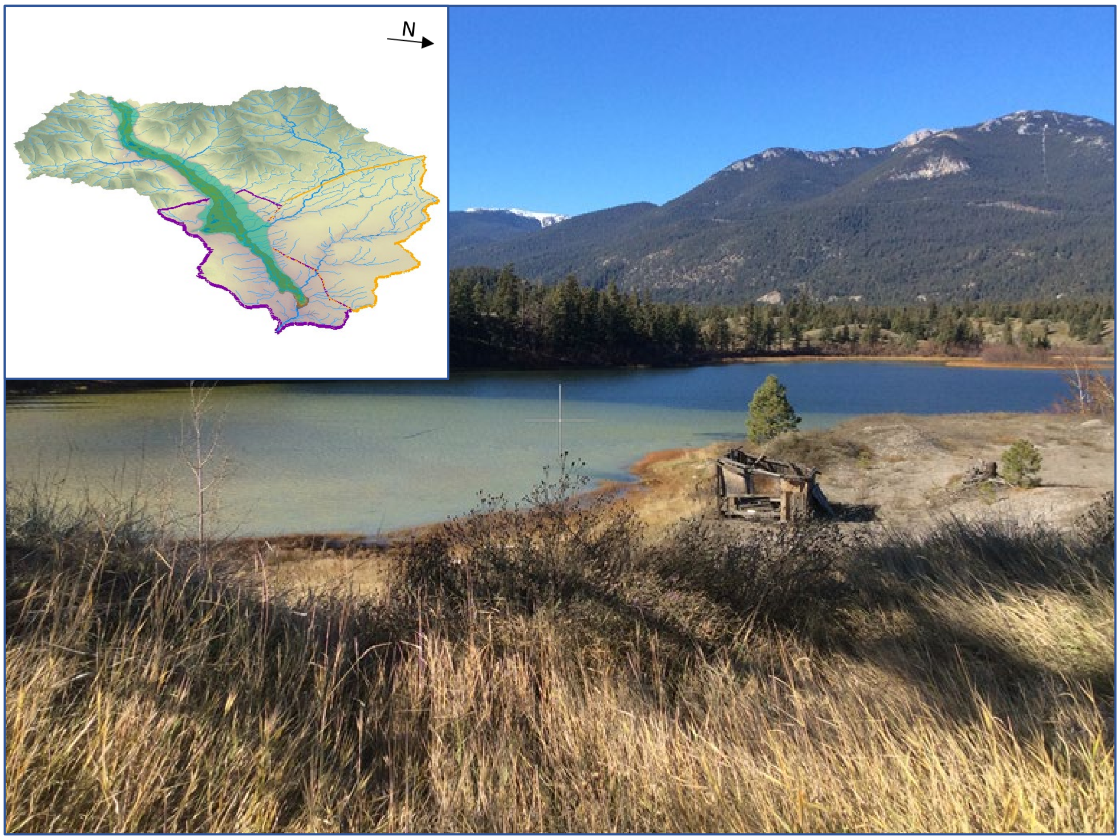
WATER SCIENCE SERIES

# Aquifer Mapping in the Clinton Creek Watershed

Christine Bieber

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**Cover Photographs:**

Duck Lake. Photo by David Thomson, October 12, 2018

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## EXECUTIVE SUMMARY


The Clinton Creek watershed is a tributary within the larger Bonaparte River watershed, which lies within B.C.'s interior plateau. Clinton Creek watershed's extents encompass several creeks, waterbodies and wetlands. All creeks within the watershed are tributaries to Clinton Creek which discharges to the Bonaparte River at its eastern extent. The watershed is located within the territories of the Secwepemc Nation and is within the jurisdiction of the High Bar First Nation government. The Village of Clinton is located at the junction of Clinton Creek, Cutoff Valley Creek and Soues Creek and several shallow water bodies are located to the south of the village.

Drinking water in the watershed is derived from both groundwater and surface water sources. The extents of historically mapped aquifers within the watershed are limited and date back to the year 2007 or earlier. Provincial decision makers, licence applicants and High Bar First Nation representatives have expressed interest in improved provincial information.

The aquifer mapping presented in this report provides updated analysis of the groundwater information available in provincial databases and other publicly available sources to support this interest. The aquifer information summarized in this report has been uploaded to the Groundwater and Wells database (GWELLS) which is maintained by the Province of B.C. Three aquifers have been re-mapped or newly mapped within the Clinton Creek watershed through the course of this study. These include: two unconsolidated aquifers that extend along the Cutoff/Clinton Creek valley which have been designated as the Clinton Creek Upper Unconsolidated aquifer (GWELLS aquifer No. 1262) and the Clinton Creek Lower Unconsolidated aquifer (GWELLS aquifer No. 920); and one bedrock aquifer designated as the Clinton Cache Creek Bedrock aquifer (GWELLS aquifer No. 1263) that extends over much of the lower elevation areas of the watershed.

The hydraulic connection between Cutoff/Clinton Creeks and unconsolidated aquifers, and the potential for hyporheic exchange between the two regimes could be the focus of future studies. It is expected that the upper unconsolidated unit is likely in hydraulic connection with the creeks while the hydraulic connection with the lower unit is unclear. Hyporheic exchange likely significantly influences both water quantity and quality of Cutoff/Clinton Creeks. Future studies to better understand groundwater and surface water dynamics of Salt Lake or other saline water bodies may also be of benefit for resource stewardship.

The extents of the aquifer units mapped have been inferred based on the data sources available, but these aquifer units may extend beyond or be absent within the mapped area due to limitations in the available information. Additional surficial aquifers could also be present within the Clinton Creek watershed where surficial mapping data indicate that fluvial or colluvial sediments are present. Bedrock throughout the study area could have a potential to transmit groundwater and be utilized as a water source, particularly in the vicinity of fault zones or formation contacts where greater hydraulic conductivity may occur. Field studies would be needed to better understand this potential.

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# 1. BACKGROUND

## 1.1 Introduction

The Clinton Creek watershed is a tributary within the larger Bonaparte River watershed (Figure 1), which lies within B.C.'s interior plateau. Clinton Creek watershed's extents encompass several creeks, waterbodies and wetlands. All creeks within the watershed are tributaries to Clinton Creek which discharges to the Bonaparte River at its eastern extent.

Figure 2 shows the Clinton Creek watershed. The Marble Range mountains and Marble Range Provincial Park extend within the western portion of the watershed with ground elevations of up to approximately 2,100 metres above sea level (masl) along the western extent of the watershed. In the east, the Bonaparte River Valley is deeply incised into the plateau and the elevation of Clinton Creek decreases more than 200 metres (m) between the junction with Cutoff Valley Creek and the confluence with the Bonaparte River in the east where ground surface descends to approximately 650 masl at the discharge point (Figure 2).

The Clinton Creek watershed is located within the territories of the Secwepemc and High Bar First Nations. The Village of Clinton is located at the junction of Clinton Creek and Cutoff Valley Creek and several shallow water bodies are located to the south of the village.

Drinking water in the watershed is derived from both groundwater and surface water sources. Nearly 110 surface water licences and 10 groundwater licences were active in the watershed on May 31, 2022.

The extents of historically mapped aquifers within the watershed are limited and date back to 2007 or earlier. Provincial decision makers, water licence applicants and High Bar First Nation representatives have expressed interest in improved provincial information related to groundwater resources. The aquifer mapping presented in this report provides updated analysis of the groundwater information available in provincial databases and other publicly available sources to support this interest.

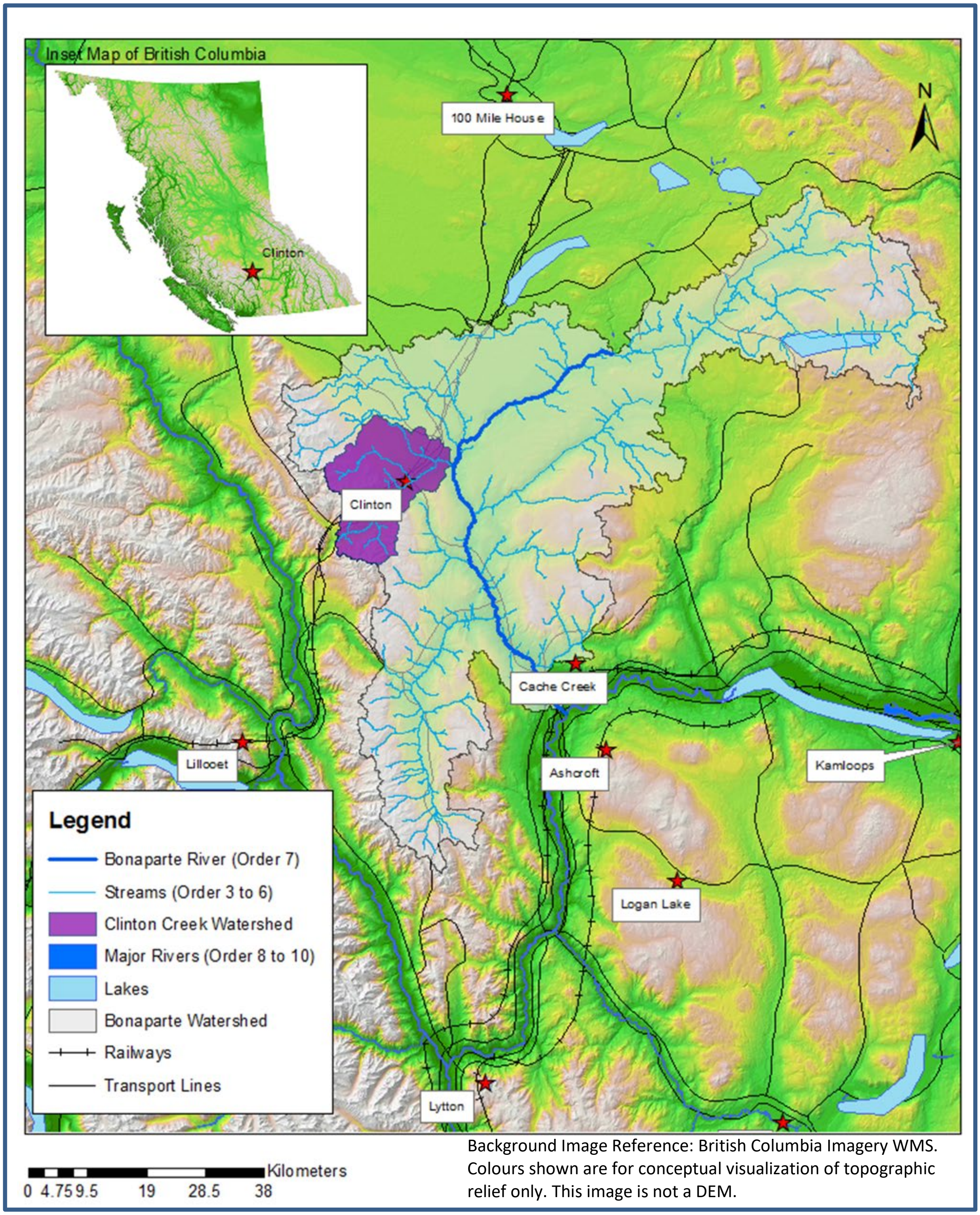
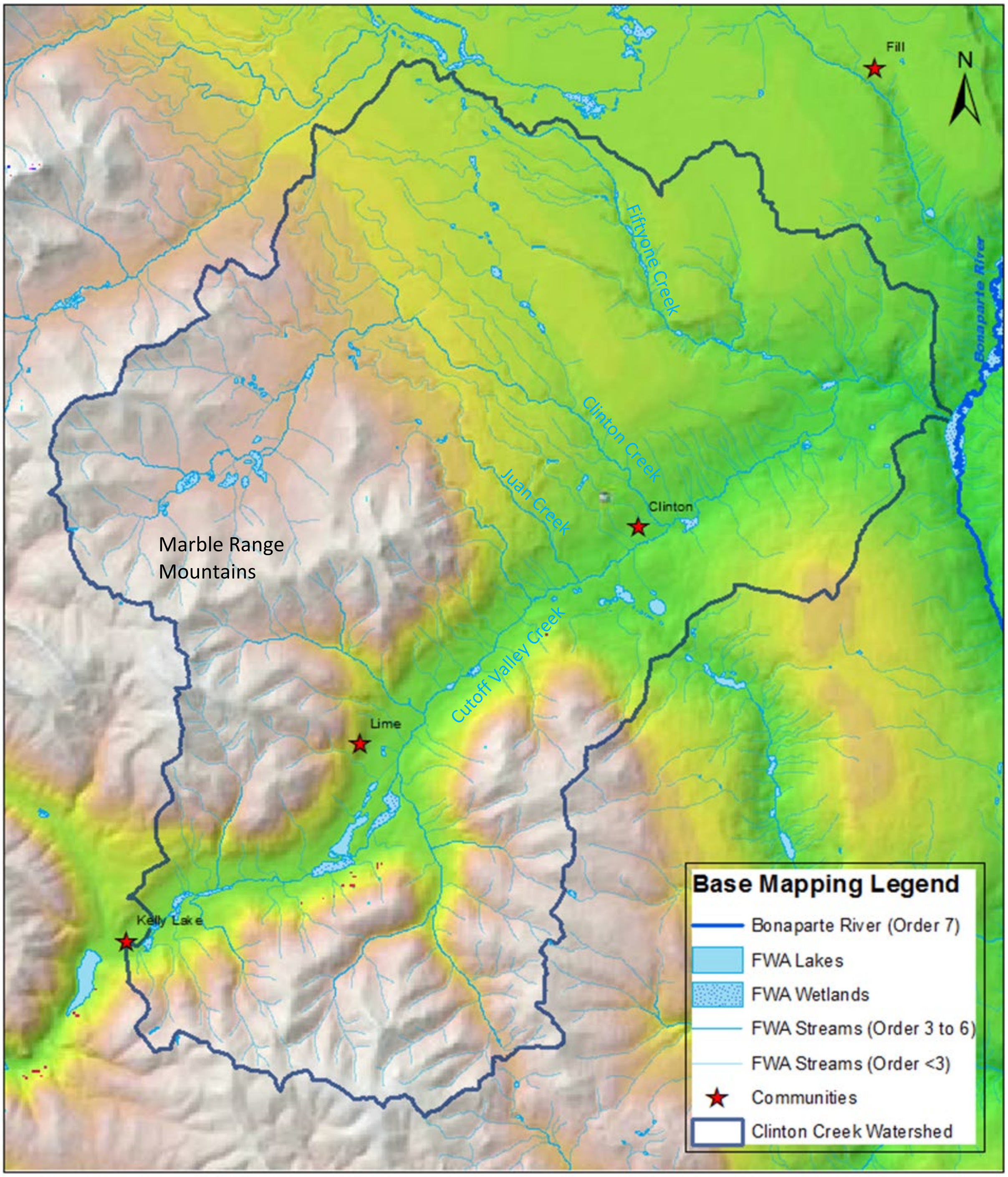



*Figure 1: Location map of the Bonaparte River watershed.*

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Colours shown are for conceptual visualization of topographic relief only. This image is not a DEM.

*Figure 2: Clinton Creek watershed map.*

# 2. METHODS

## 2.1 Data Sources

The primary data source for updating aquifer mapping in the Clinton Creek watershed is the GWELLS database which is the provincial resource for groundwater well and mapped aquifer information. A search for supplemental borehole information within the Clinton Creek watershed boundary was completed by reviewing the B.C. Data Catalogue's Borehole Log Lithology data published by the Ministry of Environment and Climate Change Strategy's Environmental Emergencies and Land Remediation Branch and Well Surface Hole Event published by the B.C. Oil and Gas Commission; however, this search did not reveal additional lithological records.

Additional B.C. Data Catalogue information that was reviewed to provide additional context for the groundwater information in the GWELLS database included:

- Water information in the B.C. Freshwater Atlas (FWA) (Province of B.C. GeoBC 2022) and water rights database (Province of B.C. Ministry of Forests 2022),
- Surficial and bedrock geologic information published by the Ministry of Energy, Mines and Low Carbon Innovation (EMLI) (Province of B.C. Geological Survey 2022),
- Terrain Inventory Mapping (TIM) information published by the Ministry of Land, Water and Resource Stewardship (LWRS) (Province of B.C. Knowledge Management Division 2022), and
- Reconnaissance Karst Potential Mapping published by the Ministry of Forests (FOR) (Province of BC Forest Analysis and Inventory 2022).

Digital Elevation Model (DEM) information for the study area was obtained from the LidarBC open LiDAR Portal (Province of B.C. 2022).

Information on the geologic history of the area was obtained from Geological Survey of Canada publications. A general search of scientific literature was performed to obtain additional information on water resources and management within the watershed, including a search of the Province's EcoCat Ecological Reports Catalogue and a review of water licensing information provided by provincial water management staff.

## 2.2 Data Processing and Interpretation

Information from the data sources described above was assembled and selected for the Clinton Creek watershed area. The data processing method described below follows a similar methodology and lithological categorization as described by Hinnell et al. (2020). Groundwater information was prepared for analysis by using the following steps:

1) *Assign ground elevation to wells*: DEM information obtained from the LidarBC Open LiDAR Data Portal was used to associate a ground elevation with each groundwater well within the study area. Although the GWELLS database can store ground elevation information, for the majority of the wells within the study area, this field was blank. For the remainder of the wells, ground elevation information was of unknown quality; therefore, the 1 m resolution DEM elevation information was assigned to all groundwater wells.
2) *Simplify and standardize lithology*: Lithologic information stored in the GWELLS lithology table was standardized programmatically into categories. Standardization was performed by removing superfluous terms, correcting common misspellings, standardizing descriptive terms and then binning the remaining lithological descriptions into categories.
3) *Cross section selection and data improvement:* Cross section lines were selected where groundwater well information coverage is adequate. Initial draft cross sections were

constructed using Strater© software. In many cases, gaps in the lithological information or errors in well data within GWELLS were revealed in the initial draft sections. Where feasible, corrections to well or lithological information within GWELLS were made to correct these issues and step 2 was then repeated with the corrected data.

4) *Cross section creation*: Five final cross sections were constructed with the corrected data. The resulting sections, and other bedrock and surficial geologic information sources, were used to develop a conceptual model of hydrostratigraphy. Sections were also used to interpret the contacts between hydrostratigraphic units (both aquifers and other units) along each section. The cross sections and a map of their locations are presented in Appendix A.

# 3. GEOLOGIC BACKGROUND

## 3.1 Surficial Geologic Context

This summary of the geologic history of the Clinton Creek watershed area follows from Tipper (1971) and Campbell and Tipper (1971). During the Fraser glaciation in the Late-Pleistocene, which reached its maximum extent approximately 15,000 years ago, the Fraser ice sheet covered the entire Interior Plateau including the area of the Clinton Creek watershed. Either subsequent to the Fraser Glaciation or in a later stage of the Fraser Glaciation, late Cariboo Mountain ice may have readvanced into the area from the Cariboo Mountains in the northeast.

During deglaciation, a large mass of ice stagnated to the east of the Marble Range and as this mass of ice shrunk, lateral overflow channels were incised by meltwaters flowing southeast throughout the watershed. Cutoff Valley Creek and Clinton Creek downgradient of their confluence follow a large meltwater or outwash channel bounded by cutbanks and terraces. Upgradient from Cutoff Creek, Clinton Creek follows what is mapped as a smaller meltwater channel. Many of the smaller meltwater channels within the watershed were likely cut by meltwater flowing between the ice margin and the valley wall while the lower reaches of the valley may still have been filled with ice.

The Cutoff/Clinton Creek Valley floor is mantled by Holocene (post-glacial) colluvial gravels, sands and silts with parts of the valley east and west of Clinton floored by damp grass covered meadows composed of muds (Renaut 1994). BC Data Catalogue data (EMLI Geology Quaternary Alluvium and Cover data and TIM data) indicate that colluvial quaternary sediments are present adjacent to Cutoff Valley Creek and Clinton Creek (downgradient of the confluence with Cutoff Valley Creek) (Figure 3). Colluvial sediments are also indicated in the TIM mapping adjacent to Fiftyone Creek which flows in the northeast area of the watershed and merges with Clinton Creek approximately 3 km northwest of the confluence of Clinton Creek and the Bonaparte River. The upper reaches of Clinton Creek and some other tributaries (Juan Creek, uppermost reaches of Fiftyone Creek) to Clinton Creek flow primarily in areas where fluvial quaternary sediments are mapped (EMLI and TIM).

Throughout much of the higher elevation areas of the watershed, TIM indicates surficial materials are composed of morainal till with minor areas of lacustrine material.

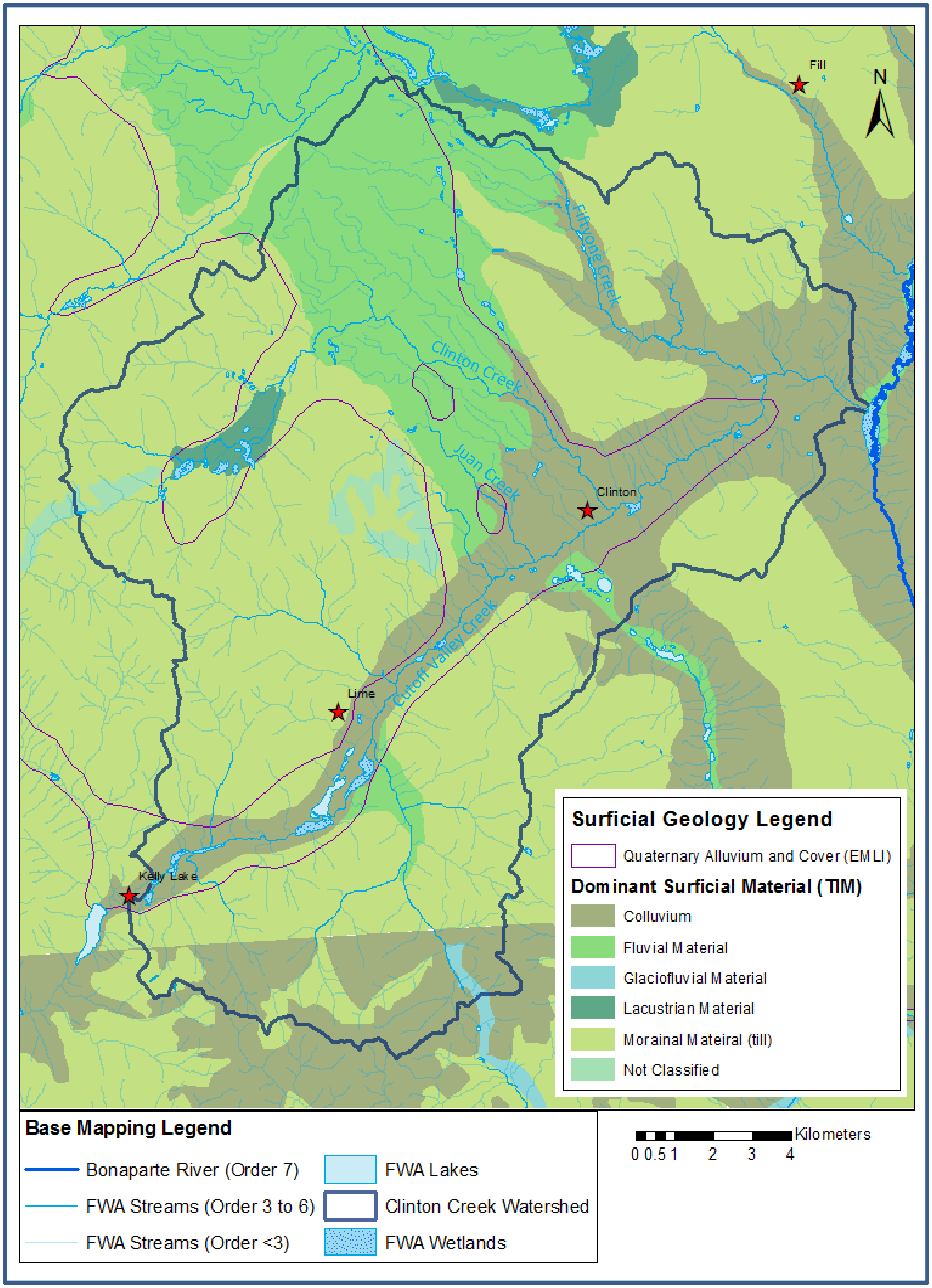



*Figure 3: Surficial geology in the Clinton Creek watershed.*

## 3.2 Bedrock Geologic Context

The following summary of bedrock geology follows from Schiarizza et al. (1994), Campbell and Tipper (1971), Fischl (1992) and Trettin (1980). Surficial deposits are underlain by bedrock of the Cache Creek Complex throughout the majority of western extent of the watershed and in the east between the village of Clinton and the confluence with the Bonaparte River (Figure 4).

The Cache Creek Complex was formed within the early Mississippian to Triassic geologic periods (approximately 360 to 200 million years ago) within an ocean or marginal ocean basin (Trettin 1980). Cache Creek Complex rocks within the western extent of the watershed are predominantly mapped as part of the Cache Creek Complex Marble Canyon Formation which consists of limestone, marble, and calcareous sedimentary rocks. In other areas of the watershed, Cache Creek Complex bedrock is mapped as a mixture of marine sedimentary and volcanic rocks. Chilcotin Group sedimentary rocks are also present in the watershed in the vicinity of the village of Clinton. To the north of the village of Clinton, Chilcotin Group basaltic volcanic rocks are present and have been mapped as provincial aquifer GWELLS aquifer No. 124.

Holocene travertine exposed by railway cuts have been mapped approximately 3.5 km southwest of Clinton (Jones and Renaut 2008) near a small spring. The travertine is no longer forming but precipitated from water discharged from a small spring approximately 10 m north of the deposit which had been converted to a covered well at the time of mapping (Jones and Renaut 2008). Renaut (1994) suggested that the presence of these travertine deposits indicates that moister conditions were present in the valley during the mid-Holocene.

Marble Range Provincial Park, which extends into the western extent of the watershed, is known for karst formations and FOR reconnaissance karst potential mapping has mapped much of the western area of the watershed as being of high karst potential.

EMLI mapping indicates that several northeast trending faults are present within the watershed, several of which run beneath Cutoff Valley or Clinton Creek. A thrust fault trending roughly east is also mapped in the northwest of the watershed.

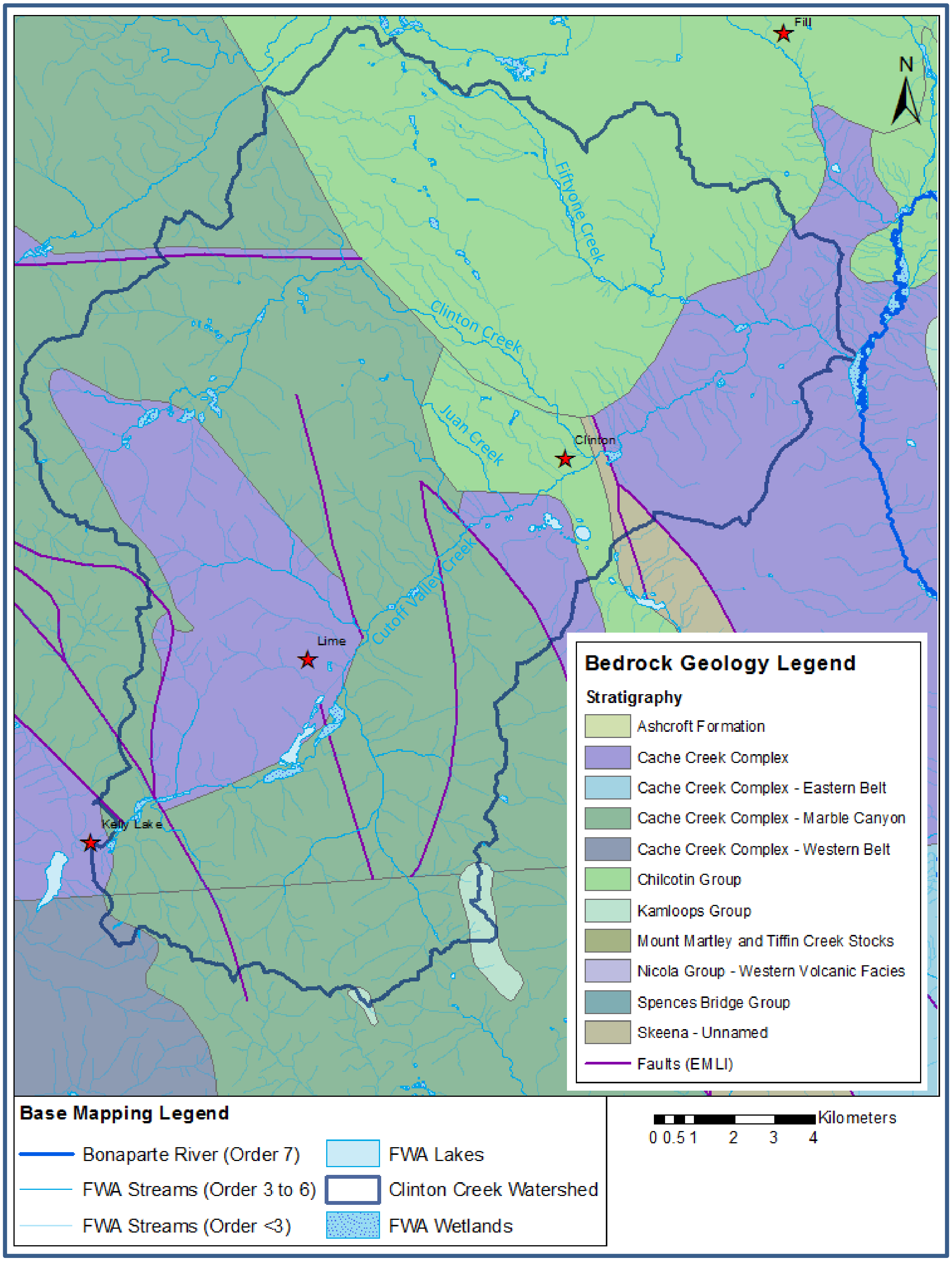



*Figure 4: Bedrock geology in the Clinton Creek watershed.*

## 4. HYDROGEOLOGY

The following conceptual model of hydrostratigraphy is based on the surficial and bedrock geological information (Sections 3.1 and 3.2) and data interpretation (Section 2.2). The hydrostratigraphic conceptual model consists of four aquifers that are currently utilized as a groundwater source in the Clinton Creek watershed:

- GWELLS aquifer No. 124, Fraser Plateau Lava Bedrock aquifer (revised from previous mapping in 2000),
- GWELLS aquifer No. 1263, Clinton Creek Bedrock aquifer (newly mapped in this study),
- GWELLS aquifer No. 920 Clinton Creek Lower Unconsolidated (revised from previous mapping as GWELLS aquifer No. 920 and No. 921), and
- GWELLS aquifer No. 1262, Clinton Creek Upper Unconsolidated (newly mapped in this study).

An overview of these mapped aquifers is included in the sections below and presented in Figure 5 and Figure 7. Figure 6 presents long term water level monitoring information for a provincial observation well completed in GWELLS aquifer No. 920. More in-depth descriptions for GWELLS aquifer No. 1263, 920 and 1262 are also included in Appendix B. Appendix B does not include a description for GWELLS aquifer 124 as the edits to this unit within the Clinton Creek watershed are minor.

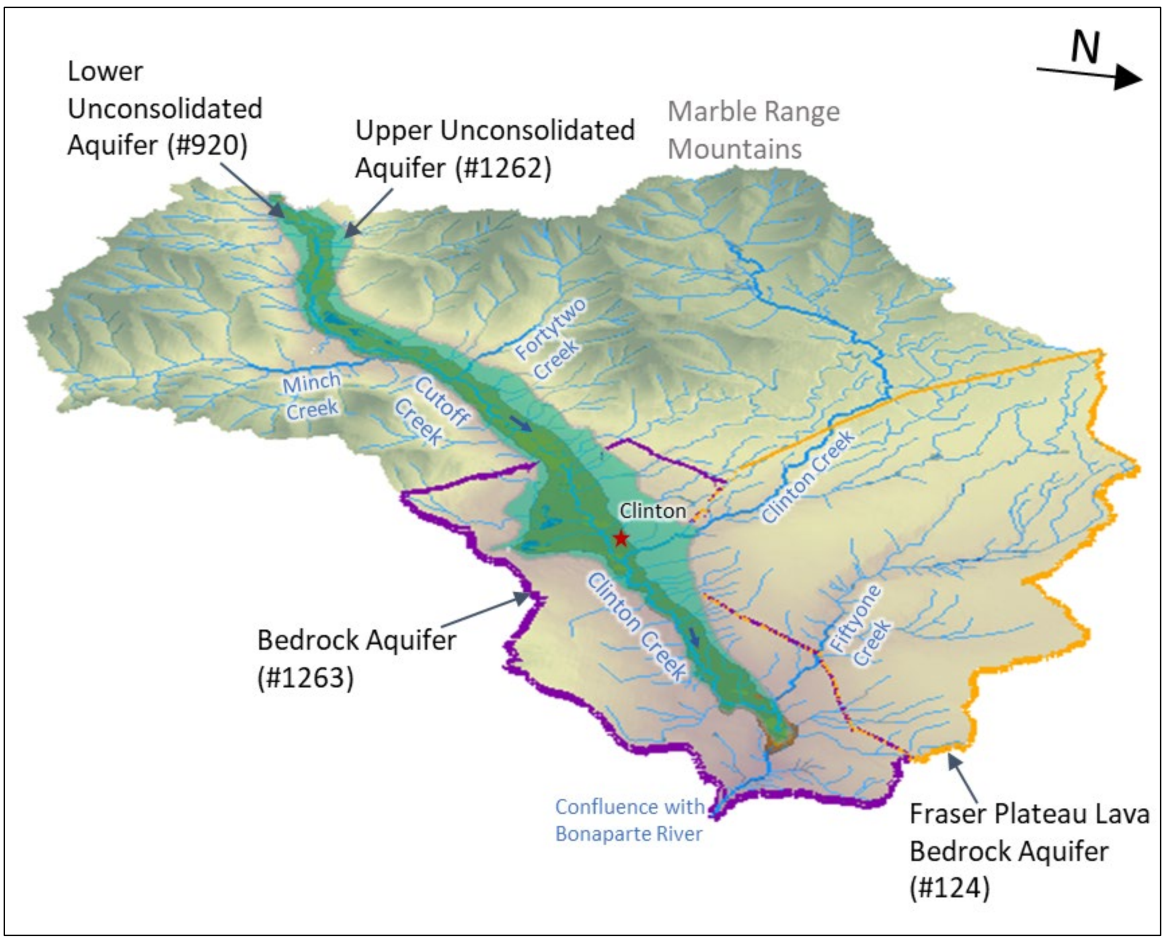



*Figure 5: Conceptual model of aquifers in the Clinton Creek watershed.*

## 4.1 Bedrock Aquifers

The Fraser Plateau aquifer (GWELLS aquifer No. 124) is a regionally extensive unit that is currently mapped as extending far beyond the extent of the Clinton Creek watershed. Within the Clinton Creek watershed, this unit extends into the northeast portion of the watershed in the areas underlying Fiftyone Creek. In previous mapping, four wells adjacent to Fiftyone Creek were mapped within this aquifer. In the present study, the extent of the Fraser Plateau aquifer has been revised and the extents somewhat decreased to match bedrock geologic mapping (Province of BC Geological Survey 2022a) (Figure 4). No wells are presently mapped as located within this bedrock aquifer within the Clinton Creek watershed (Figure 7).

The newly mapped Clinton Creek Bedrock aquifer (GWELLS aquifer No. 1263) extends in the lower elevation areas of the watershed and is generally utilized as a groundwater source where the overlying unconsolidated aquifers are thin or absent (Section A-A′ and D-D′). This unit includes marine sedimentary and volcanic bedrock of the Cache Creek Complex, coarse clastic sedimentary rock of an unnamed group, and coarse clastic sedimentary rocks of the Chilcotin Group. Well yields within this unit are generally low (less than 30 L/min) except for two higher yield wells (approximately 40 and 190 L/min) with both completed near bedrock formation contacts or faults.

## 4.2 Unconsolidated Aquifers

The Clinton Creek Upper Unconsolidated aquifer (GWELLS aquifer No. 1262) is newly mapped in this study (Figure 7). This aquifer is utilized in a minority (five) of the wells within the valley. It is generally only accessed in very shallow wells, but mapping of the aquifer is significant for characterizing the groundwater flow system within the Cutoff/Clinton Creek Valley. The Clinton Creek Upper Unconsolidated aquifer is interpreted to be hydraulically connected to Cutoff/Clinton Creek and hyporheic exchange between the creek and the upper aquifer may occur seasonally or spatially along the length of the creek. The chemistry of Cutoff/Clinton Creek and the shallow groundwater are likely to be influenced by this exchange (Hayashi and Rosenberry 2002). Groundwater flow from this unit also likely contributes shallow groundwater discharge to Salt Lake, Duck Lake and other shallow seepages and water bodies south of the village of Clinton. The significance of these groundwater discharges is discussed in Section 5.1.

GWELLS aquifer No. 1262 overlies the deeper unconsolidated unit (GWELLS aquifer No. 920). In some areas south of the village of Clinton the two aquifers are contiguous (Section C-C’ and Section E-E’) while in other areas the two aquifers are separated by an intervening sandy till unit (Section B-B’, Section D-D’). GWELLS aquifer No. 1262 appears to pinch out in the lower elevation reaches of Clinton Creek (Section D-D’ and Section A-A’). This change in stratigraphy suggests that hyporheic exchange and hydraulic connection between surface and groundwater may be less significant in the lower reaches of Clinton Creek (Section A-A’).

The Clinton Creek Lower Unconsolidated aquifer (GWELLS aquifer No. 920) was previously mapped in 2007 as two units (GWELLS aquifers No. 920 and 921) of limited areal extent centred around the communities of Kelly Lake and Clinton, respectively. In previous mapping, the units were interpreted to be of low to moderate vulnerability and to be predominantly confined. This understanding was consistent with the information that was available at that time. Additional information compiled for this study, indicates that the aquifer likely extends between and beyond the two communities and follows the route of Cutoff Valley Creek and Clinton Creek below the two creeks confluence (Figure 7). The aquifer is consistently observed in well logs throughout the valley, but it is absent in some wells located away from the creek in lower elevation reaches (Section D-D’ and Section A-A’). The unit is generally overlain by the upper unconsolidated aquifer (GWELLS aquifer No. 1262) and an intervening sandy till unit. However, as noted above, the till unit appears to be absent in some areas in the vicinity of Clinton (Section C-C’ and Section E-E’).

Provincial groundwater observation well 80 (OW 80) is completed within the Clinton Creek Lower Unconsolidated aquifer (GWELLS aquifer No. 920) and located approximately 60 metres southwest of Salt Lake and approximately 1.4 km from Cutoff/Clinton Creek. Water level information in this well has been collected since 1971 (Figure 6). Annually, water levels in this well fluctuate by approximately 0.2 m with a seasonal high in April and a seasonal low in October. Data recorded in this well suggest that the well water level generally declined from 1971 to 2004. This declining trend may be related to periods of decreased precipitation, increased water withdrawals, land use changes or changes in surface water conditions. There is a gap in the monitoring data between June 2004 and October 2005 and the raw water level data recorded between these dates indicates a water level increase of approximately 0.3 m over this period. This apparent increase should be approached with caution as the abrupt change may indicate a measurement error due to a change in the reference point for monitoring. Monitoring information collected after 2004 indicates that water level in this well decreased from 2007 to 2010 but has been increasing since 2014.

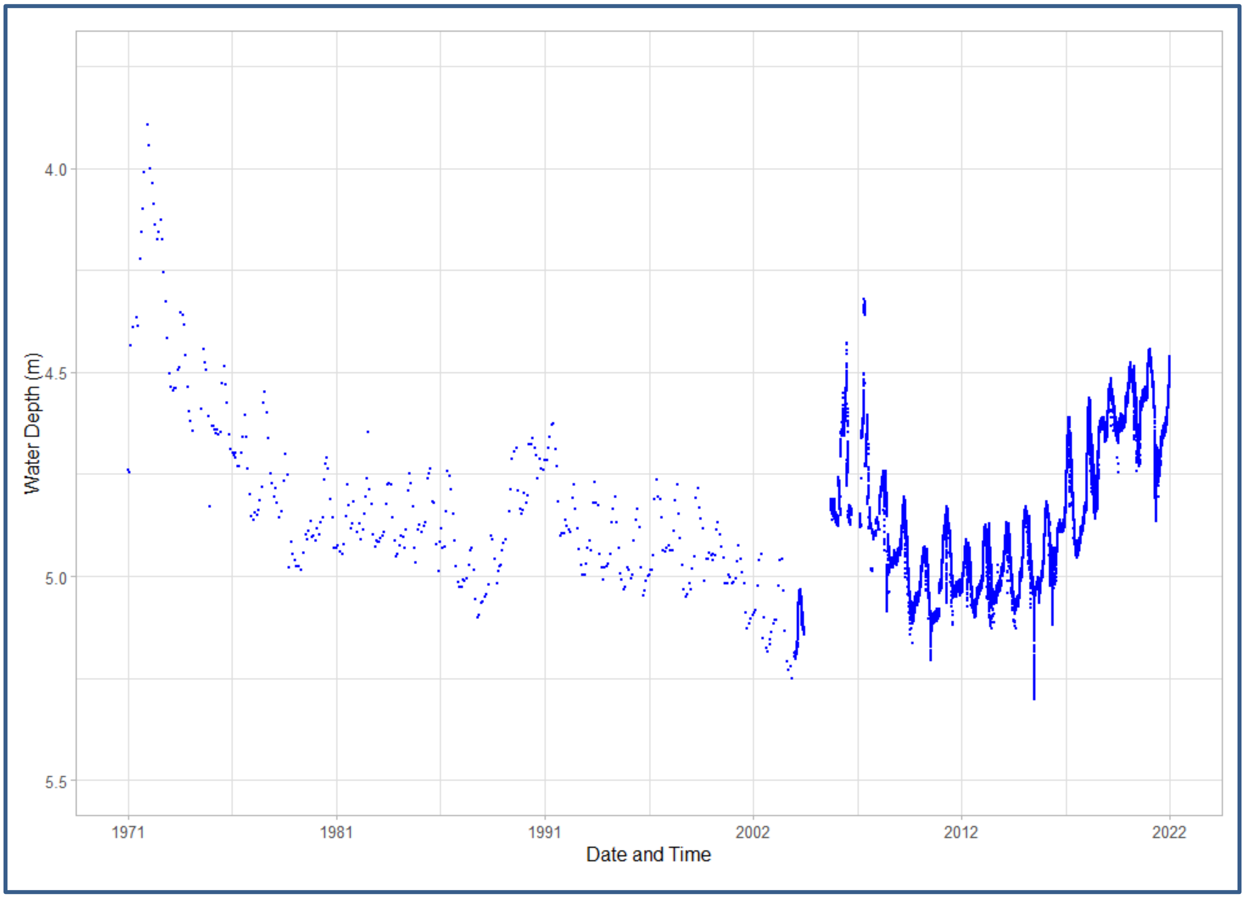



*Figure 6: Water level in provincial groundwater observation well 80 (OW 80).*

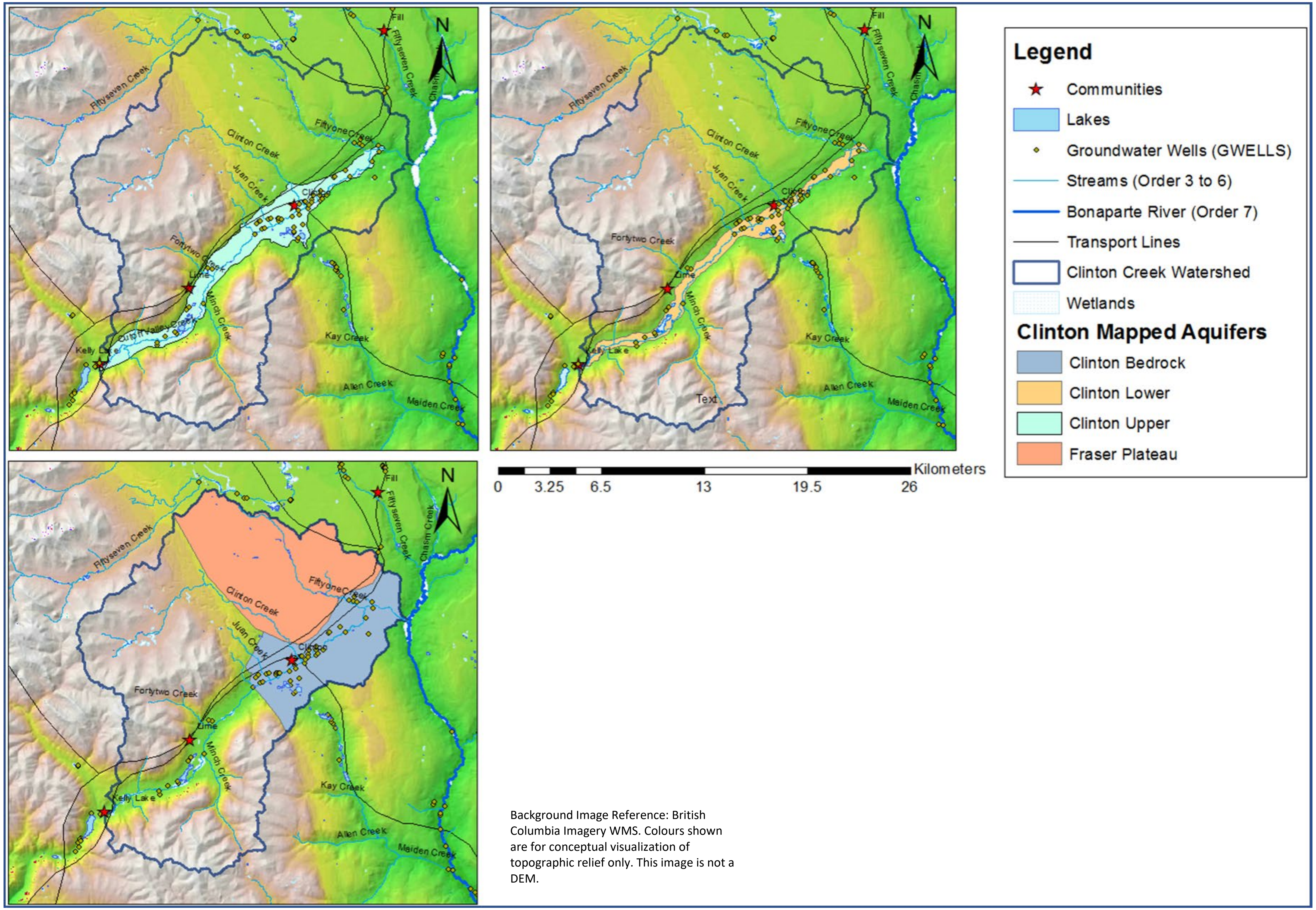



*Figure 7: Mapped aquifers in the Clinton Creek watershed.*

## 5. <u>WATER QUALITY CONSIDERATIONS</u>

### 5.1 Salt Lake and Duck Lakes

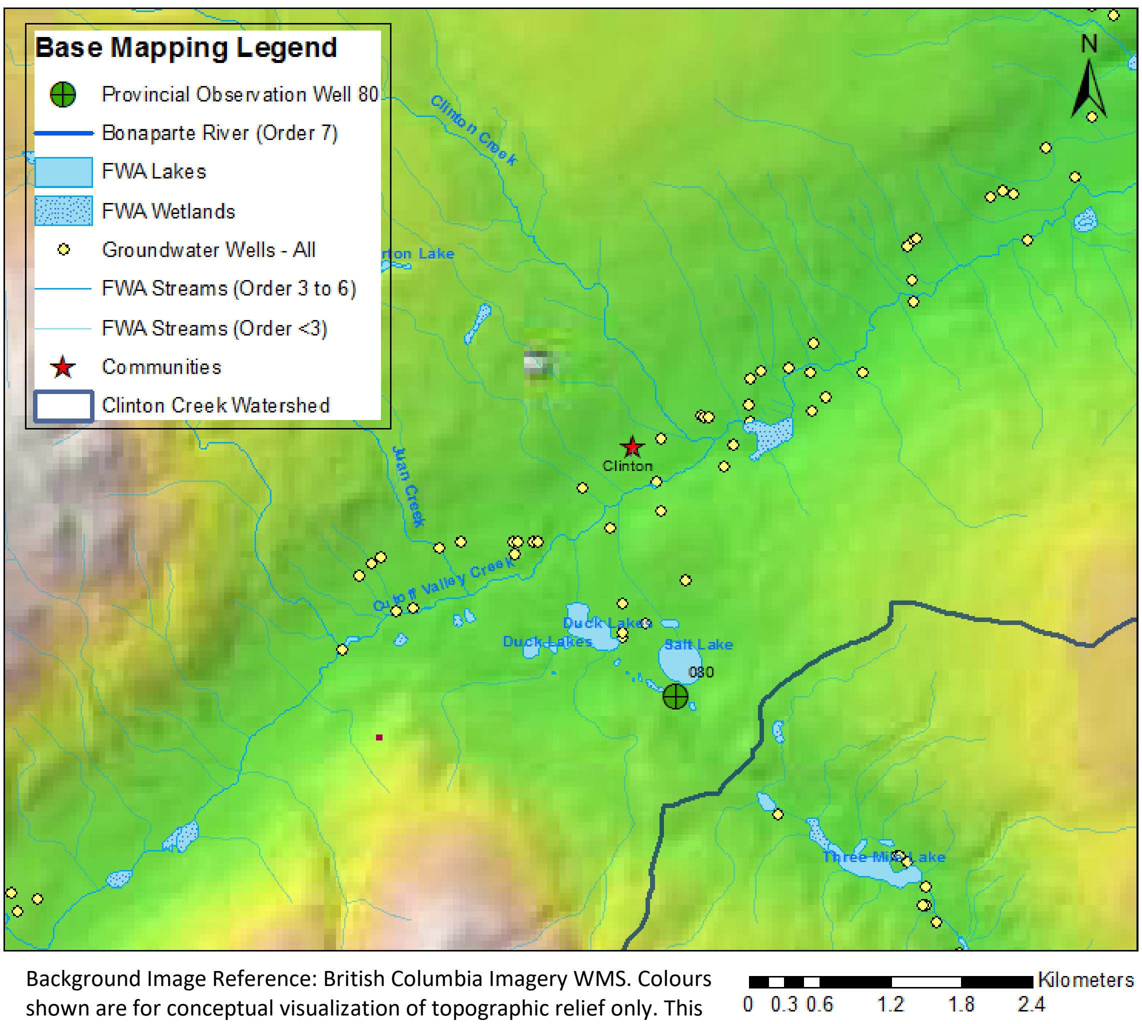
Salt Lake (also referred to as Clinton Lake by Renaut (1994)) and Duck Lakes are located to the south of Clinton (Figure 8 and Figure 9). These water bodies have elevated salinity which is characteristic of wetlands in a semi-arid climate with mineral rich glacial sediments (van der Kamp and Hayashi 2008). Saline water bodies can be ecologically significant for waterfowl as a source of food and habitat for nesting (Wurtsbaugh et al. 2017).

Studies by Renaut (1994) indicate that Salt Lake is composed of numerous shallow pools of a Mg-Na-$SO_4$ brine which ranges from less than 100 g/l total dissolved solids (TDS) in spring to more than 350 g/l TDS in summer. Renaut (1994) identified that Salt Lake is an ephemeral water body which reaches its maximum depth in early summer following snowmelt and early summer precipitation and dries seasonally in late summer. Clinton Pond is a smaller wetland documented by Renaut (1994), which is located about 120 m north of Salt Lake. Renaut described Clinton Pond as fed by a number of ephemeral springs and one perennial spring which Renaut referred to as Clinton Lake Spring. These


*Figure 8: Water bodies to the south of the Village of Clinton.*

springs are moderately saline (2.5 to 3 g/l TDS) while Clinton Pond is somewhat higher salinity (2 to 15 g/l TDS).

Both Salt Lake and Clinton Pond are surrounded by carbonate mudflats and underlain by a thin mineral crust and black carbonate/gypsum mud to an anticipated depth of 1.2 m (Renaut 1994). Research by van der Kamp and Hayashi (2008), indicates that elevated salinity in wetlands generally occurs in groundwater discharge zones; therefore, the elevated salinity of Salt Lake suggests that it is a groundwater discharge zone. Furthermore, Renaut (1994) presents geochemical evidence suggesting that saline groundwater upwells through the muds that underlie Salt Lake. The water in Salt Lake is enriched in magnesium reflecting weathering and alteration of the Cache Creek complex bedrock (Renaut 1994). The water level in Clinton Pond is described by Renaut as approximately 1 m above Salt Lake. Renaut (1994) postulated that groundwater flows southward from Clinton Pond to Salt Lake and that Salt Lake is sustained by a mix of moderately fresh shallow groundwater and diffuse artesian upwelling of deeper saline groundwater.




Background Image Reference: British Columbia Imagery WMS. Colours shown are for conceptual visualization of topographic relief only. This image is not a DEM.

*Figure 9: Location of observation well 80 and nearby water bodies.*

## 5.2 Piper Plot of Geochemical Data

Figure 10 presents a piper plot which compares a selection of representative samples collected by Renaut (1994)[1] in the 1992 field season with more recently collected samples (2015 and 2020) in provincial groundwater observation well OW-80 completed in the Clinton Creek Lower Sand and Gravel aquifer (GWELLS aquifer No. 920).[2] Comparison of these sampling results suggests that groundwater in GWELLS aquifer No. 920 is geochemically similar to Clinton Pond, Clinton Spring and the lake marginal waters on the northeast side of Clinton/Salt Lake. This result suggests that these surface water features may be hydraulically connected to OW-80. However, it should be noted that OW-80 has a greater chloride concentration than all surface water samples except that collected in Clinton/Salt Lake, which may suggest that these surface water features are also recharged by fresher shallow groundwater flow. OW-80 is also somewhat higher in calcium than surface water samples. This result is consistent with Renaut's interpretation that early precipitation of calcium-bearing carbonates in soils, at springs and at seepage sites results in depletion of calcium in surface waters.

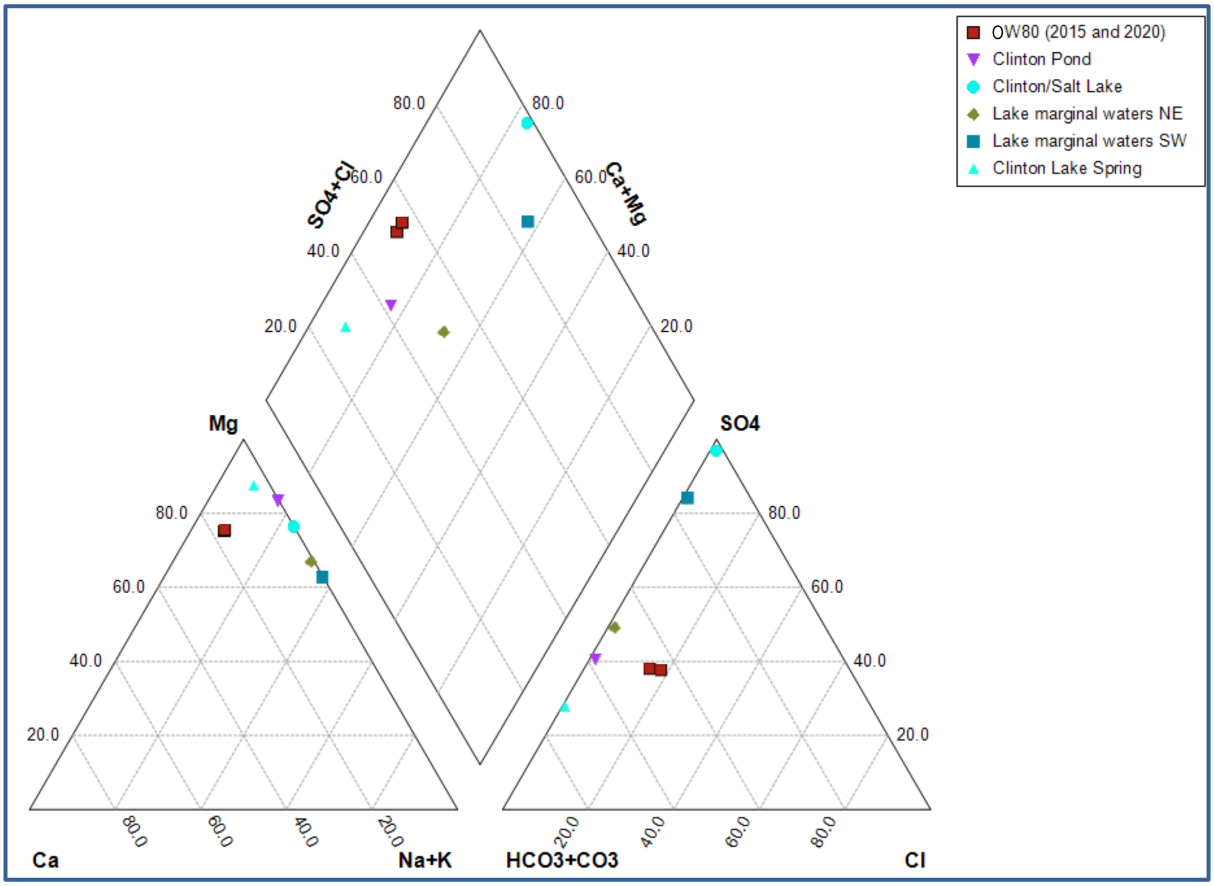



*Figure 10: Piper plot of geochemical information.*

[1] Refer to Renaut (1994) for a more complete summary of that investigation and full sampling results collected between 1985 and 1992.

[2] Historical samples in this well are also available for 1992, 2002, 2005 and 2010; however, only samples collected after 2015 are discussed as this is when the sampling methodology and laboratory analytical suite in the Provincial Groundwater Observation Well Network were standardized. Concentrations measured in earlier sampling are similar, but generally somewhat lower than more recent sampling.

Salt Lake and marginal waters on the southwest side of Salt Lake are relatively enriched in sulphate (Table 1). This result can be partially explained by precipitation of calcium carbonate bearing minerals, but the ratio of sulphate to chloride is much higher in these surface water bodies than found in OW-80. The source of this sulphate enrichment may be explained by oxidation of sulphates such as pyrite in the Cache Creek shales and argillites, and the dissolution of gypsum (Renaut 1994).

*Table 1: Summary of groundwater chemistry data.* [3]

| Location | pH | Na (mg/l) | K (mg/l) | Ca (mg/l) | Mg (mg/l) | Cl (mg/l) | $SO_4$ (mg/l) | Na/Cl (mol) | Na/K (mol) | Mg/Ca (mol) |
|---|---|---|---|---|---|---|---|---|---|---|
| OW-80 – July 2015 | - | 37.20 | 7.33 | 75.8 | 205 | 120 | 398 | 0.48 | 8.63 | 4.46 |
| OW-80 – August 2020 | 7.44 | 40.50 | 8.65 | 82.30 | 227 | 148 | 411 | 0.42 | 7.96 | 4.55 |
| Salt Lake Marginal Waters SW – June 1992 | 8.50 | 1,450 | 145 | 9 | 1,365 | 85 | 7,290 | 26.3 | 17.01 | 250.1 |
| Salt Lake Marginal Waters NE – June 1992 | 8.10 | 390 | 56 | 8 | 460 | 36 | 1,340 | 16.7 | 11.84 | 94.82 |
| Clinton/Salt Lake – July 1992 | 8.25 | 25,600 | 3,050 | 55 | 46,500 | 3,750 | 289,000 | 10.5 | 14.27 | 1,394 |
| Clinton Pond – June 1992 | 9.20 | 195 | 35 | 3 | 575 | 31 | 1,095 | 9.70 | 9.48 | 316.1 |
| Clinton Lake Spring – June 1992 | 7.20 | 72 | 11 | 30 | 410 | 12 | 510 | 9.25 | 11.1 | 22.54 |

## 5.3 Water Quality Objectives

Water Quality Objectives (WQO) were developed for the Bonaparte River and Clinton Creek in 1986 (Swain 1986) for a number of water quality parameters. Refer to Swain (1986) for detailed information about these objectives. Monitoring has been conducted to assess attainment of objectives (Brewer 1997, Kelly 2003). Where aquifers may be hydraulically connected to creeks that are tributaries to the Bonaparte River, authorization of activities that could impact water quality of this aquifer, may consider downstream impacts to the WQO in addition to local impacts. This consideration could extend to authorizations of groundwater withdrawals if withdrawals may alter the flow system such that there are impacts to the WQO.

Designated uses in Clinton Creek associated with the WQO include aquatic life, wildlife, livestock, irrigation and drinking water supply. WQOs (for dissolved oxygen) have also been set to protect spawning and rearing habitats for trout and salmon. Swain (1986) notes that WQOs had not always been

[3] All data reproduced from Renaut (1994) except OW-80 which was obtained from the provincial environmental monitor system database. Major ion charge balances are 10% or less for all samples except samples from Salt Lake and Clinton Pond which have major ion charge balances of -11% and -26%, respectively. Full analytical results for these samples are not available in Renaut so the cause of this imbalance cannot be fully investigated. However, this result could indicate sampling error or that significant levels of unanalyzed cations are present in these samples. A sample collected in Clinton Pond by Renaut in 1986 had similar chemistry, but lower alkalinity and a charge balance of approximately 1%.

met for the WQO in Clinton Creek and downstream in the Bonaparte River at that time. High levels of some parameters (fecal coliforms, suspended solids, turbidity and algae growth) were also noted in 1996 (Brewer 1997). More recent attainment monitoring indicates that the majority of the WQOs were met in Clinton Creek in 2002 with the exception of fecal coliforms (Kelly 2003).

## 6. DATA GAPS AND UNCERTAINTY

Lithological information retrieved from the GWELLS database is of unknown quality and the spatial coverage of this information is limited. The drilling method is unknown for many wells while others are often identified as excavated or air rotary method. These methods do not produce cores for interpretation, so the stratigraphic information is generally only available at a cursory level. The lithologic records have been created by a number of individuals and lithology may not have been logged with a standardized criterion.

The extents of the aquifer units mapped have been inferred based on the data sources available, but these aquifer units may extend beyond or be absent within the mapped area due to limitations in the available information. Additional surficial aquifers could also be present within the Clinton Creek watershed, particularly where TIM and EMLI data indicate that fluvial or colluvial sediments are present. Bedrock throughout the study area could have a potential to transmit groundwater and be utilized as a source. The hydraulic conductivity of bedrock may be enhanced in the vicinity of fault zones or formation contacts (EMLI fault mapping), but field studies would be needed to better understand this potential.

Additional hydrogeologic information has been collected in support of a groundwater license application (Hy-Geo 2018, Hy-Geo 2019). These reports focus on data analysis in a limited area of the Clinton watershed and may be referred to for additional site-specific information on unconsolidated aquifers and information related to that application. Information included in these reports includes the surveyed location and elevations of some wells, some water quality information, results of pumping tests and some water levels. This information is focused on assessment of a single licence application and focuses on site specific conditions. Future studies may incorporate additional information as it becomes available through license conditions or other monitoring. If data from a number of new license applications or other site-specific studies becomes available, a regional interpretation of this information may be valuable.

## 7. CONCLUSIONS AND RECOMMENDATIONS

The Clinton Creek watershed is complex and interesting from both a hydrogeologic and geologic perspective. Many streams in the area follow routes originally incised into the underlying bedrock by glacial meltwater channels. The outwash channel followed by Cutoff/Clinton Creek has since been infilled by glacio-fluvial outwash, a lower hydraulic conductivity glacial till and more permeable Holocene colluvial, fluvial and alluvial deposits. The bedrock geology of the area includes the predominantly limestone Cache Creek Complex Marble Canyon Formation in the west and the marine sedimentary and volcanic bedrock of the Cache Creek Complex and Chilcotin group in the east.

Three aquifers have been re-mapped or newly mapped within the Clinton Creek watershed through the course of this study. These include: two unconsolidated aquifers that extend along the Cutoff/Clinton Creek Valley that are designated as the Clinton Creek Upper Unconsolidated (GWELLS aquifer No. 1262) and the Clinton Creek Lower Unconsolidated aquifers (GWELLS aquifer No. 920); and one bedrock aquifer designated as the Clinton Cache Creek Bedrock aquifer (GWELLS aquifer No. 1262) that extends over much of the lower elevation areas of the watershed. Characteristics of the three mapped aquifers are summarized in Appendix C.

Additional aquifers may be present within the watershed. In particular, the limestone of the Cache Creek Complex – Marble Canyon Formation may host karst features of high permeability. Further studies would be needed to understand the hydrogeology of this formation and the potential role of features of enhanced permeability within the unit.

Numerous wetlands and small lakes are present within the watershed. The composition of some saline lakes has been extensively studied by Renaut (1994) and these are interpreted to be a discharge zone for both shallow and deep groundwater sources.

The hydraulic connection between Cutoff/Clinton Creek and unconsolidated aquifers and the potential for hyporheic exchange between the two regimes could be a focus of future studies. It is expected that the upper unconsolidated unit is likely in hydraulic connection with the creek while the hydraulic connection with the lower unit is unclear. Hyporheic exchange likely significantly influences both water quantity and quality of Cutoff/Clinton Creek. Future studies to better understand groundwater and surface water dynamics of Salt Lake or other saline water bodies may also be of benefit to improve understanding of how these features may be impacted by land or water use and climate change.

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<u>AUTHORSHIP</u>

Prepared by B.C. Ministry of Land, Water, and Resource Stewardship:

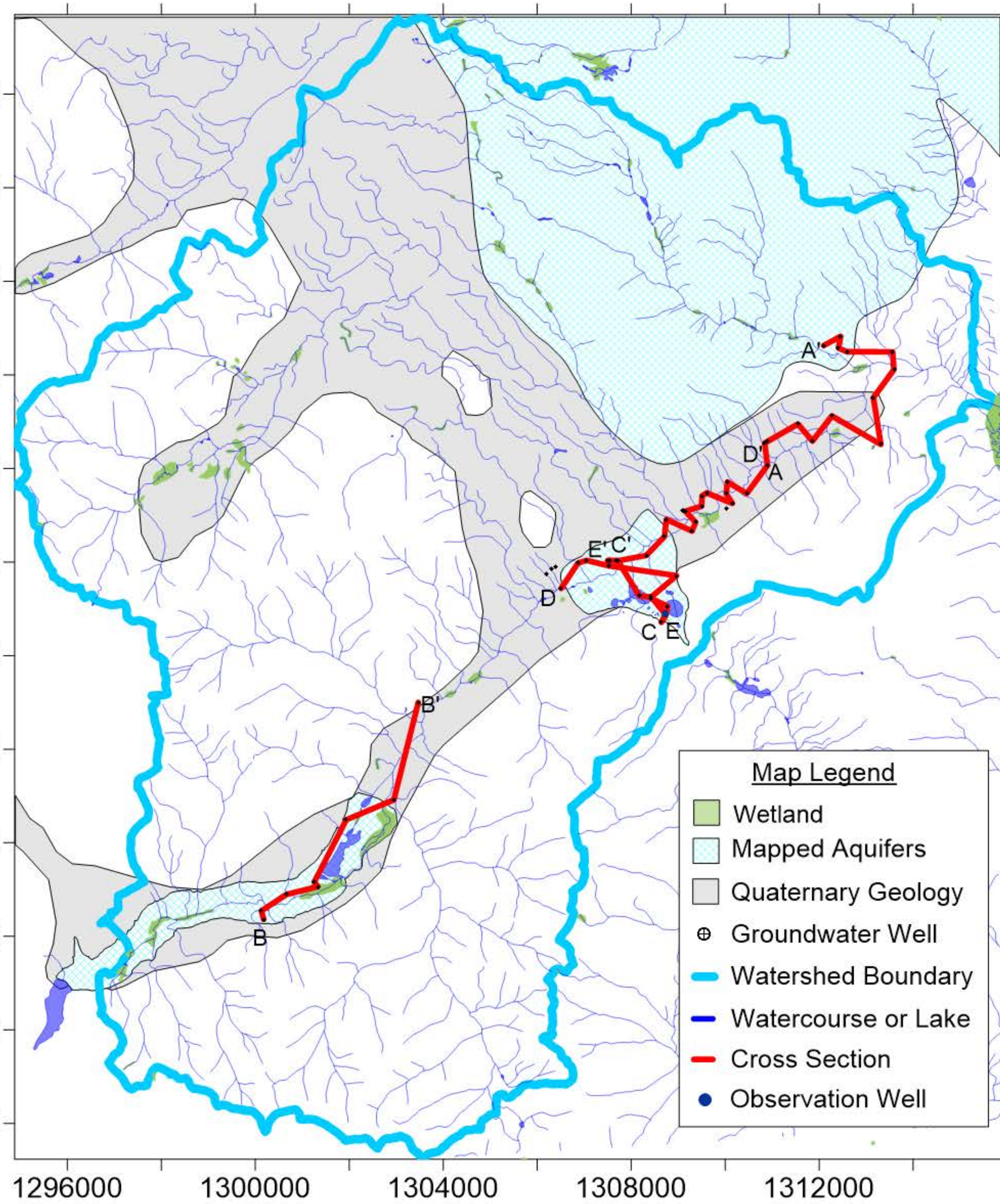
***Original Signed and Sealed***

Christine Bieber, P. Geo.

<u>DISCLAIMER</u>

Contents of this report are presented for information purposes only. The information presented in this document has been compiled for aquifer mapping and regional hydrostratigraphic characterization. This study may provide regional context for site specific decisions or planning, but additional site-specific information or studies may also be needed to better understand local site conditions. Reasonable skill, care and diligence has been used in the preparation of this report, but LWRS makes no guarantees or warranties as to the accuracy or completeness of this information.

## APPENDIX A: CROSS SECTIONS

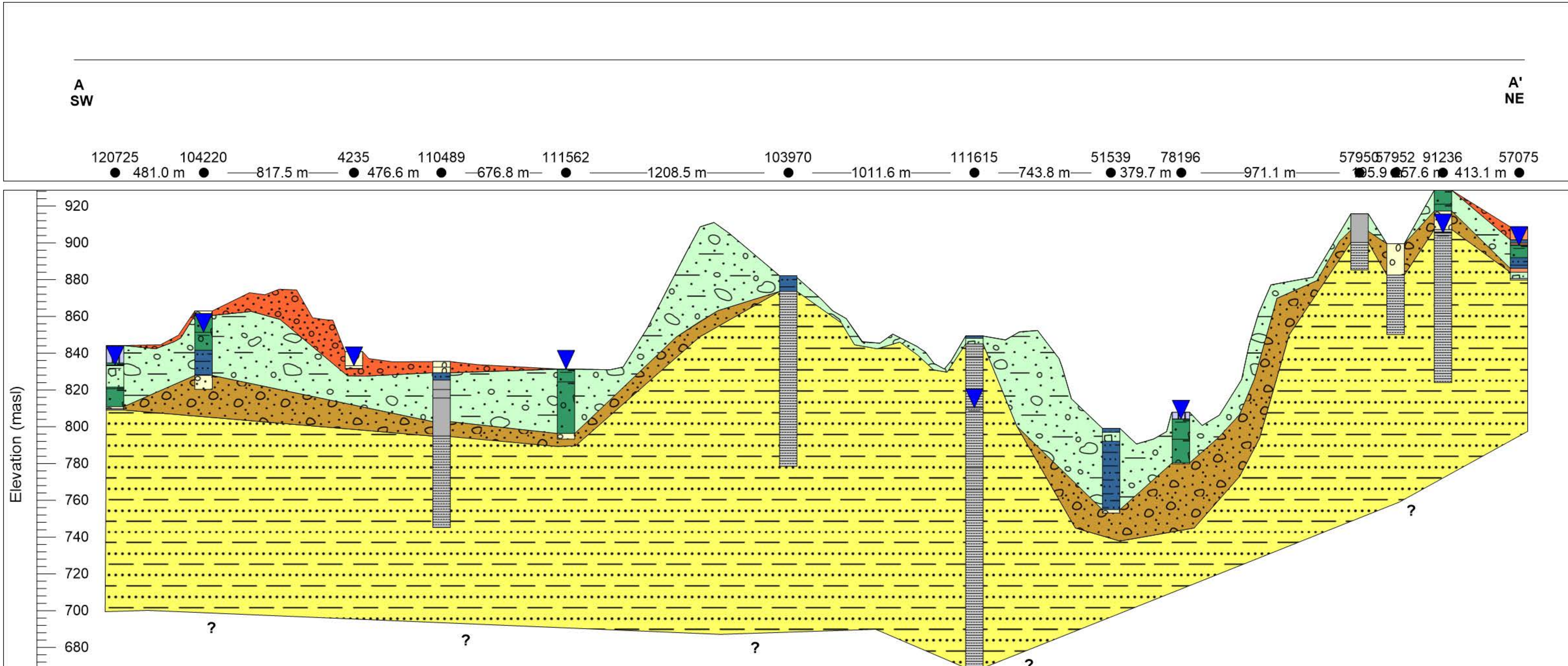


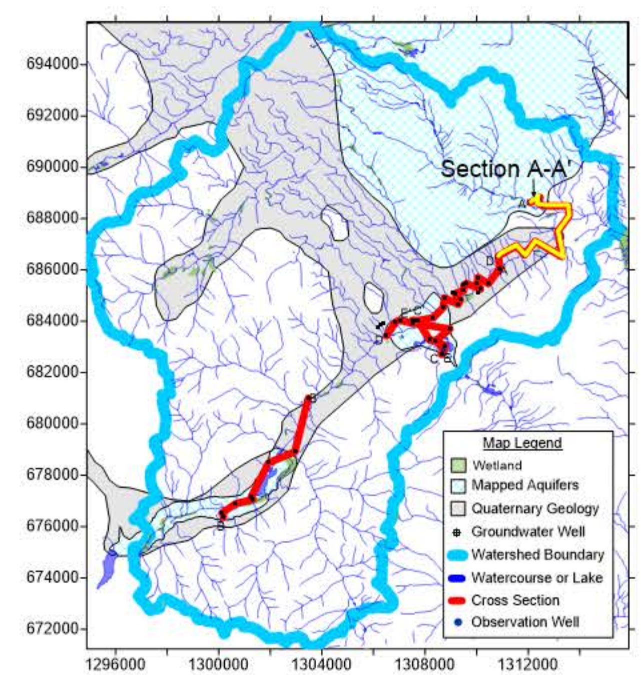

Clinton Creek Watershed Aquifer Mapping

BC Ministry of Environment and Climate Change Strategy

Figure 1
Proposed Cross Section Locations

All distances in metres.
Coordinates shown are in ESPG 3005.




All distances in metres.

**Borehole Lithology Legend**

- Bedrock
- Boulders
- Clay
- Gravel
- Gravel (Dirty)
- Medium to Clay Till
- NA
- Organics
- Sand
- Sand and Fines
- Sand and Gravel (Clean)
- Sand and Gravel (Dirty)
- Sand or Gravel Till
- Silt

**Stratigraphy Legend**

- Clinton Creek Upper Sand and Gravel
- Till
- Clinton Creek Sand and Gravel
- Clinton Cache Creek Bedrock
- Bedrock
- Alluvial to Lacustrine Plain

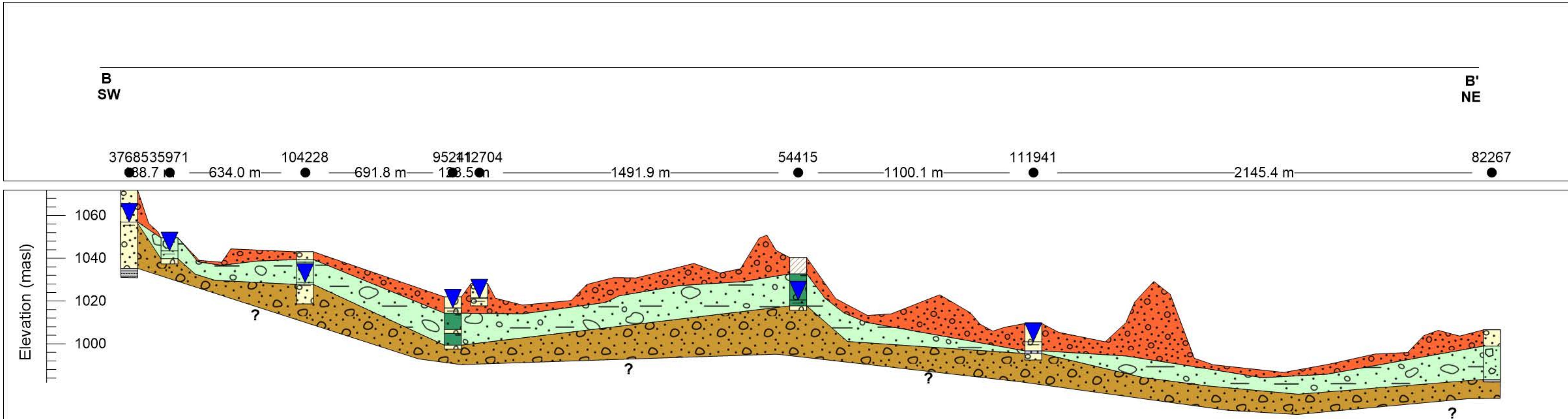
Clinton Aquifer Mapping

BC Ministry of Environment and Climate Change Strategy

BRITISH COLUMBIA

Figure 2 Cross-Section A-A' Along Clinton Creek

Date:21-07-2021 | Drawn By: CB | Reviewed By: XX

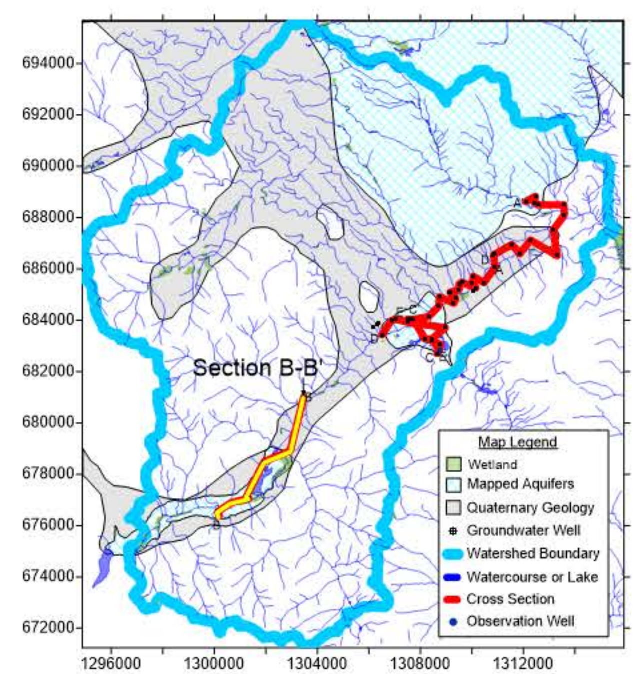



Borehole Lithology Legend

- Bedrock
- Boulders
- Clay
- Gravel
- Gravel (Dirty)
- Medium to Clay Till
- NA
- Organics
- Sand
- Sand and Fines
- Sand and Gravel (Clean)
- Sand and Gravel (Dirty)
- Sand or Gravel Till
- Silt

Stratigraphy Legend

- Clinton Creek Upper Sand and Gravel
- Till
- Clinton Creek Sand and Gravel
- Clinton Cache Creek Bedrock
- Bedrock
- Alluvial to Lacustrine Plain




All distances in metres.

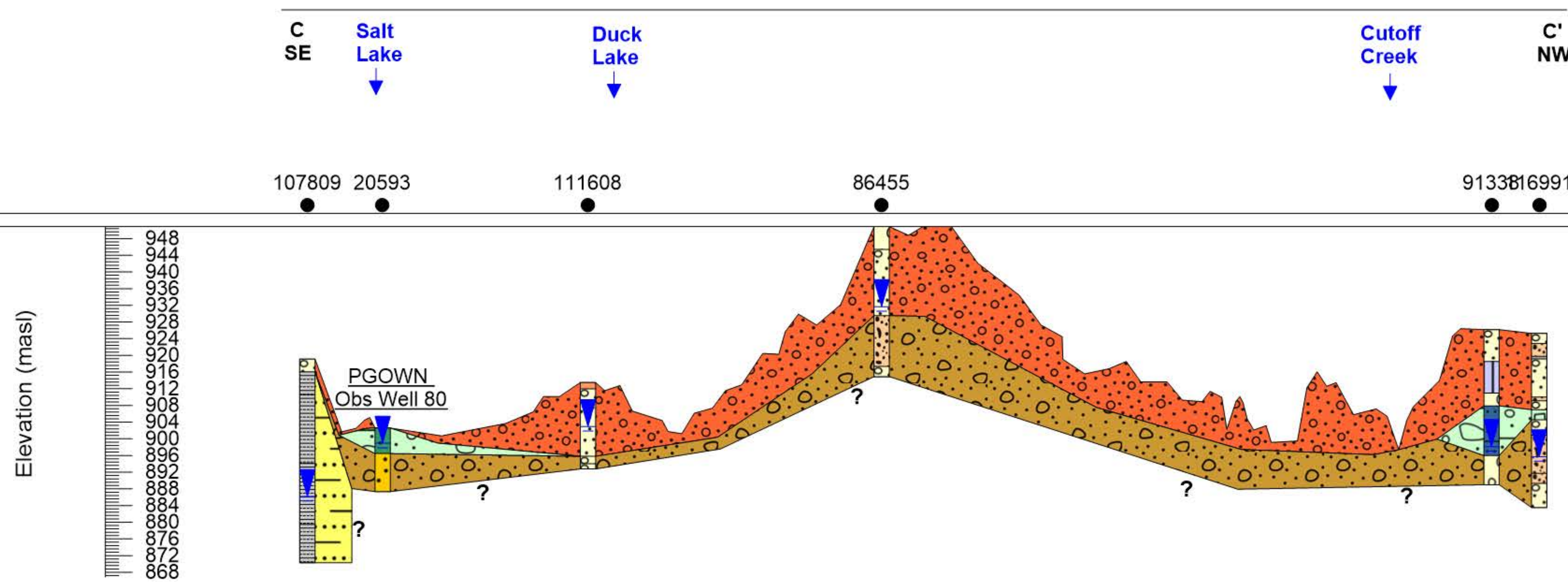
Clinton Aquifer Mapping

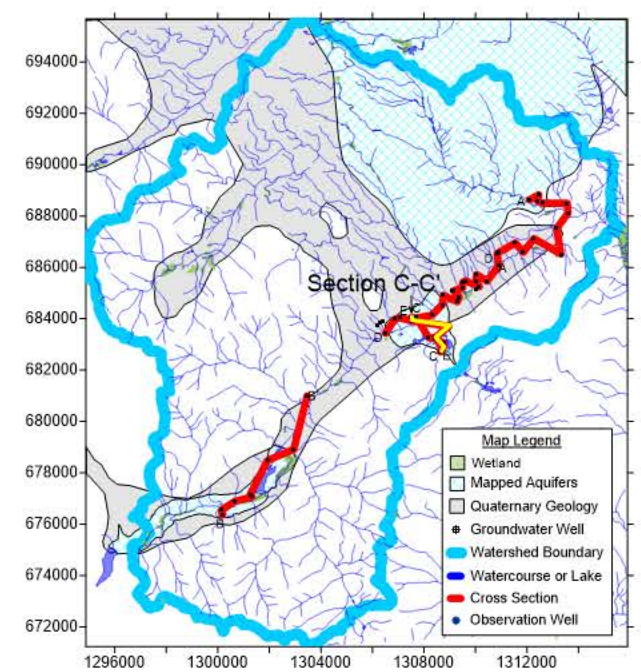
BC Ministry of Environment and Climate Change Strategy

BRITISH COLUMBIA

Figure 3 Cross-Section B-B' Along Clinton Creek

Date:21-07-2021 | Drawn By: CB | Reviewed By: XX




All distances in metres.

**Borehole Lithology Legend**

- Bedrock
- Boulders
- Clay
- Gravel
- Gravel (Dirty)
- Medium to Clay Till
- NA
- Organics
- Sand
- Sand and Fines
- Sand and Gravel (Clean)
- Sand and Gravel (Dirty)
- Sand or Gravel Till
- Silt

**Stratigraphy Legend**

- Clinton Creek Upper Sand and Gravel
- Till
- Clinton Creek Sand and Gravel
- Clinton Cache Creek Bedrock
- Bedrock
- Alluvial to Lacustrine Plain

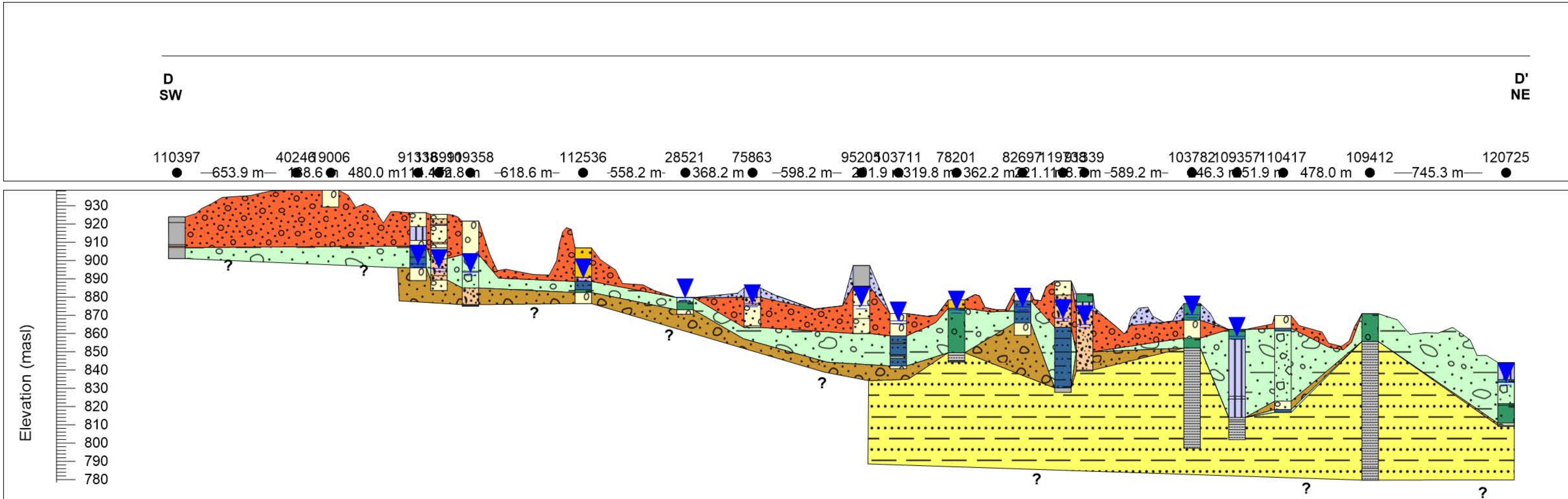
Clinton Aquifer Mapping

BC Ministry of Environment and Climate Change Strategy

BRITISH COLUMBIA

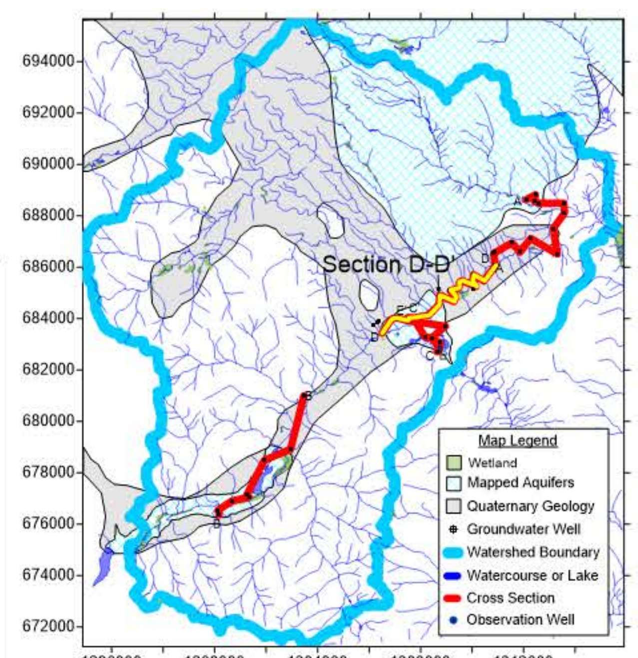
# Figure 3 Cross-Section C-C' Along Clinton Creek

Date:21-07-2021 | Drawn By: CB | Reviewed By: XX




| Borehole Lithology Legend | |
|---|---|
| Bedrock | Organics |
| Boulders | Sand |
| Clay | Sand and Fines |
| Gravel | Sand and Gravel (Clean) |
| Gravel (Dirty) | Sand and Gravel (Dirty) |
| Medium to Clay Till | Sand or Gravel Till |
| NA | Silt |

| Stratigraphy Legend |
|---|
| Clinton Creek Upper Sand and Gravel |
| Till |
| Clinton Creek Sand and Gravel |
| Clinton Cache Creek Bedrock |
| Bedrock |
| Alluvial to Lacustrine Plain |




All distances in metres.

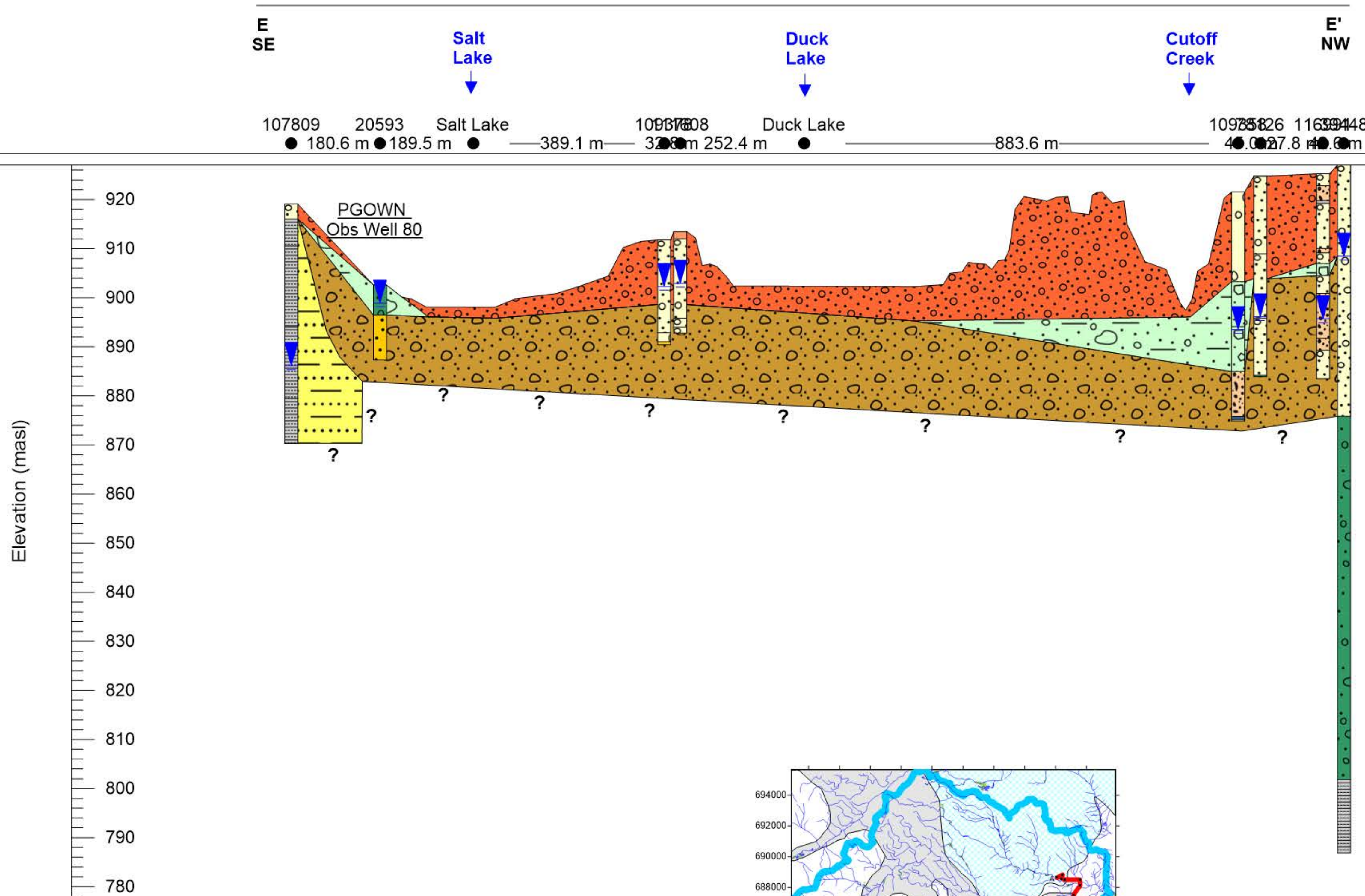
Clinton Aquifer Mapping

BC Ministry of Environment and Climate Change Strategy

BRITISH COLUMBIA

**Figure 4 Cross-Section D-D' Along Clinton Creek**

Date:21-07-2021 | Drawn By: CB | Reviewed By: XX

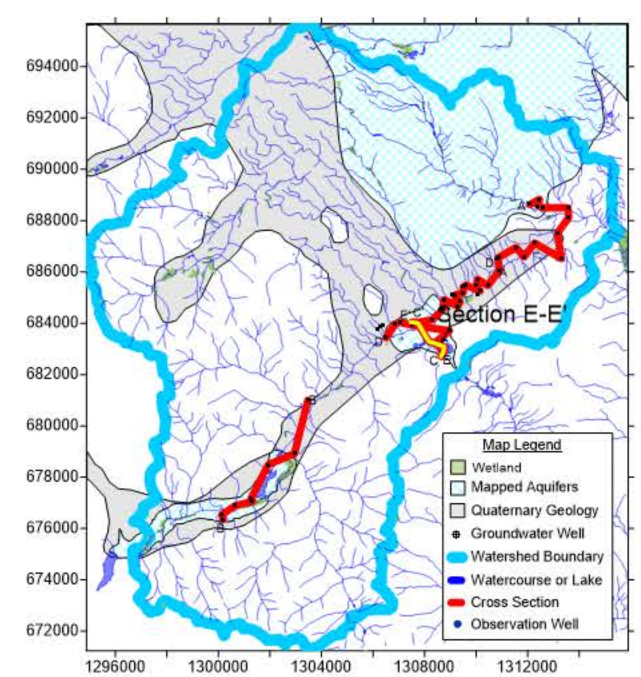



Borehole Lithology Legend

| | |
|---|---|
| Bedrock | Organics |
| Boulders | Sand |
| Clay | Sand and Fines |
| Gravel | Sand and Gravel (Clean) |
| Gravel (Dirty) | Sand and Gravel (Dirty) |
| Medium to Clay Till | Sand or Gravel Till |
| NA | Silt |

Stratigraphy Legend

- Clinton Creek Upper Sand and Gravel
- Till
- Clinton Creek Sand and Gravel
- Clinton Cache Creek Bedrock
- Bedrock
- Alluvial to Lacustrine Plain




Note: Elevations of Duck Lake and Salt Lake obtained from Hy-Geo (2018).

All distances in metres.

Clinton Aquifer Mapping

BC Ministry of Environment and Climate Change Strategy

BRITISH COLUMBIA

Figure 6 Cross-Section E-E' Along Clinton Creek

Date:21-07-2021 | Drawn By: CB | Reviewed By: XX

## APPENDIX B: AQUIFER MAPPING REPORTS

## AQUIFER DESCRIPTION FOR AQUIFER 1262 - CLINTON CREEK UPPER UNCONSOLIDATED AQUIFER

### 1. Conceptual Understanding of Hydrostratigraphy

#### Aquifer Extents

The Clinton Creek Upper Unconsolidated aquifer extends northeast from the community of Kelly Lake to Clinton Creek Falls after the junction with Fiftyone Creek. East of Clinton, the aquifer follows the path of Cutoff Valley Creek. West of Clinton the aquifer follows Clinton Creek. The extents of the aquifer have been inferred based on Provincial Terrain Inventory Mapping, the available water well information in GWELLS and topographic contours. GWELLS data are limited and lithologic descriptions are of varying quality; therefore, the actual extents of the unit may vary from the extents inferred in this study.

#### Geologic Formation (Overlying Materials)

This aquifer extends to near ground surface but may be overlain by shallow organic soils as indicated in some well logs. Streambed sediments may overlie the aquifer where it extends beneath creeks. Streambed sediments may impede the aquifer connection with surface water if colmation (clogging of the streambed with finer-grained particles) is present. Field studies would be required to determine if streambed sediments impede hydraulic connection.

#### Geologic Formation (Aquifer)

This aquifer is variably described with materials ranging from gravel to sand and gravel to silt and sand with gravel. The unit is interpreted to be derived from Holocene colluvial, fluvial and alluvial deposits. These deposits are interpreted to follow the Cutoff Valley Creek/Clinton Creek Valley and extend into adjacent low lying areas in the valley. The extent of these deposits could correspond to historic changes in the course of the streambed or flood events.

#### Vulnerability

High: The aquifer is interpreted to be near ground surface overlain only by shallow soils over much of its extent. The unit may be overlain by mixed deposits that could include shallow diamicton or lacustrine deposits in some areas at its northeastern extent.

### 2. Conceptual Understanding of Flow Dynamics

#### Groundwater Levels and Flow Direction

Shallow – The average depth of five water levels recorded in wells within this unit is approximately 8 m below ground with water level depths ranging from approximately 5 to 14 m. Water levels recorded in GWELLS within this unit are similar, but generally somewhat greater, than those in nearby creeks. Groundwater in this aquifer is generally expected to discharge to Cutoff Valley and Clinton Creeks and their tributaries, but flow reversals may occur during periods of higher river stage such as spring freshet, during winter when groundwater levels may decline or locally due to the impacts of groundwater withdrawals.

This aquifer is inferred to be unconfined and may be thin and/or unsaturated in some locations. The aquifer may also locally be saturated only on a seasonal basis.

## Recharge

Recharge is expected to be primarily derived from snowmelt and direct precipitation, but some recharge could also be derived from hydraulically connected creeks particularly during spring freshet. Spring snowmelt is expected to provide recharge from March to May of each year. Groundwater levels are expected to reach annual highs at this time of year. Water levels are expected to gradually decline in the summer months.

## Potential for Hydraulic Connection

This aquifer is expected to be hydraulically connected to all overlying streams and wetlands. However, this hydraulic connection may be buffered by lower hydraulic conductivity streambed sediments. Further study would be needed to understand if any impediment to flow within the hyporheic zone exists.

Studies by Renaut (1994) suggest that shallow groundwater flow from this unit contributes to the water balance of Salt Lake (also referred to as Clinton Lake) and other ponds and wetlands located south of the village of Clinton.

This unit is interpreted to be hydraulically connected to the underlying GWELLS aquifer No. 920 where the till unit that overlies GWELLS aquifer No. 920 is absent or thin, in particular in the area south of the village of Clinton.

# 3. Water Management

## Additional Information on Water Use and Management

Water Quality Objectives (WQO) were developed for Clinton Creek and the Bonaparte River in 1986 for a number of water quality parameters (Swain 1986). Since this aquifer is hydraulically connected to Clinton Creek which is a tributary to the Bonaparte River, authorization of activities that could impact water quality of this aquifer, may consider downstream impacts to the WQO in addition to local impacts. This consideration could extend to authorizations of groundwater withdrawals if withdrawals may alter the flow system such that there are impacts to the WQO.

Designated uses in Clinton Creek associated with the WQO include aquatic life, wildlife, livestock, irrigation and drinking water supply. WQOs for dissolved oxygen have also been set to protect spawning and rearing habitats for trout and salmon. Swain (1986) notes that WQOs had not always been met in Clinton Creek and downstream in the Bonaparte River at that time. High levels of some parameters (fecal coliforms, suspended solids, turbidity and algae growth) were also noted in 1996 (Brewer 1997). More recent attainment monitoring indicates that the majority of WQOs were met in Clinton Creek in 2002 with the exception of fecal coliforms (Kelly 2003).

## Additional Assessments or Management Actions

Additional hydrogeologic information has been collected in support of a groundwater license application (Hy-Geo 2018, Hy-Geo 2019). Further information on water licences and applications can be obtained from the BC Data Catalogue and authorizations staff. These reports focus on data analysis in a limited area of the Clinton watershed and may be referred to for additional site-specific information on unconsolidated aquifers and information related to that application. Information included in these reports includes the surveyed location and elevations of some wells, some water quality information, results of pumping tests and some water levels.

## 4. Aquifer References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## 5. Revision History

| Date | Version | Revision Class | Comments | Author |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| 20220930 | 1 | Major | Initial mapping of aquifer | Christine Bieber, P.Geo. |

# AQUIFER DESCRIPTION FOR AQUIFER 920 - CLINTON CREEK LOWER UNCONSOLIDATED AQUIFER

## 1. Conceptual Understanding of Hydrostratigraphy

### Aquifer Extents

The Clinton Creek Lower Unconsolidated aquifer extends northeast from the community of Kelly Lake to Clinton Creek Falls after the junction with Fiftyone Creek. East of Clinton, the aquifer follows the path of Cutoff Valley Creek. West of Clinton the aquifer follows Clinton Creek. The extents of the aquifer have been inferred based on surficial geologic information, the available water well information in GWELLS and topographic contours. GWELLS data is limited and lithologic descriptions are of varying quality; therefore, the actual extents of the unit may vary from the extents inferred in this study.

### Geologic Formation (Overlying Materials)

This aquifer is inferred to be generally overlain by the Clinton Creek Upper Unconsolidated aquifer (GWELLS aquifer No. 1262). In many locations, the aquifer is also directly overlain by an intervening glacial till unit between the two aquifers. This glacial till unit may have been deposited during the late Cariboo Mountain ice advance which occurred during the late stages of the Fraser Glaciation or subsequent to the Fraser Glaciation (Tipper 1971).

The till unit is generally present in wells in the southwestern portion of the aquifer but is thin or pinches out in some well locations (well tag numbers (WTNs) 37685 and 111941). The till unit is also generally present in wells located near Clinton Creek in the northeastern portion of the aquifer.

The till unit appears to be absent in wells located in the vicinity of Duck Lake and Salt/Clinton Lake (WTNs 111608, 109378 and 86455). In this area, the Clinton Creek Upper Unconsolidated aquifer (GWELLS aquifer No. 1262) appears to directly overlie the lower unconsolidated aquifer.

### Geologic Formation (Aquifer)

This aquifer is generally described as coarse-grained ranging from sand and gravel to gravel. The unit is interpreted to be a glacial outwash deposited in a large meltwater channel that flowed beneath the present Cut Off/Clinton Creek Valley (Tipper 1971). These deposits are interpreted to follow the Cutoff Valley Creek/Clinton Creek Valley but are expected to be less extensive than the overlying Upper Clinton Creek Upper Unconsolidated aquifer (GWELLS aquifer No. 1262). The width of the unit increases where the valley widens in the vicinity of the Village of Clinton.

### Vulnerability

Moderate to High: The aquifer is interpreted to be overlain by a permeable aquifer (GWELLS aquifer No. 1262) and a glacial till unit. However, in some locations the overlying till is absent or very thin and may not provide significant protection for the underlying aquifer. Water levels are shallow to moderately shallow ranging from less than a metre to nearly 30 metres corresponding to a variable vulnerability ranging from moderate to high.

## 2. Conceptual Understanding of Flow Dynamics

### Groundwater Levels and Flow Direction

Shallow – The average of nineteen water levels recorded in wells within this unit is approximately 14 m below ground with water level depths ranging from less than 1 m to nearly 30 m. Water levels in this unit are often somewhat higher than nearby surface water, but in some cases are somewhat lower. This result may be due to the unit being semi-confined with hydraulic connection to the overlying Clinton Creek Upper Unconsolidated aquifer (GWELLS aquifer No. 1262) or nearby creeks in some locations while in other locations the unit is hydraulically isolated by the overlying till unit. The limited available water level information in the lower bedrock aquifer unit indicates that water levels in the lower bedrock aquifer (GWELLS aquifer No. 1263) are greater than those recorded in this aquifer. This suggests that there is an upward vertical gradient between this unit and the underlying bedrock aquifer (GWELLS aquifer No. 1263).

Provincial groundwater OW-80 (Well Tag Number 20593) is completed within this aquifer unit and water level information in this well has been collected since 1971. Annually, water levels in this well fluctuate by approximately 0.2 m with a seasonal high in April and a seasonal low in October.

Data recorded in this well suggest that the well water level generally declined from 1971 to 2004. There is a gap in the monitoring data between June 2004 and October 2005 and the raw water level data recorded between these dates indicates a water level increase of approximately 0.3 m over this period. Interpretation of this apparent increase should be approached with caution as the abrupt change could indicate a change in the reference point for monitoring. Monitoring information collected after 2004 indicates that water level in this well decreased from 2007 to 2010 but has been increasing since 2014.

### Recharge

Recharge to this aquifer is likely to be derived from flow from the overlying Clinton Creek Upper Unconsolidated aquifer (GWELLS aquifer No. 1262) and hydraulically connected streams where the till unit is absent, thin or composed of relatively higher hydraulic conductivity materials. These sources of recharge are likely to be seasonal with recharge from these sources most probable and at a maximum during spring snowmelt and freshet. Upward vertical gradients are likely present in some locations between this aquifer and the underlying bedrock and recharge to this aquifer from the underlying bedrock (mountain-block recharge) may also be a significant source of water. Recharge from the underlying bedrock unit is likely heterogeneous and governed by preferential flow paths associated with spatial variability in weathering and fractures.

### Potential for Hydraulic Connection

This aquifer is interpreted to be semi-confined and expected to be hydraulically connected to overlying streams, lakes and wetlands in locations where the till unit is thin, absent or composed of relatively higher hydraulic conductivity materials. Therefore, hydraulic connectivity over the aquifer extent is expected to vary. Further studies would be needed to understand how hydraulic connectivity varies over the aquifer extent. These studies would require careful design as hydraulic connectivity may not be apparent in the closest reach of nearby creeks where the till is locally present; however, effects may be observed at more distant locations where the till is absent.

Comparison of water sampling information collected by Renaut (1994) with water sampling in OW-80 suggests that groundwater in GWELLS aquifer No. 920 is geochemically similar to Clinton Pond, Clinton Spring and the lake marginal waters on the northeast side of Clinton/Salt Lake. This result suggests that these surface water features are hydraulically connected to OW-80. However, it should be noted that OW-80 has a greater chloride concentration than all surface water samples except that collected in Clinton/Salt Lake. This result suggests that these surface water features are also recharged by fresher shallow groundwater flow potentially from GWELLS aquifer No. 1262.

## 3. Water Management

### Additional Information on Water Use and Management

Water Quality Objectives (WQO) were developed for the Bonaparte River and Clinton Creek in 1986 for a number of water quality parameters (Swain 1986). Since this aquifer may be hydraulically connected to Clinton Creek which is a tributary to the Bonaparte River, authorization of activities that could impact water quality of this aquifer, may consider downstream impacts to the WQO in addition to local impacts. This consideration could extend to authorizations of groundwater withdrawals if withdrawals may alter the flow system such that there are impacts to the WQO.

Designated uses in Clinton Creek associated with the WQO include aquatic life, wildlife, livestock, irrigation and drinking water supply. WQOs for dissolved oxygen have been specifically set to protect spawning and rearing habitats for trout and salmon. Swain (1986) notes that WQOs had not always been met in Clinton Creek and downstream in the Bonaparte River at that time. High levels of some parameters (fecal coliforms, suspended solids, turbidity and algae growth) were also noted in 1996 (Brewer 1997). More recent attainment monitoring indicates that the majority of the WQOs were met in Clinton Creek in 2002 with the exception of fecal coliforms (Kelly 2003).

### Additional Assessments or Management Actions

Additional hydrogeologic information has been collected in support of a groundwater license application (Hy-Geo 2018, Hy-Geo 2019). Further information on water licences and applications can be obtained from the BC Data Catalogue and authorizations staff. These reports focus on data analysis in a limited area of the Clinton watershed and may be referred to for additional site-specific information on unconsolidated aquifers and information related to that application. Information included in these reports includes the surveyed location and elevations of some wells, some water quality information, results of pumping tests and some water levels.

## 4. Aquifer References

Bieber, C. 2022. Aquifer Mapping in the Clinton Creek Watershed. Water Science Series, WSS2022-06. Province of British Columbia, Victoria

Brewer, L. 1997. State of Water Quality of the Bonaparte River Near Mouth 1985-1995. Water Quality Section. Water Management Branch. February 1997.

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Swain, L.G. 1986. Ambient Water Quality Objectives for the Bonaparte River. Overview Report. Water Management Branch, Resource Quality Section. Ministry of Environment.

Tipper, H.W. 1971. Glacial Geomorphology and Pleistocene History of Central British Columbia. Geological Survey of Canada. Bulletin 196.

Trettin, H.P. (1980): Permian Rocks of the Cache Creek Group in the Marble Range, Clinton Area, British Columbia; Paper 79-17.

## 5. Revision History

| Date | Version | Revision Class | Comments | Author |
|---|---|---|---|---|
| 20220930 | 2 | Major | Revision and extension of inferred aquifer extents. Retired aquifer 921 and merged with 920. | Christine Bieber, P.Geo. |
| 20070330 | 1 | Major | Initial mapping of aquifer as two units formerly aquifers 920 and 921 | William Hodge, P.Geo. |

# AQUIFER DESCRIPTION FOR AQUIFER 1263 - CLINTON CREEK CACHE CREEK BEDROCK AQUIFER

## 1. Conceptual Understanding of Hydrostratigraphy

### Aquifer Extents

The Clinton Creek Cache Creek Bedrock aquifer extends along the lower reaches of the Cutoff/Clinton Creek Valley and corresponds to an area where primarily Cache Creek Complex marine sedimentary and volcanic bedrock has been mapped, but the aquifer also extends into areas mapped as coarse clastic sedimentary Chilcotin and Skeena group bedrock.

The southeastern extent of the unit corresponds to the Clinton Creek watershed boundary as this likely corresponds to a groundwater divide. The northern extent corresponds to the mapped interface between Cache Creek Complex marine sedimentary and volcanic and Chilcotin Group basaltic volcanic rocks. Chilcotin Group basaltic volcanic rocks to the north of this aquifer unit have been mapped in previous aquifer mapping projects as GWELLS aquifer No. 124.

The mapped extent of this aquifer follows the Cache Creek complex/Chilcotin basaltic volcanic boundary until the interface reaches 1,200 masl elevation. The aquifer boundary turns to approximately follow the 1,200 masl elevation contour (within bedrock mapped as Chilcotin Group coarse clastic sedimentary rocks) extending southwest until it reaches the Marble Canyon Formation of the Cache Creek Complex. The boundary follows the 1,200 masl elevation contour in this location as the depth to groundwater is expected to increase with elevation and distance from the main aquifer valley. Additional information would be needed to better understand the viability and characteristics of the aquifer above this elevation; however, the selection of the 1,200 masl contour is somewhat arbitrary, and the aquifer may extend beyond it.

The southwest boundary of the aquifer corresponds to the mapped interface of the Marble Canyon Formation of the Cache Creek Complex and other Cache Creek Complex marine sedimentary and volcanic bedrock. This boundary was selected as the limestone of the Marble Canyon Formation is expected to have different hydraulic properties than bedrock to the east. Notably, the Marble Canyon Formation may host karst features as have been observed within the Marble Range to the west of the Clinton Creek Watershed. None of the bedrock wells currently available within GWELLS within the Clinton Creek watershed have been completed within the Marble Canyon Formation.

### Geologic Formation (Overlying Materials)

This aquifer is overlain by the Clinton Creek Upper Unconsolidated aquifer (GWELLS aquifer No. 1262), a till unit and the Clinton Creek Lower Unconsolidated (GWELLS aquifer No. 920). In the lowermost areas of the watershed, the Clinton Creek Upper Unconsolidated aquifer appears to be absent (Section A-A’, Bieber 2022) while in other areas particularly in the vicinity of the village of Clinton, the till unit may be absent.

### Geologic Formation (Aquifer)

This aquifer unit is primarily composed of bedrock mapped as Cache Creek Complex marine and sedimentary volcanic rocks of Permian to Triassic Age (approximately 200 to 300 million years old). This formation is complex, but east of Clinton and along the Bonaparte River, it has been noted as mainly comprised of basic volcanic flow, tuff, chert, argillite and minor limestone (Campbell and Tipper 1968). The volcanic rocks have been described as dark green to black, brecciated and sheared (Campbell and Tipper 1968). In GWELLS lithologic logs, the bedrock aquifer is variably described as basalt, volcanic, and shale. Where the bedrock is described as shale, this may correspond to the argillite described in Campbell and Tipper (1968). In several well locations (well tag numbers (WTNs) 107809, 91339 and 39448), the bedrock is described as broken or fractured and in one location (WTN 107809) a large well yield of 50 USGPM is noted. The locations of these wells generally correspond to a mapped formation contact or mapped fault lines. Further investigation would be needed to better understand how hydraulic conductivity of the formation may be enhanced along contacts or faults; however, this information suggests that enhanced hydraulic conductivity along these zones may be present.

## Vulnerability

High to Low: The vulnerability of the aquifer is variable depending on the overlying materials. In some locations, the overlying materials are highly permeable and the water table is relatively shallow (e.g., WTN 107809) while in others the overlying material is interpreted to be lower hydraulic conductivity (e.g., WTN 120725). The vulnerability of this unit is expected to be higher in the vicinity of Clinton Creek and within the footprints of the overlying unconsolidated aquifers while further from the creek in higher elevation areas, the aquifer is expected to be overlain by lower hydraulic conductivity materials and water levels are expected to be deeper, resulting in lower vulnerability.

# 2. Conceptual Understanding of Flow Dynamics

## Groundwater Levels and Flow Direction

Moderate – The average of ten water levels recorded in wells within this unit is approximately 17 m with water level depths ranging from approximately 4 to 39 m. Water levels recorded in GWELLS within this unit are spatially variable. This likely reflects local variation in hydraulic conductivity due to heterogeneity in weathering and fractures. In some locations, water levels within this aquifer are interpreted to be higher than nearby surface water features, while in other locations, GWELLS information suggests that the water levels are lower. This result suggests that groundwater flow in the bedrock is complex and varies based on local scale variability in hydraulic conductivity of the bedrock unit and the overlying materials.

## Recharge

Recharge is expected to be primarily derived from snowmelt and direct precipitation in higher elevation areas of the watershed. The rate of recharge to the bedrock will be constrained by the hydraulic conductivity of the overlying unconsolidated materials. In many locations, a relatively low hydraulic conductivity glacial till unit is interpreted to overlie this bedrock aquifer. Both ephemeral and perennial creeks in higher elevation areas of the watershed may recharge the bedrock unit. This recharge will be concentrated in areas where the till unit is thinner, absent or more permeable and the bedrock is locally more conductive (e.g., along geologic contacts or fault zones).

## Potential for Hydraulic Connection

This aquifer may be hydraulically connected to streams in some locations, but the extent of these connections is expected to be highly variable depending on local variation in the overlying materials and heterogeneity in the hydraulic conductivity of the bedrock unit. Local scale field investigations would be needed to assess hydraulic connection at the site scale.

## 3. Water Management

## Additional Information on Water Use and Management

Water Quality Objectives (WQO) were developed for Clinton Creek and the Bonaparte River in 1986 for a number of water quality parameters (Swain 1986). Since this aquifer may be hydraulically connected to Clinton creek which is a tributary to the Bonaparte River, authorization of activities that could impact water quality of this aquifer, may consider downstream impacts to the WQO in addition to local impacts. Designated uses in Clinton Creek associated with the WQO include aquatic life, wildlife, livestock, irrigation and drinking water supply. WQOs for dissolved oxygen have also been set to protect spawning and rearing habitats for trout and salmon. Swain (1986) notes that WQOs had not always been met for the WQO in Clinton Creek and downstream in the Bonaparte River at that time. More recent attainment monitoring indicates that the majority of the WQOs were met in Clinton Creek in 2002 with the exception of fecal coliforms (Kelly 2003).

## Additional Assessments or Management Actions

Groundwater characterization studies have been completed in support of water licence applications within the Clinton Creek watershed. Further information on water licences and applications can be obtained from the BC Data Catalogue.

## 4. Aquifer References

Bieber, C. 2022. Aquifer Mapping in the Clinton Creek Watershed. Water Science Series, WSS2022-06. Province of British Columbia, Victoria

Campbell, R.B. and H.W. Tipper. 1968. Bonaparte River Map-Area, British Columbia (92P). GSC Project 640020. Geological Survey of Canada. October 8, 1968

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Kelly. S.T. 2003. Ambient Water Quality Objective Attainment for the Bonaparte River, 2001 and 2002. Environmental Protection. Ministry of Water, Land, and Air Protection. December 2003.

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Swain, L.G. 1986. Ambient Water Quality Objectives for the Bonaparte River. Overview Report. Water Management Branch, Resource Quality Section. Ministry of Environment.

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Trettin, H.P. (1980): Permian Rocks of the Cache Creek Group in the Marble Range, Clinton Area, British Columbia; Paper 79-17.

## 5. Revision History

| Date | Version | Revision Class | Comments | Author |
|---|---|---|---|---|
| 20220930 | 1 | Major | Initial mapping of aquifer | Christine Bieber, P.Geo. |

## APPENDIX C: AQUIFER SUMMARY

### Aquifer Summary Table

| # | Name | Lithostratigraphic Unit | Descriptive Location | Vulnerability | Sub-type | Material | Quality Concerns | Productivity | Artesian Conditions Noted | Obs. Well | Summary of Changes |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1262 | Clinton Creek Upper Unconsolidated | Holocene fluvial and alluvial | Cutoff / Clinton Creek Valley | High | 1b | Sand and Gravel | Unknown | Moderate | No | - | New |
| 920 | Clinton Creek lower unconsolidated | Glacial Outwash deposited in a large meltwater channel | Cutoff / Clinton Creek Valley | Moderate to High | 4a to 4b | Sand and Gravel | Unknown | Moderate to High | Yes, one well 110397 | 80 | Update of extents, Merged with 921 |
| 1263 | Clinton Cache Creek Bedrock | Cache Creek complex | Cutoff / Clinton Creek Valley | High to Low | 6b | Bedrock | Unknown | Low to Moderate | No | - | New |

Notes:

1. Refer to Berardinucci, J. and K. Ronneseth, 2002. Guide to using the BC Aquifer Classification Maps for the Protection and Management of Groundwater. BC Ministry of Water, Land and Air Protection. ISBN 0-7726-4844-1 June 2002 for guidance on classification of vulnerability and productivity.

2. Refer to Wei, M., Allen, D., Kohut, A., Grasby, S., Ronneseth, K., and B. Turner. Understanding the Types of Aquifers in the Canadian Cordillera Hydrogeologic Region to Better Manage and Protect Groundwater. Streamline Water Management Bulletin, Vol. 13/No. 1, Fall 2009

## APPENDIX D: AQUIFER SHAPEFILES

Electronic files provided.

## APPENDIX E: AQUIFER WELL CORRELATIONS

Electronic files provided.

## APPENDIX F: AQUIFER WELL STRATIGRAPHY

Electronic files provided.