the watershed a *Fisheries Sensitive Watershed*?	Provide information on conditions surrounding fish and fish habitat	Presence/absence	Fisheries Sensitive Watershed Database
What is the environmental flow sensitivity risk level for the primary course in the watershed?	Provides information on sensitivity of aquatic ecosystem to changes in streamflow	Risk level	B.C. Water Tool Environmental Flow Needs Policy
If salmon are present, are they part of a specific conservation unit?	Helpful for evaluating status of salmon stocks in each watershed	Unit identifier	Pacific Salmon Conservation Units
Are any hatcheries present in the watershed?	Helpful for evaluating status of salmon stocks in each watershed	Presence/absence	Hatcheries and Spawning Channels
What are the projected changes to salmon exposure in the freshwater environment within B.C.?	Understanding risks to salmon populations from changes to water temperature as a result of climate change	Indices describing exposure to various streamflow and water temperature hazards	Salmon Climate Impacts Portal (SCIP)
How will wildfires impact salmon populations and habitat in B.C.?	Identifying assessment procedures to measure wildfire impacts and risks to salmon and salmon habitat	Risk-based guidance	Wildfire Playbook

3.1.11 Terrestrial Ecology

To better understand key aspects of terrestrial ecology in a watershed, numerous resources are available. A sample of key questions, metrics, and resources are listed below in Table 3.10.

Table 3.10: Questions related to terrestrial ecology.

Question	Purpose	Metrics	Resources
Have endangered species been identified in the watershed?	Key consideration for effects of changes in streamflow or water quality, and for general changes to land cover	Presence/absence by species	Conservation Data Centre Interactive Map
Have federally listed species at risk been identified in the watershed?	Provide information on sensitive species within the watershed	Presence/absence by species	Government of Canada Species at Risk
Are sensitive ecosystems present in the watershed?	Provide information on presence of sensitive ecosystems	Presence/absence, boundary data	Sensitive Ecosystems Inventory (SEI) Project Boundaries
What BEC zones does the watershed contain?	Provides information on general ecological conditions	Zone type and area	ClimateBC iMapBC
What ecoregion/ecosection does the watershed fall within?	Provides information on general ecological conditions	Ecosection type	Biogeoclimatic Ecosystem Classification (BEC) Program
What fraction of the watershed is forested?	Implications for watershed hydrology and historical/future changes to flow characteristics re: forest cover	% forested area	BC Vegetation Resource Inventory Google Earth Pro
What is the species composition of forested and riparian areas?	Can provide clues surrounding watershed disturbance and land use history	Area by species (km^2)	BC Vegetation Resource Inventory
What fraction of the watershed is old growth?	Relevant to watershed hydrology and disturbance history	Area by age (km^2)	BC Vegetation Resource Inventory

3.1.12 Geology and Geomorphology

The mountainous terrain and glacial history of B.C. create complex geologic and geomorphological conditions that fundamentally influence key watershed processes (Slaymaker, 2017) and aquatic habitat conditions (Reid et al., 2019). Questions, resources, and metrics associated with geology and geomorphology are shown in Table 3.11. Often, satellite or aerial imagery is needed to address many of the questions below.

Table 3.11: Questions related to watershed geology and geomorphology.

Question	Purpose	Metrics	Resources
Have there been any recent extreme floods? If not, how long ago was the last major flood?	May indicate consequences of watershed disturbance; may indicate additional channel change is possible	Floods of high return period (>1:10) in last five years	Water Survey of Canada
Are there landslides or debris flows in the watershed, or are these likely to occur?	Can indicate risk of channel change, flooding, and other downstream hazards from changes in sediment inputs	Presence of landslides/debris flows, steep, mountainous terrain	iMapBC Google Earth Pro Sentinel Hub BC Air Photo Viewer
Is water often observed to be turbid during high flows or after rain, but otherwise clear?	Can indicate a high level of sediment input, supply or movement; may indicate water quality issues	NTU or SSC (mg/l), unit hydrograph	Surface Water Monitoring Sites Interactive Map Sediment Data Search
Are large or new gravel bars apparent in the stream or river channel?	Indicates high sediment input and channel migration potential	Presence of large gravel bars	Google Earth Pro Sentinel Hub BC Air Photo Viewer
Does the channel show signs of erosion / sediment deposition?	Can indicate a change in the quantity of sediment supplied to the channel, or changes in streamflow from watershed disturbance	Lateral movement of stream, ratio of channel depth to width, collapsing streambanks	Google Earth Pro Sentinel Hub BC Air Photo Viewer
Does the watershed contain any active alluvial fans, historical channel widening, or obvious sediment sources?	Can indicate a potential for change in the quantity of sediment supplied to the channel	Presence of fans, change in channel width, prominent erosion features	Google Earth Pro Sentinel Hub BC Air Photo Viewer
What is the surficial and bedrock geology of the region?	Can provide general information on the erodibility of the watershed	Presence of weak sedimentary rock, glacial deposits	BC Surficial geology mapping BC Geological Survey

3.1.13 Watershed Disturbance

Land cover disturbances in watersheds can take many forms, but in B.C., prominent disturbance factors are related to wildfire, insect infestations (e.g., Mountain Pine Beetle), and those related to forestry. A watershed disturbance can be considered distinct from land use in that the disturbance is usually temporary, with recovery of forest likely to occur. As with changes in land use, watershed disturbances

influence hydrology and water quality through changes in land cover (in B.C., often forests), and potentially, through changes in the infiltration capacity of the soil surface (Winkler et al., 2010). Table 3.12 outlines relevant questions, resources, and metrics associated with characterizing disturbance factors in a watershed. Table 3.13 outlines potential impacts of listed disturbance drivers to water quality and quantity.

Table 3.12: Questions related to watershed disturbance.

Question	Purpose	Metrics	Resources
Has the watershed been logged? If so, when, where and how much?	Implications for watershed hydrology and historical/future changes to flow characteristics	Area logged (km^2), area by logging date, area as a % of watershed	iMapBC BC Vegetation Resource Inventory
Have wildfires occurred in the watershed?	Implications for watershed hydrology and sediment yield, and ongoing changes in flow characteristics	Area burned (km^2), burn area as a % of watershed area	iMapBC Google Earth Pro
Has the watershed been affected by forest pests such as pine beetle?	Implications for watershed hydrology and historical/future changes to flow characteristics	Area affected (km^2), severity of outbreak, area as % of watershed area	iMapBC
Have any major windstorms affecting forest cover occurred?	Implications for watershed hydrology and potentially future sediment yield	Area (km^2) and % watershed affected	Environment Canada Google Earth Pro iMapBC
Have any major landslides or debris flows been documented?	Implications for sediment transport and stream channel stability	Presence of landslides/debris flows, volume of material added to streams	Google Earth Pro BC Air Photo Viewer
Has placer mining ever occurred in the watershed?	Implications for sediment transport and stream channel stability	Presence of mining, length of channel affected (km)	Google Earth Pro Mineral Titles Online
What length of road network is present in the watershed?	Implications for watershed hydrology, landslide hazard, and suspended sediment yield	Length of road by surface type (km)	iMapBC
How has river morphology (e.g., channelization, width) been modified over time?	Implications for flow, sediment transport and stream channel stability	Shape of channel and width between channel side banks	iMapBC Google Earth Pro
How much historic floodplain has been lost due to diking?	Implications for flow, sediment transport and stream channel stability	Change of floodplain area over time	iMapBC Google Earth Pro
What is the future disturbance potential in the watershed?	Indication of future planned or unplanned disturbance (e.g., forestry, wildfire risk)	Potential project changes	Forest Operations Map iMapBC

Table 3.13: Potential impacts of disturbance drivers on water quantity and quality.

Stream flow or quality parameter	Sector / Activity	Drivers / Stressors
Streamflow	Natural systems	Weather, climatic variability, natural alterations to vegetation and ground surfaces, high tides, wildfire, natural dam failures (e.g., beavers, landslides, glacial outbursts), forest health, insects (e.g., mountain pine beetle)
	Forestry	Equivalent clearcut area (ECA), location of harvest, vegetation replacement, roads, stream crossings, altered drainage, soil disturbance, log driving
	Range	Water extraction/diversions, soil compaction, vegetation changes
	Agriculture	Roads, water extraction/irrigation/diversions, vegetation alteration, dikes
	Urban	Stormwater systems, roads, water extraction, percentage of impervious surfaces, dikes/dams, regulated systems, vegetation alteration
	Oil/Gas	Roads, borrow pits, water extraction, vegetation alteration, drilling requirements, drainage diversions
	Mining	Roads, drainage alterations, borrow pits, water extraction, vegetation alteration, tailing ponds (including seepage), open pit / underground workings drainage, channel diversions associated with works
	Power/run-of-river projects	Flow impoundments (dams), penstock diversions, flow retention and release schedules
	Other	Climate change, glacier recession, fisheries-related diversions, water extraction/irrigation/diversions
Sediment/turbidity	Natural systems	Instream erosion, mass wasting, surface erosion from fine-grained materials, extreme runoff events, wildfire, forest health drivers
	Forestry	Roads, road deactivation (level of), watershed restoration (level of), stream crossings, increased mass wasting, altered drainage, log driving
	Range	Livestock near water bodies (pugging), removal of riparian vegetation
	Agriculture	Certain tillage/crop practices, runoff over bare soil
	Urban	Construction near waterways, stormwaters, roads
	Oil/Gas	Roads, borrow pits, waste waters, construction activities
	Mining	Tailings, roads, open pit excavations, placer and other operations, construction activities
	Recreation	Motorized vehicles, jet boats
	Power/run-of-river projects	Increased turbidity at penstock outlet, reduction in sediment loads due to upstream impoundments, lake drawdown and bank instability
	Other	Gravel extraction, disturbed lake beds, reduction of flushing fluids due to hydrograph changes (natural or anthropogenic)

Table 3.13 continued: Potential impacts of disturbance drivers on water quantity and quality.

Stream flow or quality parameter	Sector / Activity	Drivers / Stressors
Pathogens	Natural systems	Wildlife (e.g., beavers, wolves, waterfowl), natural occurrence
	Forestry	Site specific /camps
	Range	Livestock near water bodies
	Agriculture	Manure runoff, waste waters
	Urban	Stormwater, septic/sewer, waste waters
	Oil/Gas	Site specific with camps or operations
	Mining	Sewage and putrescible waste
	Recreation	Campsites / human wastes, boats and/or gear moving between ecosystems and spreading diseases (e.g., whirling disease)
Nutrients (e.g. nitrogen, phosphorous)	Natural systems	Wildfire, widespread insect outbreaks, animals (e.g., salmon), forest health, mass wasting
	Forestry	Vegetation clearing, vegetation replacement, herbicides, fertilizers, soil disturbance, soil erosion, prescribed burning, fire retardants and suppressants, blasting residue (e.g., nitrates from explosives), increased mass wasting
	Range	Livestock near water bodies (manure), soil erosion, fertilizer, herbicides
	Agriculture	Fertilizers, herbicides, soil disturbance, manure runoff, wastewater discharges, soil erosion and sediment delivery
	Urban	Stormwater, fertilizers, septic/sewer, waste-water discharges, development that exposes soils
	Oil/Gas	Sewage associated with camp or other operations, roads, activities that increase sedimentation
	Mining	Sewage associated with camps, blasting residue (e.g., nitrates from explosives), soil erosion and sediment delivery
	Recreation	Recreational vehicle sanitation dumps, brown/grey water discharges, campsite outhouses
	Other	Any activity that alters background pH (e.g., some mining activities), retention of nutrients (e.g., phosphorus) by activities such as hydroelectricity generation and damming, increases erosion and sedimentation, or alters nutrient cycles (soil/vegetation)
Metals	Natural systems	Natural metal-bearing rock, atmospheric deposition (e.g., mercury), runoff levels
	Forestry	Fertilizers, herbicides, soil disturbance, road building
	Range	Fertilizers, herbicides, soil disturbance
	Agriculture	Fertilizers, herbicides, soil disturbance
	Urban	Stormwater, sewer/septic, waste-water treatment, permitted discharges

Table 3.13 continued: Potential impacts of disturbance drivers on water quantity and quality.

Stream flow or quality parameter	Sector / Activity	Drivers / Stressors
Metals, continued	Oil/Gas	Borrow pits, discharges and return flow associated with hydraulic fracturing practices that alter pH
	Mining	Tailings (deposited at surface or in natural water bodies by historical operations), seepage from tailings impoundments and waste rock dumps, open pit / underground oxidation products, permitted discharges, and other mining activities or practices that alter pH of drainage
	Other	Any activity that alters drainage and/or increases flow and drainage through metal-rich materials / soils, or practices that alter pH of drainage, other permitted discharges
Dissolved oxygen	Natural systems	Low flows, anoxic environments, forest health
	Forestry	Deposition of slash and organics in water ways, fertilization with phosphorus (P), alteration of stream temperatures, alteration of channel roughness
	Range	Removal of riparian vegetation, stream bank alterations that cause channel widening
	Agriculture	Added organics (including runoff), fertilization with phosphorus, reductions in streamflow, groundwater extraction
	Urban	Reductions in flow, organics in stormwater, waste/septic discharges, groundwater extraction
	Oil/Gas	Reductions in flow, groundwater extractions, drainage diversions to borrow pits
	Mining	Reductions in flow, groundwater extractions, drainage diversions
	Power/run-of-river projects	Upstream impoundments, flow release schedule
	Other	Activities that lead to the addition of organic matter and/or wastes
Water temperature	Natural systems	Presence of wetlands/lakes, climatic variability, drought, insects, wildfire, wildlife (e.g., beavers), forest health, natural events that alter riparian vegetation, streamflow, or channel conditions
	Forestry	Harvesting riparian areas, altered sediment and flow regimes, stream channel widening (sometimes historic), road /ditch drainage diversions
	Range	Removal of riparian vegetation, stream bank alterations that cause channel widening
	Agriculture	Reductions in surface flows, groundwater extractions, riparian/channel modifications/diversions
	Urban	Reductions in surface flows, groundwater extractions, riparian modifications, drainage diversions
	Oil/Gas	Reductions in flows, groundwater extractions, drainage diversions

Table 3.13 continued: Potential impacts of disturbance drivers on water quantity and quality.

Stream flow or quality parameter	Sector / Activity	Drivers / Stressors
Water temperature, continued	Mining	Reductions in flows, groundwater extractions, drainage diversions, tailings impoundments, and process-water recycling
	Power/run-of-river projects	Upstream impoundments, penstock return flow, hydro reservoir releases
	Recreation	Riparian modifications
	Other	Removal of wood from stream channels
pH	Natural systems	Atmospheric deposition (precipitation), flow regime changes
	Forestry	Fertilizers, herbicides, new plant ecosystems from regrowth activities that may change soil pH
	Range	Fertilizers, herbicides, manure
	Agriculture	Application of lime agents, water extraction from lakes with long residence times
	Urban	Discharges, water extraction from lakes with long residence times
	Oil/gas extraction	Discharges, flow back (water returned to the surface via hydraulic fracturing operations)
	Mining	Permitted discharges, seepage from mine infrastructure (tailings ponds, ore stockpiles, waste rock dumps), and other discharges
	Other	Water extraction from lakes with long residence times, retention of nutrients (e.g., phosphorus) by activities such as hydroelectricity generation and damming
Electrical conductivity	Natural systems	Annual variability between different runoff storage reservoirs (i.e., snowpack, groundwater, surface, rain, glaciers)
	Forestry	Road de-icing, drainage diversions/alterations
	Agriculture	Surface runoff, drainage diversions / alterations
	Urban	Road and surface runoff, road de-icing operations, road salts
	Oil/Gas	Hydraulic fracturing return flow (saline waters), drainage diversions/alterations
	Mining	Permitted discharges, drainage diversions/alterations, other discharges
	Recreation	Road de-icing (e.g., for ski hill operations and access to other recreational sites)
	Other	Runoff from airports, chemical discharges, saltwater intrusion to aquifers

3.1.14 Traditional Territories, Land Titles, and Ownership

The details of watershed territories, titles, and ownership often have implications for watershed development and should be considered in a characterization. A summary of questions, metrics, and associated resources for characterizing watershed territories, titles, and ownership is shown in Table 3.14.

Table 3.14: Questions related to watershed territories, titles, and ownership.

Question	Purpose	Metrics	Resources
Whose traditional territory does the watershed of interest fall in? Are there reserve lands or treaty lands present in the watershed?	Identify ownership, rights and titles in the watershed	Identification and location(s) of traditional territory, reserve lands, or treaty lands	Native Land Digital First Peoples Map of BC First Nations Profiles Interactive Map
Are there community forest agreements (CFAs) present in the watershed?	Identify CFAs in the watershed	Identification and location(s) of CFAs	Community Forest Agreements
What private land is present in the watershed?	Implications of what impacts and future developments are possible in the watershed	Area (km^2) and location of private land	B.C. Land Title and Survey Map
What parkland/other protected land is within the watershed?	Implications of what impacts and future developments are possible in the watershed	Area (km^2) and location of protected land	iMapBC
What mineral titles and timber licences are present in the watershed?	Implications of what impacts and future developments are possible in the watershed	Area (km^2) and location of titles and timber rights	iMapBC

3.1.15 Other Land Use (Non-Forestry)

The details of watershed land use have profound implications for watershed hydrology, water quality, and habitat conditions. In particular, land uses that have a high direct water use (especially during dry periods), which remove large swathes of forested area, or create impermeable surfaces can cause substantial changes to streamflow characteristics (Winkler et al., 2010). A summary of questions, metrics, and associated resources for characterizing watershed land use is shown in Table 3.15. For questions relating to forestry and potential disturbances, see Section 3.1.13.

Table 3.15: Questions related to land use.

Question	Purpose	Metrics	Resources
Agriculture presence?	May have implications for existing water use, water quality, and stream channel characteristics	Presence or absence of agricultural areas	Google Earth Pro iMapBC
What land area has been cleared for agriculture and what types of agriculture occur?	May have implications for watershed hydrology and water quality	Area (km^2)	Google Earth Pro iMapBC
Are other industries operating in the watershed (e.g., mining, oil and gas)	May have implications for watershed hydrology and water quality, and impacts on water availability	Presence or absence of industry	iMapBC BC Water Tool
Do any communities exist in the watershed?	Implications for water quality (e.g., from urban runoff), risk of impacts from flooding or river dynamics	Presence or absence of communities	Google Earth Pro GeoGratis
How does the timing of water demand compare to timing of water availability?	Implications for effects to streamflow	Relative timing	Agricultural Water Use Calculator
Is the watershed a Community Watershed?	Provide information on special considerations needed for the watershed	Presence/absence	Community Watershed Tool
What fraction of the watershed is urbanized?	Implications for water quality (e.g., from urban runoff), risk of impacts from flooding or river dynamics	% area of total watershed	Google Earth Pro GeoGratis
What parkland/other protected land is within the watershed?	Implications of what impacts and future developments are possible in the watershed	Area (km^2) and location of protected land	iMapBC

3.1.16 Socio-Cultural Values

Many watersheds in B.C. possess high levels of social, recreational, and cultural values, ranging from significant sites for First Nations, to recreational sites and parkland. Understanding the cultural values present in each watershed is important when undertaking a characterization. A summary of questions, metrics, and resources related to watershed characterization is shown in Table 3.16.

Table 3.16: Questions related to watershed cultural values.

Question	Purpose	Metrics	Resources
Are there known sites of cultural significance?	Identify watershed areas of high cultural importance	Presence/absence of First Nations cultural sites	First Nations Profiles Interactive Map
What recreational opportunities / uses exist in the watershed?	Identify sites of high value or which may be of high recreational value in the future	Presence/absence of recreational opportunities by type	iMapBC
What recreation infrastructure is present?	Identify existing sites of high importance	Presence/absence of infrastructure by type	Sites and Trails BC Trailforks

4. EXAMPLE WATERSHED CHARACTERIZATION

In this section, an example of a watershed characterization is presented using the resources (Section 2) and guiding questions (Section 3) outlined in this Watershed Characterization report. The purpose of this example is to illustrate how these resources can be applied to address specific (in our example, fictional) watershed characterization objectives, and how to build a broader understanding of a watershed. This example uses information about hydrology, climate, ecology, land use, etc. obtained from the data sources identified in Section 2.1 (*Data Sources*). The example characterization links primary themes together as outlined in Figure 4.1, a sequence which leads to a comprehensive watershed characterization. While this example aims to be thorough by incorporating many of the question templates, tools, and resources outlined previously, in practice, every watershed characterization is different and hence additional elements may need to be considered.

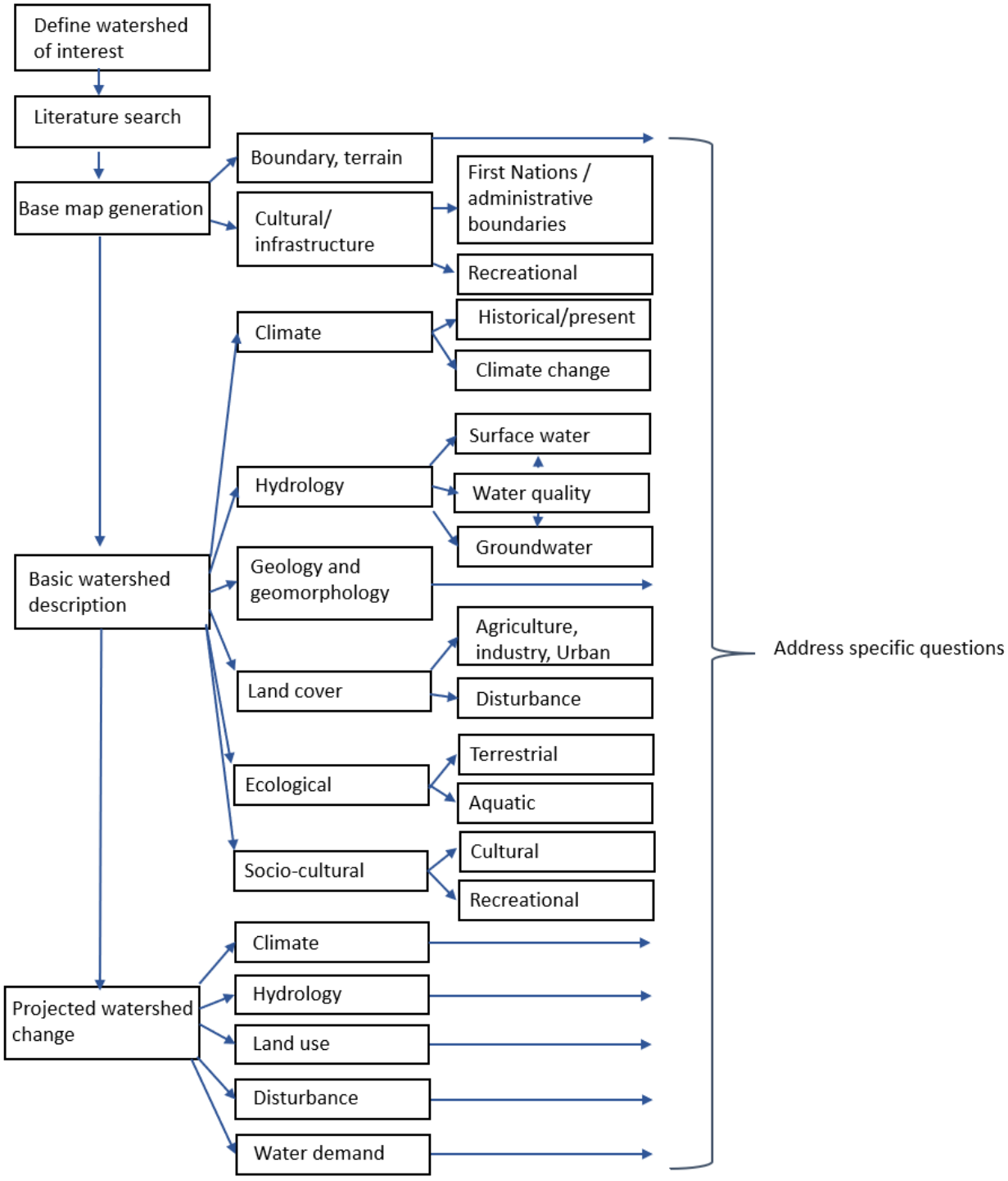


Figure 4.1: Generalized workflow for undertaking a comprehensive watershed characterization.

4.1 Background Prompting Characterization

After a series of hotter and drier-than-average summers, a farmer near Clinton, B.C. contemplates the need to expand irrigating their crops during future growing seasons. The farmer is interested in applying for a licence to withdraw water from Clinton Creek (near the mouth) just northeast of the village of Clinton, B.C. (elevation 900 m asl). The farmer is aware that water availability is a concern in the region and as a first step would like to do a preliminary watershed characterization prior to deciding whether to apply for a water licence. The characterization is to help identify information and answer questions to better understand the watershed and its associated pressures past and future with respect to their property (referred to as the 'farm property'; located at 51° 5'50.00"N, 121°35'25.00"W) and intended water use for irrigation.

In this example, the farmer intends to follow the general workflow in Figure 4.1 and templates under Section 3 (*Potential Characterization Questions and Objectives*) of this report but is not concerned with obtaining information on every potential watershed characterization category nor obtaining detailed information for each category (i.e., only as much detail required for them to understand watershed context). The focus of the characterization is developing an understanding of the general hydrology of the watershed, in particular, the streamflow and groundwater availability in the watershed, and how pressures like climate change may affect future water availability on their farm. Information of secondary importance for them includes better understanding the ecological values and cultural values associated with the watershed, and potential cumulative watershed impacts. NOTE: This is not a template for gathering information to support a water licence application.

4.2 Characterization Components

4.2.1 General Description and Overview Map

Using the most recent (default) satellite images from Google Earth Pro as a basemap, the BC Freshwater Atlas (FWA) from the BC Webmap library was imported as a KML file into Google Earth Pro. Google Earth is a suitable environment to view data layers because of the application's ability to easily import multiple datasets at once. Layers can be turned on (visible) and off (invisible), and viewed holistically (i.e., all at once) by the user.

With the Freshwater Atlas layer added to Google Earth, the 'FWA Assessment Watersheds' and 'FWA Assessment Watersheds Outlined' layer check boxes were selected. These layers were selected because of their similarity, in terms of watershed boundary information, to the BC Water Tools. Selecting these layers in Google Earth resulted in the ability to display basic watershed details such as the watershed boundary and the location of streams (Figure 4.2).

Additional information obtained and displayed indicated the following about the watershed. Topographic information from Google Earth indicates that the watershed ranges in elevation from 850 to 2000 m asl and is largely forested with some development (industrial, commercial, and residential) located in the lower reaches. The predominant drainage direction is east / southeast into the Bonaparte River, located downstream of the farm property. The drainage network within the watershed contains multiple tributaries (1st, 2nd and 3rd order streams based on the FWA) draining into Clinton Creek. The watershed is approximately 69.5 km^2 with a perimeter of approximately 51 km (using polygon area and perimeter measurement tools in trace mode) for the displayed watershed boundary from the BC Freshwater Atlas (Figure 4.2). Historic imagery (dating back to 1985) suggests that roads and land use have not changed significantly in the watershed based on the visible physical features that can be identified in areal imagery.

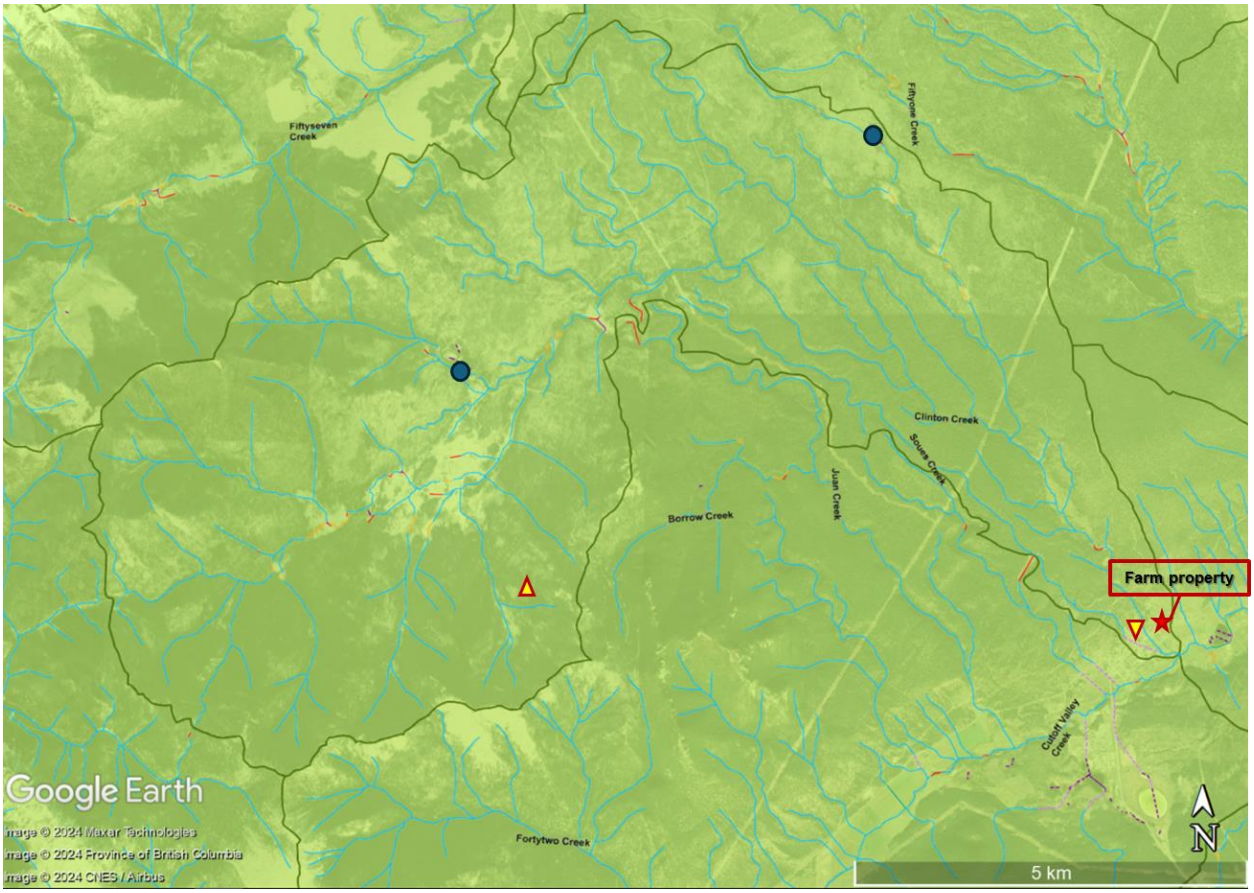


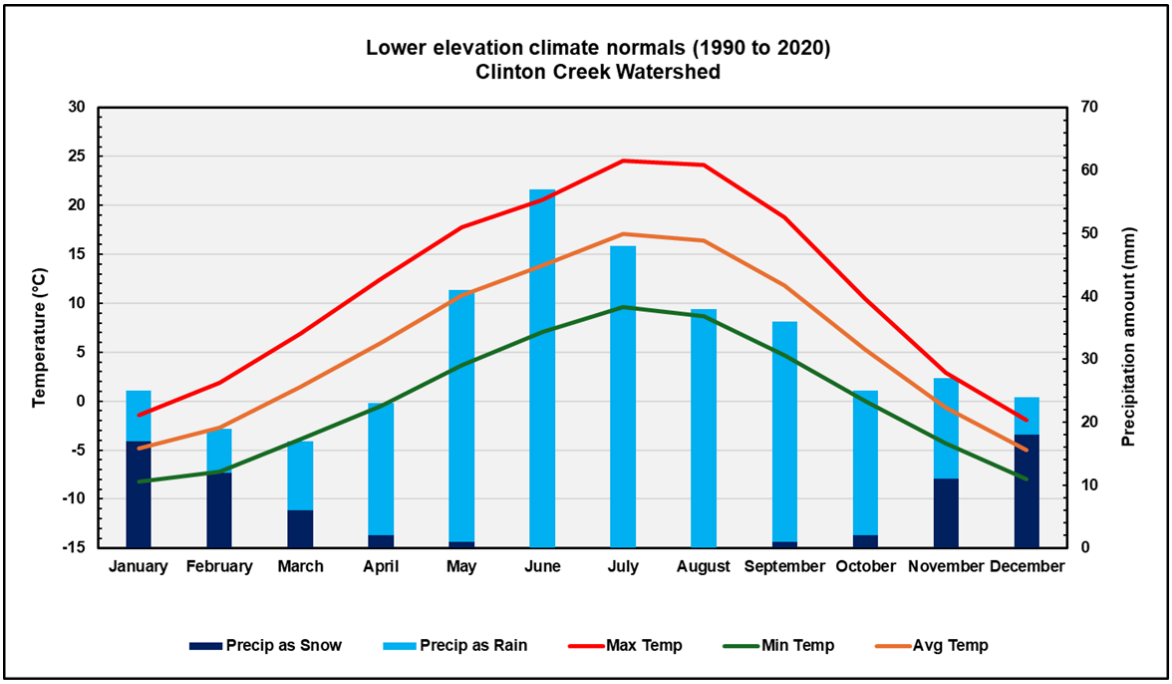
Figure 4.2: Clinton Creek watershed shown with the locations of the Farm property (star), watershed boundaries (dark green lines), and streams (blue lines), and higher elevation (triangle) and lower elevation (inverted triangle) climate data location from ClimateBC. Approximate locations of reservoirs (blue circles) shown based on information from BC Water Tool (Cariboo).

Key points / interpretations: *There is a significant drainage area (~70 km^2) and stream network upslope of the farm. The drainage basin area is of sufficient size and elevation range to possibly receive inflows of surface runoff and groundwater across the seasons as well as capture, detain and release cold and warm weather precipitation. The characterization now looks at climate, future changes, and hydrologic-related information.*

4.2.2 Historical Climate

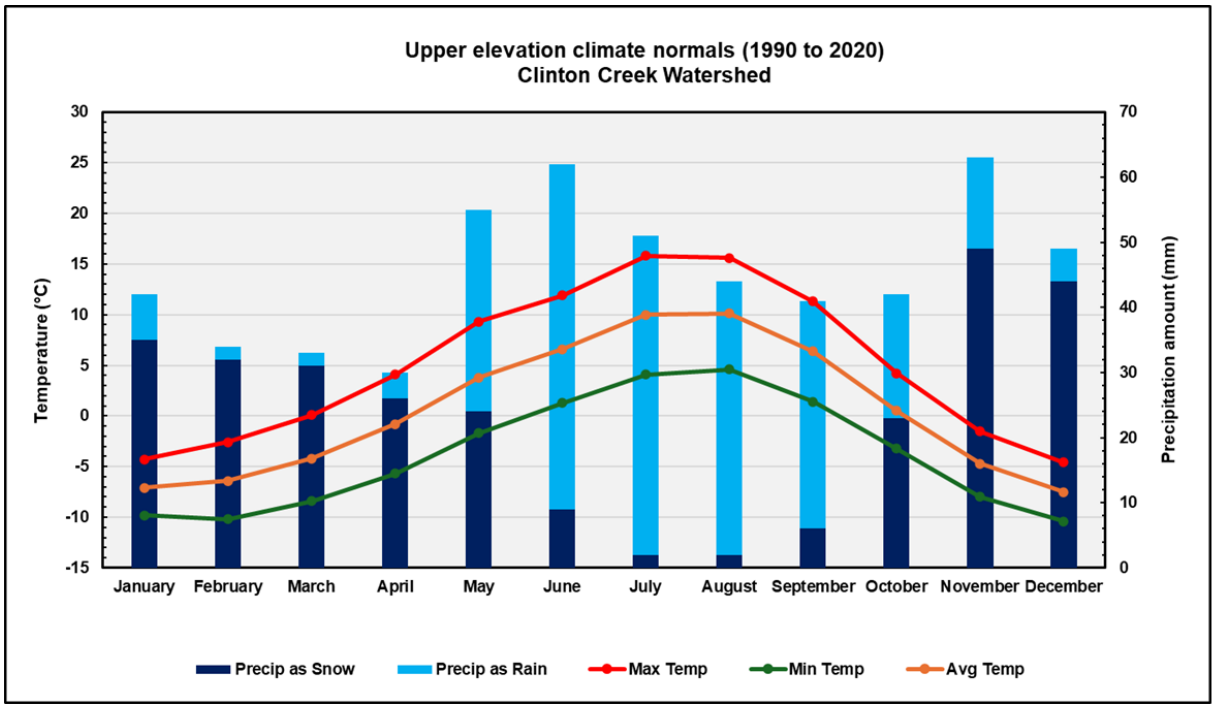
A search for climate data on the Government of Canada's Historical Climate Data website indicates two Environment Canada climate stations near the Village of Clinton: i) Clinton A (Station ID 1161662), and; ii) Clinton RCS (Station ID 1161663). Neither of these stations are located within the Clinton Creek watershed, but due to close proximity (~20 km from the watershed boundary) and elevation (1126.2 masl and 1059.0 masl, respectively), data from these stations are deemed to be representative of the lower elevation areas of the watershed. While data is currently available at these two stations, a long-term climate record (i.e., 30-year data set) is not. A search for climate data on the Historic Climate Data website indicates another climate station, Clinton (AUT) (Station ID 1161661), however it is an incomplete dataset for most of the 1990s and 2000s. As such, information from ClimateBC was used to learn about climate normal for the area of interest due to the unavailability of continuous climate data.

Historic climate data from ClimateBC is reported for higher elevation (1985 masl) and lower elevation (885 masl) areas of the Clinton Creek watershed within the historic period of 1991 to 2020. The higher elevation data is from the headwaters of the watershed while the lower elevation data is from the approximate location of the farm property (Figure 4.2). The historic climate data from these two locations provides an understanding of the potential climate variability across the entire watershed. Climate data was exported into Microsoft Excel and graphed (Figure 4.3 and Figure 4.4), and further summarized in Table 4.1. The farmer is interested in precipitation amounts, form (i.e., rain vs snow), timing, and air temperatures that may influence the seasonal availability of water. Additionally, there is an interest in seasonal temperatures that are important to consider for their business (i.e., what and when to plant).



	Max Temperature (°C)	Min Temperature (°C)	Average Temperature (°C)	Precipitation as Snow (mm)	Precipitation as Rain (mm)	Total Precipitation (mm)
January	-1.4	-8.2	-4.8	17	8	25
February	1.9	-7.2	-2.7	12	7	19
March	6.9	-3.9	1.5	6	11	17
April	12.5	-0.5	6	2	21	23
May	17.8	3.7	10.8	1	40	41
June	20.6	7.1	13.9	0	57	57
July	24.6	9.6	17.1	0	48	48
August	24.1	8.7	16.4	0	38	38
September	18.8	4.7	11.8	1	35	36
October	10.5	0	5.3	2	23	25
November	2.9	-4.3	-0.7	11	16	27
December	-1.9	-8	-5	18	6	24

Figure 4.3: Climate normal data (1990 to 2020) for the Clinton Creek watershed at 885 masl provided by ClimateBC.



	Max Temperature (°C)	Min Temperature (°C)	Average Temperature (°C)	Precipitation as Snow (mm)	Precipitation as Rain (mm)	Total Precipitation (mm)
January	-4.3	-9.8	-7.1	35	7	42
February	-2.6	-10.2	-6.4	32	2	34
March	0.1	-8.4	-4.2	31	2	33
April	4.1	-5.7	-0.8	26	4	30
May	9.3	-1.7	3.8	24	31	55
June	11.9	1.3	6.6	9	53	62
July	15.8	4.1	10	2	49	51
August	15.6	4.6	10.1	2	42	44
September	11.3	1.4	6.4	6	35	41
October	4.2	-3.2	0.5	23	19	42
November	-1.5	-8	-4.7	49	14	63
December	-4.6	-10.4	-7.5	44	5	49

Figure 4.4: Climate normal data (1990 to 2020) for the Clinton Creek watershed at 1985 masl provided by ClimateBC.

Table 4.1: Historical climate for the Clinton Creek watershed.

Question	Notes	Value
What is the total precipitation of the watershed?	Mean annual precipitation from 1991 to 2020; data from ClimateBC	Lower elevation precipitation: 379 mm/yr Higher elevation precipitation: 547 mm/yr Total precipitation at lower and higher elevation stations is averaged: 463 mm/yr = VERY LOW Precipitation regime, flagged for possible drought stresses.
What is the seasonal form of precipitation?	Precipitation from 1991 to 2020; data from ClimateBC	At lower and higher elevation, snowfall is the predominant form of precipitation overall in the winter (November to February)
How much precipitation falls as rain vs. snow?	Precipitation as snow from 1991 to 2020; data from ClimateBC	Lower elevation: 18.5% as snow (70 mm/yr); 81.5% as rain (309 mm/yr) Higher elevation: 52.1% as snow (285 mm/yr); 47.9% as rain (262 mm/yr)
What is the average depth of snowpack in the watershed?	No snowpack data available Precipitation as snow (i.e., snow water equivalent [SWE]) from 1991 to 2020 reported; data from ClimateBC	Lower elevation SWE: 70 mm/yr Higher elevation SWE: 285 mm/yr
What is the mean annual temperature?	Mean annual temperature from 1991 to 2020; data from ClimateBC	Lower elevation: 5.8°C Higher elevation: 0.6°C
Are moisture deficit information available for the watershed?	No evapotranspiration data available Hargreaves climatic moisture deficit from 1991 to 2020 reported; data from ClimateBC	Lower elevation moisture deficit: 374 mm Higher elevation moisture deficit: 112 mm

Key points / interpretations: *The watershed is relatively arid, with a continental climate and substantial moisture deficit, particularly in the lower watershed where the farm is situated. Elevation in the watershed plays a strong control on the form of precipitation. This means that in the upper elevations, precipitation in the wintertime falls as snow and is stored for the spring snowmelt. In the upper elevations approximately 50% is snow and 50% falls as rain, suggesting this watershed should see a spring snowmelt peak, but also higher water levels where and when warm precipitation falls. Seasonal temperatures vary with elevation, with greater moisture deficits present at lower elevations due to higher temperatures, especially in summer.*

4.2.3 Climate Change Projections

Information on climate change projections for the Clinton Creek watershed are available from ClimateBC. Climate change information can be used to help the farmer understand plausible future climates and changes and how those may influence water resources as well as temperatures as related to their operations (e.g., diversifying crop production, planting more drought tolerant crops, identifying secondary or tertiary sources of irrigation water such as groundwater sources or water storage options). Regional information (Bonaparte Lake) about changes to Growing Degree Days (GDD) in Clinton has been obtained from the Climate Atlas of Canada to understand changes from the baseline GDD of the region (Figure 4.5). Additional information about the presence of glaciers and wildfires in the watershed has been obtained from Google Earth Pro and iMapBC. A summary of climate change information for the Clinton Creek watershed is shown in Table 4.2.

Table 4.2: Projected climate change for the Clinton Creek watershed.

Question	Notes	Value
What are the projected changes in total precipitation in the watershed?	For SSP370 scenario, a mid-point projection for 2041 to 2070*; data from ClimateBC	Lower elevation: Increase of 14 mm Higher elevation: Increase of 36 mm
What are the projected changes to growing degree days (GDD)**?	Based on a climate scenario whereby greenhouse gas emissions continue to increase at current rates through the end of the century (RCP8.5); projected for 2051 to 2080; data from the Climate Atlas of Canada	Increase of 785 GDD from 1115 GDD (1976 to 2005) to 1900 GDD (2051 to 2080)
What are the projected changes in average summer temperature?	For SSP370 scenario, a mid-point projection for 2041 to 2070*; data from ClimateBC	Lower elevation: Increase of 3.5°C Higher elevation: Increase of 3.6°C
How are snow amounts expected to change in the region?	For SSP370 scenario, a mid-point projection for 2041 to 2070*; data from ClimateBC	Lower elevation: Decrease of 4 mm Higher elevation: Decrease of 25 mm
Are there glaciers in the watershed?	Interpretation from Google Earth Pro; imagery date 10/7/2021	None
Is the region prone to wildfire or are wildfires likely to become more common?	Information from iMapBC; fire threat rating layer	Most of the watershed has been mapped as having a moderate to high fire threat rating.

* Based on the ensemble of 13 global climate models (GCMs);

** Base 5°C

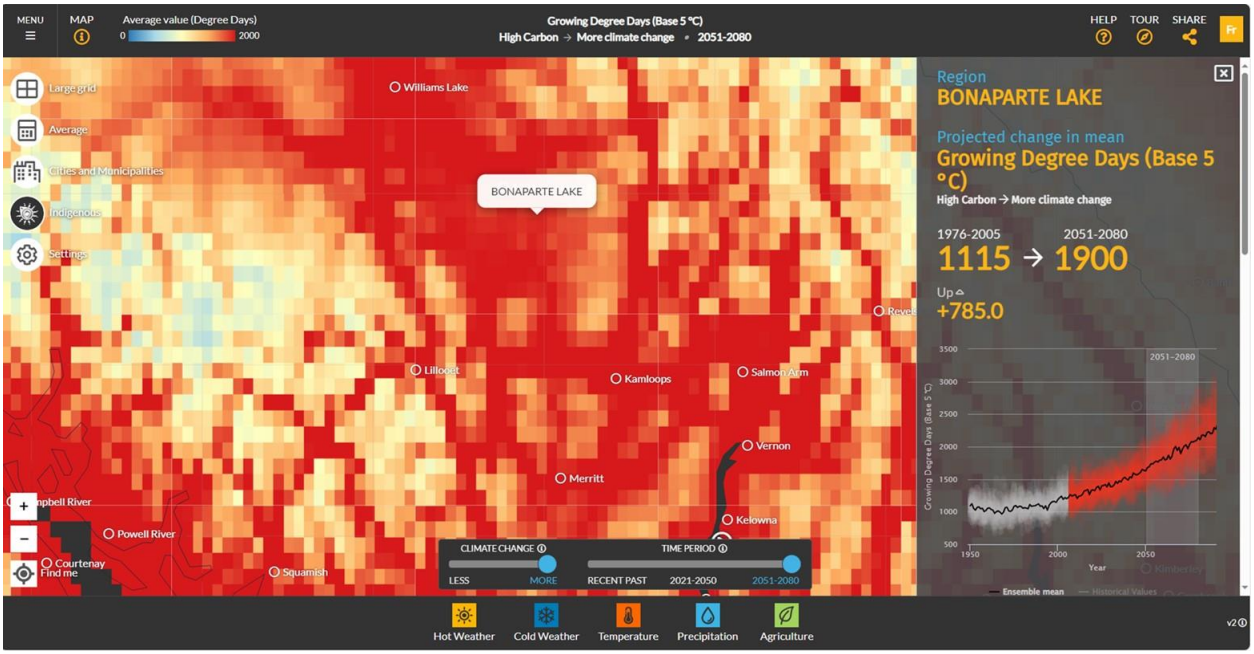


Figure 4.5: Project change in mean Growing Degree Days (GDD) for the Bonaparte Lake region where Clinton, B.C. is located. The increase of 785 GDD in the period 2051 to 2080 is relative to baseline conditions (1976 to 2005). Projections provided by the Climate Atlas of Canada.

Key points / interpretations**:** *The watershed is arid, with a continental climate and substantial moisture deficit. Climate change is likely to warm the region, but also lead to slightly wetter conditions annually. Precipitation falling as snow will be reduced by more than 20%, which will likely lead to a lower overall snow amounts and possibly less water availability seasonally during the spring snowmelt (possibly indicating a need for storage solutions in the future or alternate crops to adjust to the changed water availability). The increase of air surface temperatures in the summer may increase evaporation rates in the watershed, and as such may reduce water availability for irrigation. Such changes will need to be considered when planning for long-term crop investments to ensure productivity and farm viability.*

The increase in GDD from normal, baseline conditions can have implications for the farmer regarding what types of crops are grown on the farm in the future, and the amount of irrigation water required for future crops. The farmer can use the projected GDD information to plan for crops that are grown optimally under these conditions and adjust water usage plans as necessary. To further assist with water use planning on the farm, the Climate Atlas of Canada tool can also be used to project average date of first fall frost, date of last spring frost, and length of the frost-free season for the region.

4.2.4 Surface Water Hydrology

A critical component of watershed characterization is building an understanding of water availability within the watershed in the present and future. If insufficient water is available, then a water use licence for farm irrigation may not be achievable. Reviewing available surface water hydrology information can assist in understanding seasonal and annual patterns in streamflow.

Available Information on surface water for Clinton Creek based on output from the fasstr R package and an exported report from the BC Water Tool – Cariboo (Figure 4.6) is summarized in Table 4.3. While the BC Water Tool series does not provide equal functionality (i.e., each regional tool differs) across the entire province, the Cariboo region is covered by a subset of the tool that can provide summary

reporting. Note that publicly available data for Clinton Creek is from two discontinued hydrometric stations (1923-1960 data, Clinton Creek at Clinton (08LF038), and 1968-1975 data at Clinton Creek near the Mouth 08LF064). Given the proximity of the earlier station to the Village of Clinton itself and the longer record during the summer growing season, Station 08LF038 was selected for detailed plotting (data only available from April 1 to September 30). If winter flows were a focus, then a different station might need to be sought. Information on partial daily flow series and monthly values are visualized in Figure 4.7 and Figure 4.8 (generated using fasstr R package using WSC data).

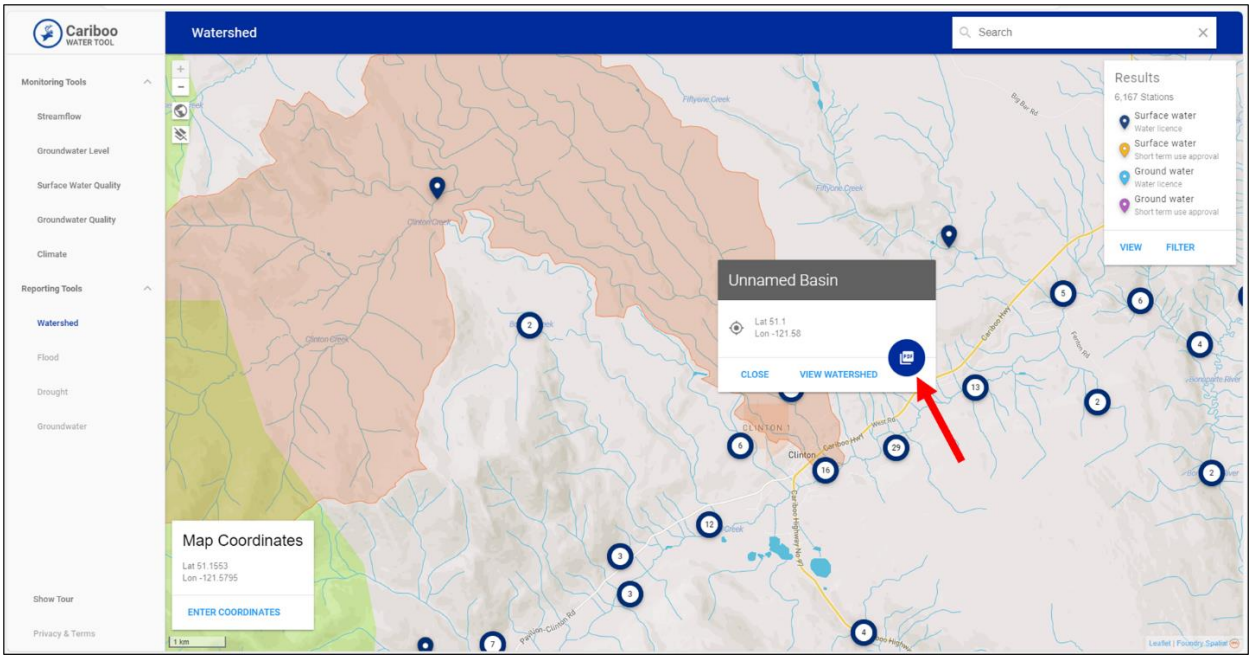


Figure 4.6: Clinton Creek watershed (source: BC Water Tool) showing the location of hydrological stations. The red arrow shows the PDF download option for users where a summary of available hydrological data can be accessed.

Key points / interpretations**:** *Clinton Creek is a snowmelt dominated system with a relatively low predicted mean annual discharge (0.113 m^3/s). Predicted peak annual flows range from 0.500 to 0.750 m3/s, while low flows are thought to be in the order of < 0.020 m^3/s, but little information was available to substantiate the wintertime period. In combining climate information from above, it is very likely that early April and May peaks are snowmelt driven, while those occurring later in the summer are a combination of snowmelt enhanced by rain events or plausibly entirely rainfall driven. After the snowmelt season, flows drop rapidly to low levels below 0.1 m^3/s. As a result, during the irrigation months, water supply seems to be limited and storage of diverted water during the high flow season or alternate source water may be something to consider based on the observed surface water characteristics for Clinton Creek. There are multiple surface water licences in the area. Although allocation is reported as 19.9% (BC Water Tool - Cariboo), this allocation value appears to be outdated as it reflects reporting from the 1960s. As such, more updated information regarding current water use and allocation is required.*

Table 4.3: Surface water attributes for the Clinton Creek watershed.

Question	Notes	Value
What is the mean annual discharge (MAD)?	Information from WSC (via fasstr) and BC Water Tool - Cariboo	0.113 m^3/s (BC Water Tool - Cariboo). LTMAD can't be calculated from 08FL038 due to the seasonal record
What is the median streamflow on each day of the year?	Information from WSC (via fasstr)	Values available from April 1 – Sept 30th for the period of record (Figure 4.7)
What is the lowest expected discharge observed once every 5 and 10 years?	Information from WSC (via fasstr)	0.018 and 0.015 m^3/s
Is there a historical trend in MAD and how variable is MAD year – to year?	Information from WSC (via fasstr)	Limited information due to partial record
Does the watershed contain any lakes?	Information from BC Water Tool - Cariboo	Yes, two small reservoirs (see Figure 4.2)
When do the highest streamflow usually occur?	Information from WSC (via fasstr)	May to June (Figure 4.7);
What is the expected hydrologic regime (rain, snow, hybrid, glacial) of the area?	Information from WSC (via fasstr)	Snowmelt based on the shape of the hydrograph
In terms of water storage and release components, what is the role of wetlands, lakes, dams/diversions, glaciers, preferential flow, and groundwater in shaping daily and/or seasonal discharge?	Interpretation from Google Earth Pro; imagery date 10/7/2021	Presence of two dams and a reservoir in Clinton Creek; reservoir stores surface water and attenuates flow
Is runoff rapid or a prolonged event? Does runoff occur immediately after a storm or is it delayed? What is the primary hydrologic driver (snow, rain, groundwater, glaciers, or convective storms)?	Information from WSC (via fasstr) and BC Water Tool - Cariboo	Appears generally prolonged; snowmelt from upper elevations is primary driver
What is the seasonality of flow? Do low flows occur only in specific seasons or at any time during the year?	Information from WSC (via fasstr)	Peak flows appear dominant mid spring to early summer (April to July); low flows appear dominant in winter to early spring (November to March); partial data renders detailed analysis challenging
Does streamflow ever become intermittent along the channel profile? Have zero-flow conditions been measured in the watershed?	No Information was found in available reports; best answered via local information, interviews or onsite investigations.	No information
Are drainage diversions, roads, ditches, or other impervious surfaces affecting runoff patterns and timing?	No Information was found in available reports; best answered via local information, interviews or onsite investigations.	No information online, this information is best gathered by driving the watershed

Table 4.3 continued: Surface water attributes for the Clinton Creek watershed.

Question	Notes	Value
Does the stream network freeze in the winter?	No Information was found in available reports; best answered via local information, interviews or onsite investigations.	No information
Has a flood frequency analysis been undertaken in the watershed?	No Information was found in available reports; best answered via local information, interviews or onsite investigations.	No information
What surface water licences currently exist in the watershed?	Information from BC Water Licence Search	48 licences found within the watershed; all surface water with no groundwater licences
Are water use allocation reservations or restrictions in place in the watershed? Have orders curtailing water use even been applied to the watershed?	Information from the following sources: B.C. Drought Monitoring B.C. Water Allocation Notations B.C. Water Reservations *Water Sustainability Act* temporary protection orders	No current reservations, notations, or temporary protection orders
Are major industrial or agricultural water users present in the watershed?	Information from BC Water Licence Search and BC Water Tool	Yes

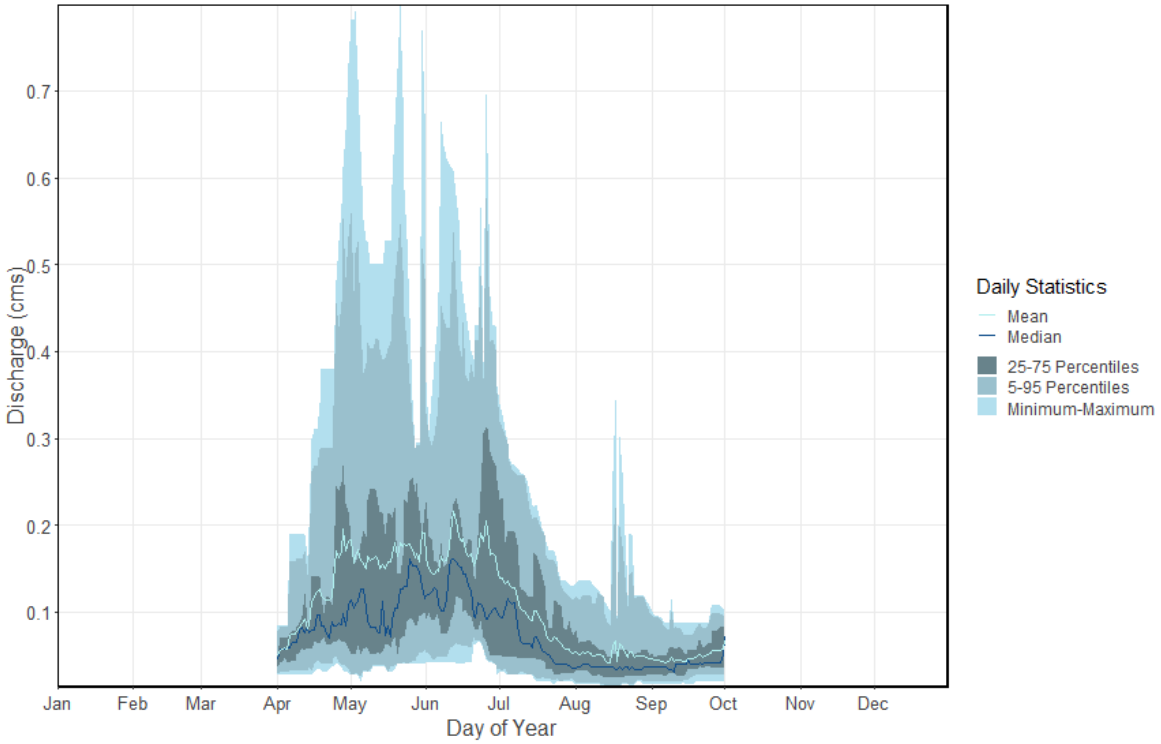


Figure 4.7: Daily discharge values for Clinton Creek available from Water Survey Canada (WSC Station 08LF038 1923-1960) via fasstr R package (discontinued station). Note that data are not available between October 1st and April 1. Note cms = m^3/s.

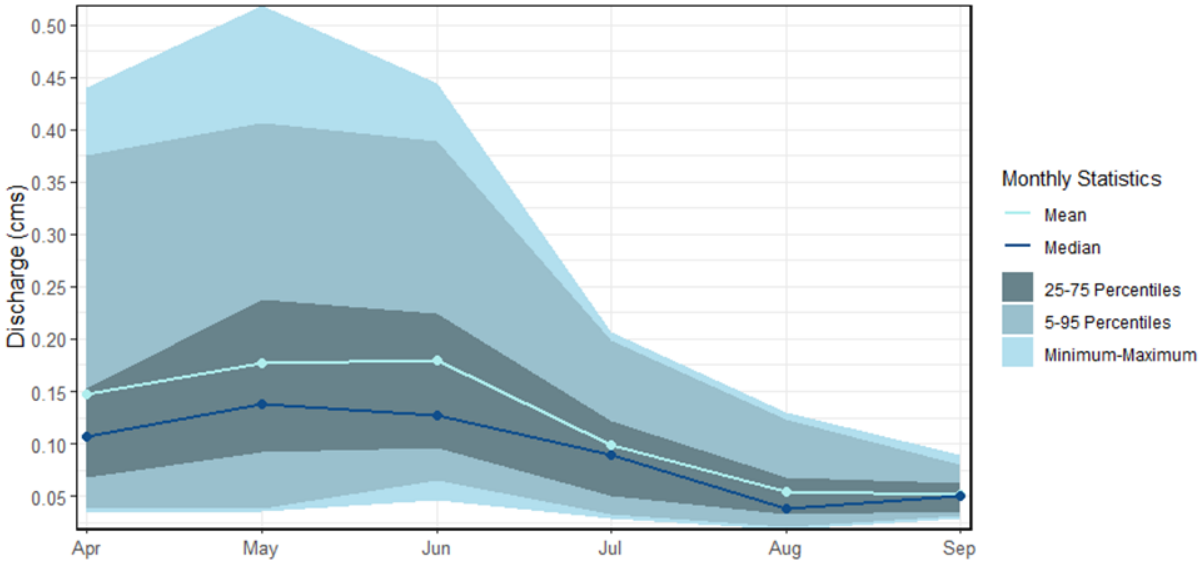


Figure 4.8: Mean monthly discharge values estimated for Clinton Creek available from Water Survey Canada (WSC Station 08LF038 1923-1960) via fasstr R package (discontinued station). Note that data are not available between October 1 and March 31.

4.2.5 Groundwater Hydrology

Groundwater Wells and Aquifers Search was used as a supplementary data source for groundwater information (Figure 4.9) and aquifers (Figure 4.10). This data source indicates that the watershed overlies portions of mapped Aquifers 124, 1262, and 1263. Aquifer 124 is characterized as flat-lying to gently-dipping volcanic bedrock aquifer with moderate productivity and moderate vulnerability. Aquifer 1262 is characterized as an unconfined sand and gravel aquifer with moderate productivity and high vulnerability, and Aquifer 1263 is characterized as a fractured crystalline bedrock aquifer with low productivity and moderate vulnerability. Although there are no wells within the Clinton Creek watershed (groundwater use wells or observation wells), there are wells south of the Village of Clinton immediately outside of the Clinton Creek watershed. One well is identified as an active monitoring well that is part of the Provincial Groundwater Observation Well Network.

Understanding the location of groundwater wells and current groundwater licensing within the watershed may inform which water sources may (or not) have water for the farmer's intended purpose. An absence of groundwater licences in a watershed may possibly suggest that groundwater usage is not a feasible source of water. Conversely, a high number of groundwater licences may indicate competing use from other users. The BC Drought Monitoring and *Water Sustainability Act* temporary protection orders websites have been used to search for current and historic water use restrictions in the watershed. Table 4.4 summarize groundwater characteristics, searched licences, and water use restrictions.

Key points / interpretations**:** *Five aquifers are found in the area, with three that appears to be within the watershed of interest (Aquifers 124, 1262, and 1263). The proximity of Aquifer 124, and the fact that it is mostly a bedrock aquifer indicates that it may be a possible source of baseflow. However, limited online information is available to corroborate likely wintertime flows. A lack of wells within the watershed also limit investigation of the groundwater characteristics and how they contribute to the flow regime. As a result of the limited information available, caution should be taken with inferences drawn in relation to groundwater availability in the system*.

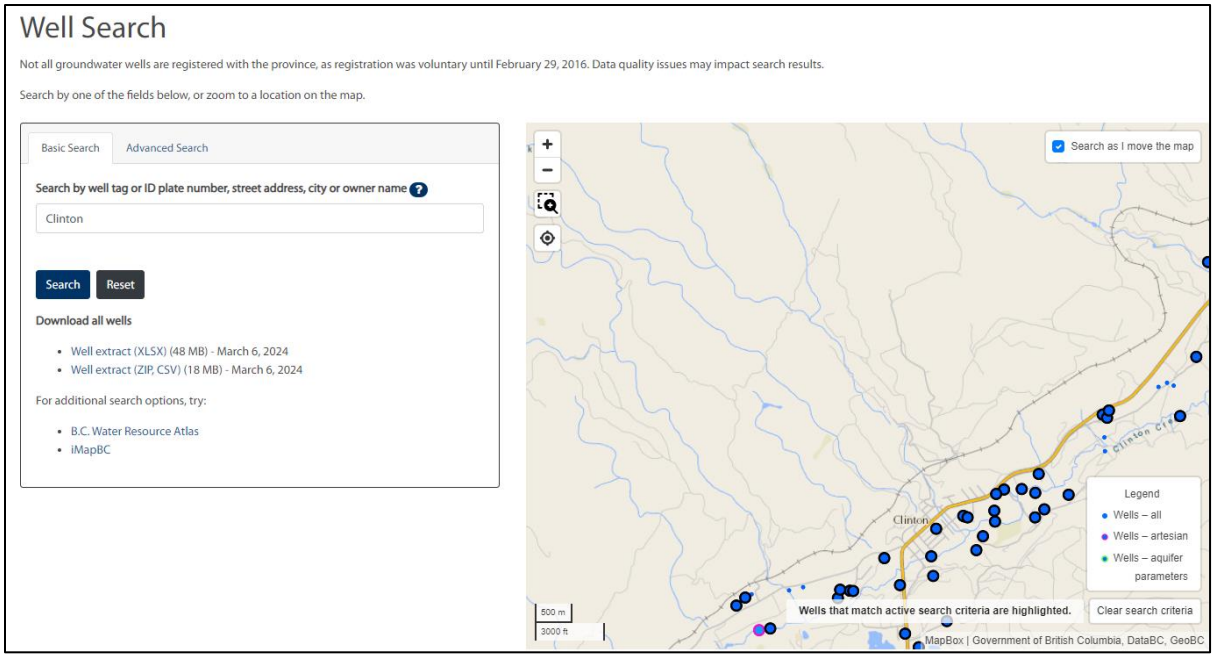


Figure 4.9: Well search screenshot for Clinton, B.C.

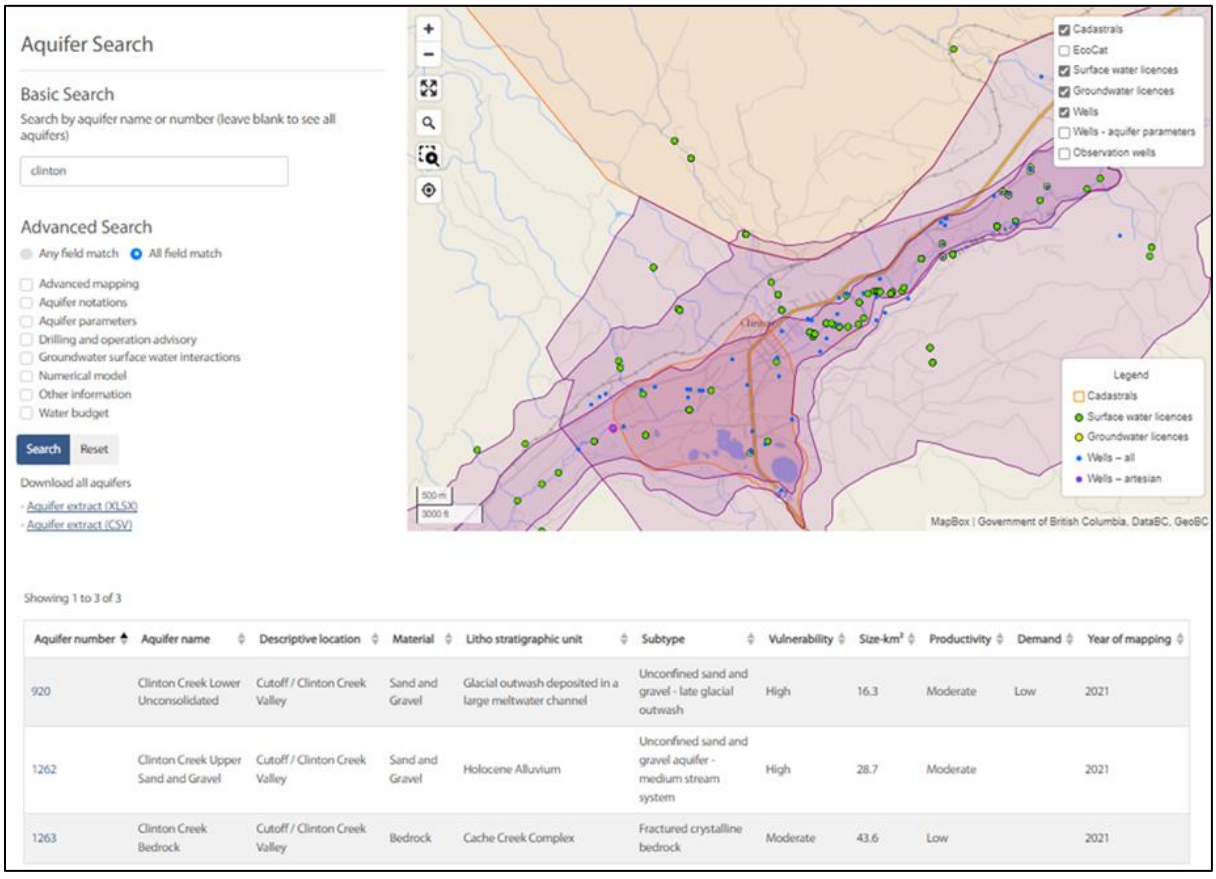


Figure 4.10: Aquifer/ Groundwater well search screenshot with surface water licences for Clinton, B.C.

Table 4.4: Groundwater attributes for the Clinton Creek watershed.

Question	Notes	Value
What groundwater licences exist in the watershed?	Information from GWELLS	No groundwater licences mapped within the watershed boundary, though there are several wells mapped on the east side of Aquifer 1262; aquifer mapping indicates that this aquifer extends east beyond the Clinton Creek watershed
Is groundwater the dominant water source for streams during dry periods?	Further studies needed	Plausible based on hydrologic regime; based on historic climate data, at higher elevation, snowfall is the predominant form of precipitation in the winter
What is the quality of the groundwater?	No observation wells within the watershed belonging to the Provincial Groundwater Observation Well Network; nearest active observation well is south of the Village of Clinton OBS WELL 80 - CLINTON - RODEO GROUNDS CARIBOO HWY 97N however no data is available regarding the water quality	No active groundwater quality monitoring within the watershed
Are water use restrictions in place in the watershed?	Sources did not identify historic and current water use restrictions in this watershed	No information
What groundwater monitoring occurs in the watershed?	No observation wells within the watershed belonging to the Provincial Groundwater Observation Well Network; nearest active observation well is south of the Village of Clinton OBS WELL 80 - CLINTON - RODEO GROUNDS CARIBOO HWY 97N	No active groundwater monitoring within watershed
What groundwater wells are present in the watershed?	Information from GWELLS and BC Water Licence Search	None
What are the aquifers in the area?	Information from GWELLS	3 aquifers are mapped as being within Clinton Creek watershed: Aquifers 124, 1262, and 1263. 2 aquifers, Aquifers 920 and 921, are mapped as being west of the Clinton Creek watershed boundary.
Are aquifers unconfined/vulnerable?	Information from GWELLS	Aquifer 124: moderate vulnerability Aquifer 1262: high vulnerability; unconfined Aquifer 1263: moderate vulnerability
Have trends in groundwater level been observed over time?	No observation wells within the watershed belonging to the Provincial Groundwater Observation Well Network	No information

4.2.6 Water Quality

As part of the watershed characterization, developing a better understanding of water quality may be important for the farmer regarding suitability of waters for the intended crop(s), animals and other uses presently, and into the future. For example, if there are known water salinity issues, the farmer may need to plan to ensure crops are not being adversely affected to ensure the productivity and viability of their business. A look for surface water quality data (sources in Table 2.11) for the Clinton Creek watershed turned up no data for the area. For groundwater, the farmer found data for a well south of the Village of Clinton just outside of the Clinton Creek watershed. This well is identified an active without real-time data as part of the Provincial Groundwater Observation Well Network. There is also a report by Bieber (2022), found on EcoCat, titled "Aquifer Mapping in the Clinton Creek Watershed" containing water quality information for the area. This report also references numerous historic reports (e.g., Swain, 1986; Brewer 1997; Kelly, 2003) containing water quality information for Clinton Creek and the downstream Bonaparte River. Water quality data details and availability for surface and groundwater are summarized in Table 4.5.

Table 4.5: Watershed water quality attributes for the Clinton Creek watershed.

Question	Notes	Value
Are high levels of turbidity often observed in the river?	Suspended solids and turbidity information reported by Brewer (1997) based on data collected in 1996	High levels of suspended solids and turbidity noted in 1996 in Clinton Creek and the downstream Bonaparte River
What is the stream water temperature in summer?	No recent surface water data	No recent information
What is the pH of surface and groundwater?	No recent surface water data; groundwater data from OBS WELL 80 - CLINTON - RODEO GROUNDS CARIBOO HWY 97N (sample date 2020/08/11) and Brewer (1997)	pH of groundwater from adjacent watershed is 7.44 to 7.99
What is the electrical conductivity of surface and groundwater?	No recent surface water data; groundwater data from OBS WELL 80 - CLINTON - RODEO GROUNDS CARIBOO HWY 97N (sample date 2020/08/11)	Specific conductivity of groundwater from adjacent watershed is 1991 µS/cm = HIGH ECt
Have algae blooms been observed?	Algal growth information reported by Brewer (1997) based on data collected in 1996	High levels of algal growth noted in 1996 in Clinton Creek and the downstream Bonaparte River
Water quality objective reports for the area	Kelly (2003) and Swain (1986)	Both reports contain potentially outdated information, and report water quality objectives for the area downstream from the Farm property
Do any water quality metrics exceed guidelines?	No recent surface water data; groundwater data from OBS WELL 80 - CLINTON - RODEO GROUNDS CARIBOO HWY 97N (sample date 2020/08/11)	Groundwater from adjacent watershed exceeds total dissolved solids (TDS) specific conductance, and turbidity limits as per Canadian Drinking Water Quality guidelines

Key points / interpretations**:** *Dated water quality data was located (Thompson-Bonaparte Area Water Quality Assessment and Objectives report from 1986), which identifies a need to further investigate to determine suitability for the farmer's application. Such investigations are beyond a desktop watershed characterization. The Water Quality and Objectives report (Swain, 1986) indicates a seasonal component to water quality in Clinton Creek. Permitted waste discharge during the time of reporting had its greatest influence during winter low flows in the creek, with notable increases in nutrients, fecal coliforms, and algal growths due to reduced effluent quality and increased effluent flow rates. Knowledge of the seasonality of water quality can help the farmer plan what time of year may be best to seek potential water available for irrigation. Groundwater electrical conductivities are high and could factor into farm planning. As data is limited, relatively little can be inferred about the state of water quality in the region.*

4.2.7 Ecological Values

A search on EcoCat identified several reports related to how the planning, construction, and characteristics of a municipal water reservoir in Clinton Creek are likely to impact the ecological values of the watershed. Awareness of the municipal water reservoir can assist the farmer to better understand other water uses in the Clinton Creek watershed.

As part of this watershed characterization example, withdrawing water from a stream system or nearby aquifer for irrigation can potentially influence the aquatic habitat conditions for aquatic species. A search of Habitat Wizard indicates that Clinton Creek provides habitat for rainbow trout, with the last observations of rainbow trout recorded in February 2023 (Figure 4.11). Approximate forest cover (%) of the watershed was estimated by interpreting recent satellite imagery provided by Google Earth Pro. Table 4.6 outlines key ecological characteristics of the Clinton Creek watershed. Information pertaining to the species composition and old growth fraction of forested areas in the area are from the website containing pre-made maps of VRI based on the Vegetation Resource Inventory (VRI) dataset.

Key points / interpretations: *No stream specific environmental flows specific to rainbow trout were located in the information search of available resources. The review of applicable ecosystem information indicates that fish are present in Clinton Creek, and it is therefore possible that aquatic habitat could be affected via potential water withdrawals, and near site riparian agricultural practices/ farmer plans could also be further considered regarding this new information. For example, should the farmer plan to establish drainage ditches on the farm property (e.g., for excess water management), knowledge of fish presence indicates a hazard that if these ditches become flooded and hydrologically connect to the fish bearing system, these drainage ditches could become populated with fish and subsequently become fish habitat. Such unintended outcomes would have implications with regulations under the Fisheries Act and would be of highlight for the farmer to consider in their farm management plan*.

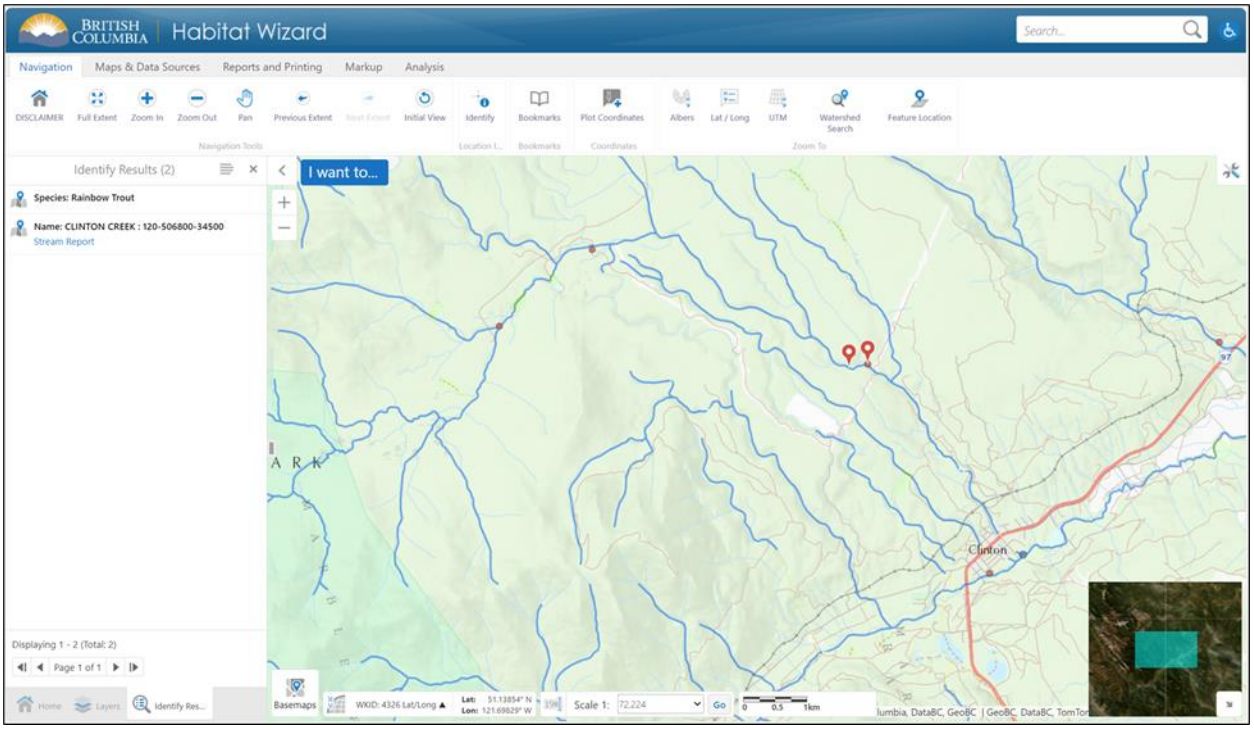


Figure 4.11: Aquatic species observation points (small red dots) recorded along Clinton Creek in the Clinton Creek watershed. Data obtained from Habitat Wizard.

Table 4.6: Ecological values for the Clinton Creek watershed.

Question	Notes	Values
What fish species are present in the watershed?	Three aquatic observation points shown on Clinton Creek; data from Habitat Wizard	Rainbow trout
Have endangered or at-risk species been identified in the watershed?	No endangered or at-risk species identified in Habitat Wizard	N/A
What fraction of the watershed is forested?	Interpretation from Google Earth Pro; imagery dated 10/7/2021	Majority of watershed is forested; estimated 80 to 85% forest cover
What is the species composition of forested areas?	Provincial Species Group Map (2019) from pre-made maps of VRI	Predominantly Douglas Fir with some areas of lodgepole pine and spruce
What fraction of the watershed is old growth?	Provincial Age Class Map (2019) from pre-made maps of VRI	Mapping suggest old growth is limited in the area

4.2.8 Geology and Geomorphology

Geological information, particularly surficial geology, may be important towards understanding the potential impacts from additional groundwater withdrawals from a new water use licence. Geomorphic information may be less relevant. Information about geology and geomorphology of the watershed has been obtained from Google Earth Pro and iMapBC. Results are shown in Table 4.7.

Key points / interpretations**:** *The Clinton Creek watershed is situated in a relatively low-relief and arid landscape, and as a result, recent hillslope failures and erosion events are not of significant concern in the watershed. Similar to most other B.C. watersheds, the watershed geomorphology characteristics have been strongly shaped by past glacial processes. As the creek itself is quite small and its channel morphology appears fairly geomorphologically stable, it seems as though no recent major sediment delivery events have occurred. A lack of information limits what inferences can be drawn on the relationship between watershed geology and water quality in the creek.*

Table 4.7: Geology and geomorphology in the Clinton Creek watershed.

Question	Notes	Values
Have there been any recent extreme floods? If not, how long ago was the last major flood?	No recent flow data is available for the watershed; regional flooding occurred in July 2020 but local impacts within the Clinton Creek watershed are unclear	No information
Are there landslides or debris flows in the watershed, or are these likely to occur?	Information from iMapBC; terrain stability polygons layer	No evidence of recent or historical slope failures, but headwaters are steep enough for these to occur
Is water often observed to be turbid during high flows or after rain, but otherwise clear?	Inconclusive: no information identified	No information
Are large or new gravel bars apparent in the stream or river channel?	Interpretation from Google Earth Pro; imagery dated 10/7/2021	No gravel bars apparent but a floodplain is adjacent to lower portions of the creek, indicating sediment deposition at times
Does the channel show signs of erosion and/or deposition?	Channel is too small and overgrown to see signs of erosion and/or deposition using available satellite imagery	No information
Does the watershed contain any active alluvial fans, historical channel widening, or obvious sediment sources?	Interpretation from Google Earth Pro; imagery dated 10/7/2021	No active fans, channel change or sediment sources are obviously visible
What is the surficial and bedrock geology of the region?	Information from iMapBC; surficial geology layer	Overlain by glacial till deposits; bedrock composed of basalt in eastern portions with possible limestone/karst in western portions.

4.2.9 Cultural Values

Understanding the cultural values of the Clinton Creek watershed helps to recognize and preserve history, traditions, and shared experiences of those who live on the land and promotes shared responsibility when protecting the quality and quantity of water across the watershed. Table 4.8 contains a summary of key cultural values obtained from a variety of information sources including Google Earth Pro, Sites and Trails B.C., Native Land Digital, Review of First Nations A-Z Listing, and the BC Treaty Commission.

Key points / interpretations: *This area is the traditional territory of the Secwépemc people. While limited information is available, the farmer uses this learning to research more on the traditional territory of this interior plateau area. They also find a local contact through which to learn more about the history and all things relevant. The farmer also contacts the regional BC Parks contact to query some questions they have on the headwaters and recreational use and development plans in the present and future. The fact that it is a park provides some important information on the likelihood of future forestry operations (likely none) in the headwaters that are the important water source in this watershed.*

Table 4.8: Cultural values in the Clinton Creek watershed.

Question	Notes	Values
Whose traditional territory does the watershed of interest fall in?	Information from Native Land Digital	Secwépemc territory
Are there known sites of cultural significance to First Nations?	Information not available	No information available
Do treaties or other agreements with First Nations exist for this watershed?	Information from BC Treaty Commission	No treaty agreements appear to exist within the watershed
Are any mapped culturally sites present in the watershed?	Review of First Nations A-Z Listing	No mapped sites were found however this does not suggest none exist
What recreational opportunities exist in the watershed?	Interpretation from Google Earth Pro; imagery dated 10/7/2021	No park facilities appear to exist within the watershed; the headwaters of the watershed are located within Marble Range Provincial Park
What recreation infrastructure is present?	Information from Sites and Trails B.C.	A small portion of a snowmobile trail is present in the watershed
What private land is present in the watershed?	Information from the B.C. Land Title and Survey	Approximately 4% of the watershed area is private land; most remaining land is public
What reserve land is present in the watershed?	Information from the First Nations Profiles interactive map	Clinton 1 Reserve is partially located in the watershed

4.2.10 Land Use

Knowledge of the different types and levels of land use can inform both past, present, and perhaps future stressors in the watershed. Table 4.9 provides an overview of key land use characteristics in the watershed are outlined. Information has been obtained from a variety of sources including Google Earth Pro, the BC Water Tool, the B.C. Community Watersheds Data Catalogue, the B.C. Land Title and Survey, the First Nations Profiles Interactive Map, and iMapBC. Key findings in this section include the fact that the watershed is a Community Watershed, and that it is relatively undeveloped.

Key Points / interpretations: *The primary watershed land use appears to be tied to agriculture, though only a small portion of the watershed appears to be actively farmed. Additionally, small areas of the watershed have been developed for the Village of Clinton, but large impermeable areas do not appear to be present. Large scale industrial development is absent, which corroborates information gained about other water users in the watershed.*

Table 4.9: Watershed land use in the Clinton Creek watershed.

Question	Notes	Values
Does agriculture occur in the region?	Interpretation from Google Earth Pro; imagery dated 10/7/2021	Minimal agriculture appears to occur
What land area has been cleared for agriculture and what types of agriculture occur?	Interpretation from Google Earth Pro; imagery dated 10/7/2021	<5% of land area appears to be cleared for agriculture; appears to be pastureland from imagery
Are other industries operating in the watershed (e.g. mining, oil and gas)	Interpretation from Google Earth Pro; imagery dated 10/7/2021	No other industry appears present
How does the timing of water demand compare to timing of water availability?	Information from the BC Water Tool (Cariboo); stream data for Clinton Creek provided by Water Survey of Canada (1923 to 1960 data set; discontinued station)	Demand is highest before peak flows in mid spring
Do any communities exist in the watershed?	Interpretation from Google Earth Pro; imagery dated 10/7/2021	Yes; Village of Clinton
Is the watershed a Community Watershed?	Information from the BC Community Watersheds Catalogue	Yes; Clinton Community Watershed, PD46006, 350 connections, Village of Clinton
What fraction of the watershed is urbanized?	Interpretation from Google Earth Pro; imagery dated 10/7/2021	Small portion of the lower end of the watershed is urbanized
What parkland/other protected land is within the watershed?	Information from iMapBC	Marble Range Provincial Park is in the headwaters of the watershed

4.2.11 Watershed Disturbance

The watershed characterization process identified disturbances in the Clinton Creek watershed to include previous forest fire in the headwaters and mountain pine beetle infestation (based on interpretation of imagery provided by Google Earth Pro). Mapping from iMapBC (insect layer) identifies several Douglas fir beetle infestation points in the watershed with each point indicating an infestation area of <0.25 ha suggesting localized infestation. Additionally, roads constructed within the watershed may have altered runoff processes (e.g., surface runoff diversions and quickened flow). The Digital Road Atlas layer from the BC Web Map Library was imported (as a KML file) into the Google Earth Pro environment to display the location of local, service, and resource roads (Figure 4.12). A summary of watershed disturbances in the Clinton Creek watershed is shown in Table 4.10.

Key Points / interpretations: *The Clinton Creek watershed shares a disturbance history which is common among interior B.C. streams. Most significantly, Mountain Pine Beetle attack was extensive throughout the region, with widespread forest mortality. This is likely having some ongoing impacts to watershed hydrology, though a quantification of these effects is beyond the scope of this characterization. While forestry impacts appear low in the watershed (and as a result, road network density is low), the loss of forest cover due to mountain pine beetle may have important hydrologic effects.*

Table 4.10: Historical disturbance in the Clinton Creek watershed.

Question	Notes	Value
Has the watershed been logged? If so, when, and how much?	Interpretation from Google Earth Pro (imagery dated 10/7/2021) and historic air photos from iMapBC (1963 to 2016)	The watershed is largely unlogged, with small openings identified from 1963; powerline corridors that pass through the watershed required forest clearing
Have wildfires recently occurred in the watershed?	Interpretation from Google Earth Pro dated12/31/2004 to 10/7/2021 and IMap BC	Most recent wildfire occurred in 2009 in the watershed headwaters and just outside the headwater boundaries
Has the watershed been affected by forest pests such as mountain pine beetle?	iMapBC indicates a current infestation (Douglas fir beetle under the 'Pest Infestation' layer). Interpretation of historic air photos from Google Earth indicates a historic mountain pine beetle infestation.	A high fraction of the forest (>50%) was affected by Mountain Pine Beetle in the past. Currently, there are localized Douglas fir beetle infestations in the watershed.
Have any major windstorms affecting forest cover occurred?	Interpretation from Google Earth Pro dated12/31/2004 to 10/7/2021	No visual evidence of major windstorms
Have any major landslides or debris flows been documented?	Information from iMapBC; terrain stability polygons layer	No evidence of recent or historical slope failures, but headwaters are steep enough for these to occur
Has placer mining ever occurred in the watershed?	Interpretation from Google Earth Pro; imagery dated 10/7/2021	No visual evidence of placer mining in stream beds
What length of road network is present in the watershed?	Interpretation from Google Earth Pro; imagery dated 10/7/2021	Between 50 and 100 km of small dirt roads appear present in the watershed; a large powerline right-of-way passing through the watershed may also have an access road underneath

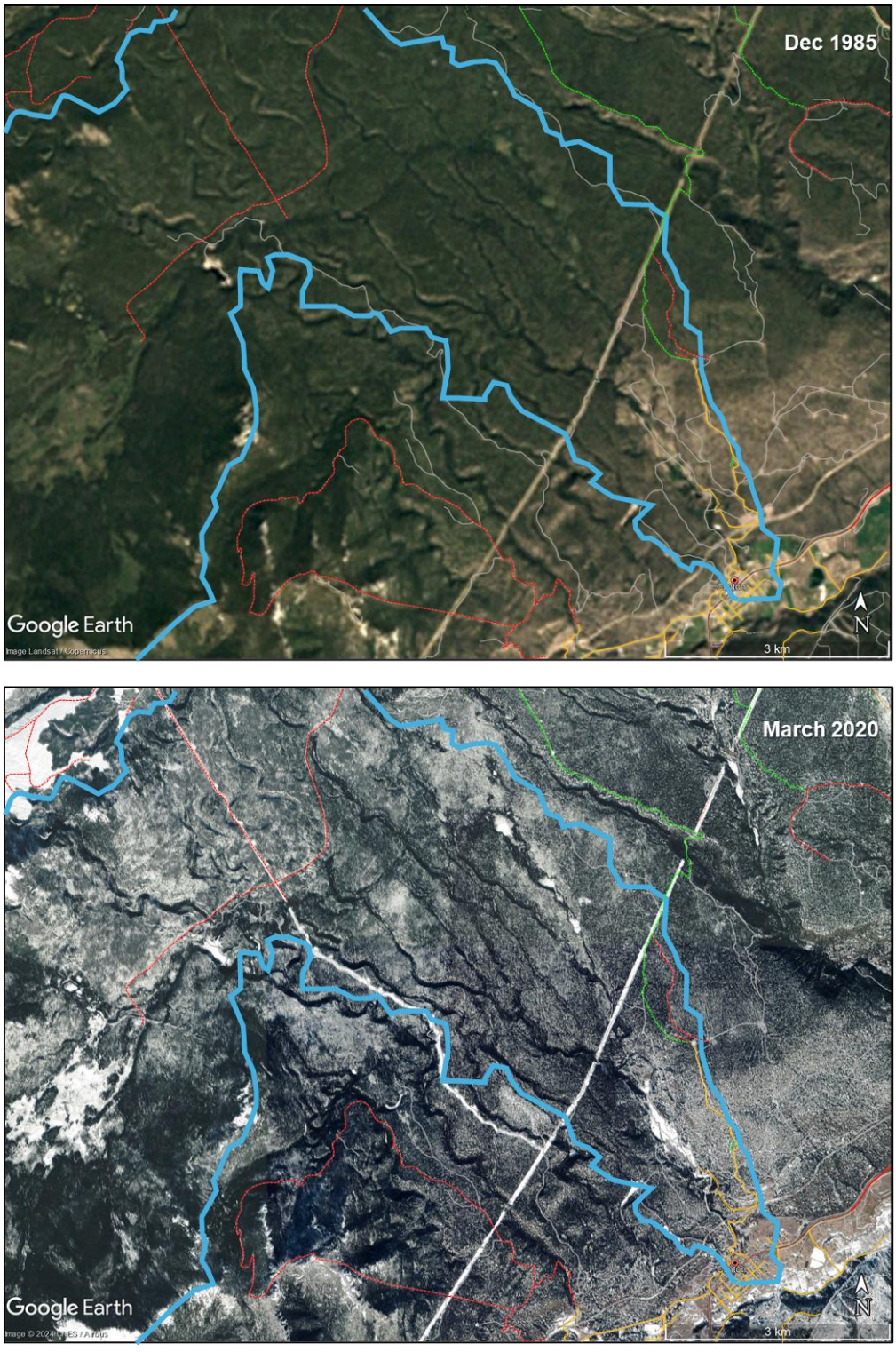


Figure 4.12: Roads in the Clinton Creek watershed 1985 compared to 2020. Key: local roads (yellow lines), service roads (grey lines), resource roads (dashed red lines), and recreation roads (dashed green lines) from the Digital Road Atlas layer. The mapped watershed boundary is shown as a solid blue line. Note that the thickness of the lines increased for the purpose of visualizing road and watershed boundary locations observed at this scale on Google Earth.

4.3 Summary of Example Watershed Characterization

Using publicly available data and guided templates, this watershed characterization has provided information on a range of attributes and values for the Clinton Creek watershed. The characterization highlights that the watershed is typical of the region, both in terms of physiographic setting but also land use and water use pressures. To return to the initial objective for the characterization (that of identifying the opportunity and value of crop irrigation), the farmer might conclude that a cautious approach should be taken in the pursuit of crop irrigation. The existing arid climate in combination with projections of significant climate warming will lead to an increase in water demand which is unlikely to be offset by the slight increase in projected precipitation. Relatively little is known about the groundwater hydrology in the region based on existing publicly available data, and all existing licences are for surface water withdrawal. Given the low flows of the stream, it is possible that additional withdrawals could lead to excessively low flows in late summer, and water may be limited. As a result, the farmer may need to further modify their farm plan considering the new information they gathered on watershed characteristics. Overall, the watershed characterization provides the farmer with an informed basis for evaluating water supply alternatives and the associated merits of pursuing a water licence application.

While this example has focused on an agricultural application of the desktop watershed characterization procedure, the principles are similar for other applications, including those related to habitat restoration, forest cover change, ecological assessments, or industrial expansion. This example also highlights a realistic feature of watershed characterizations more broadly; that, in most cases, complete information is not always available for a given region and/or watershed, and inferences must be drawn from partial data. While incomplete information may pose a challenge for specific applications, identifying gaps in data is in and of itself an important component of the characterization process.

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