Report

Geoscience BC

Aquifer Classification Mapping in the Peace River Region for the Montney Water Project

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LHC

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EXECUTIVE SUMMARY

This report summarizes the results of hydrogeologic work carried out in two phases; one from 2002 to 2004 and the second one in 2010-2011. The purpose of the work was to identify, delineate and classify developed aquifers in the Peace River Region of British Columbia for Geoscience BC. The project is part of the Montney Water Project; Unconsolidated Sediments and Shallow Bedrock Water – Component A. The work included reviewing information on aquifers identified in previous studies and examining available hydrogeologic data to identify and classify additional developed aquifers for the region.

In 2004, 40 aquifers were mapped, covering a total area of 3,413.7 km^2. These aquifers have been reviewed in 2011 with revision of statistics for 38 of the 40 aquifers, revised boundaries for 21 of the 40 aquifers and the mapping of 16 new aquifers. A total of 55[1] aquifers are now mapped in the Peace River Region, covering an extent of 10,491.5 km^2.

Regionally, permeable zones within the Dunvegan Formation and overlying formations dominated by competent sandstone strata such as the Kaskapau Formation, for example, comprise the main bedrock aquifers. Potential unconsolidated aquifers in the region are likely to be associated with the following geologic units from youngest to oldest:

- Type 1. Sand and gravels deposits at near present stream levels associated with modern alluvium along major creeks and rivers;
- Type 2. Glaciofluvial deposits at or near surface formed by glacial melt waters at the end of the last glaciation and specifically those associated with the latest lacustrine deposits;
- Type 3. Glaciofluvial and fluvial interglacial sand and gravel units deposited during advance and retreat of ice sheets, including those deposited in preglacial and interglacial valleys and older glacial periods;
- Type 4. Preglacial sand and gravel deposits, including those deposited in preglacial valleys.

Interglacial aquifers found in preglacial and interglacial valleys are of special significance in the region. These bedrock-channel systems are made up of valleys that existed prior to glaciation (preglacial valleys) and those that were cut into bedrock during the Pleistocene epoch (glacial or interglacial valleys). Both types of valleys occur in the region and may be either partly or completely filled with glacial drift. Some of these buried valleys contain sand and gravel aquifers hence they are important targets for groundwater exploration.

[1] The aquifers 622 and 623 were merged to comprise only one aquifer, referenced as 622. Thirty-nine (39) original aquifers plus the delineation of 16 new ones leads to a total of 55 aquifers.

Fifty-five unconsolidated and bedrock aquifers have been identified, delineated and classified within the Peace River Region, to date. Thirty-two (32) of the aquifers are unconsolidated and twenty-three (23) are consolidated (sedimentary bedrock). Aquifers range in size from 0.53 km^2 to 3286 km^2. A total of 162 map sheets[2] containing wells were reviewed to see if sufficient information were available to map an aquifer. 104 BCGS map sheets contained sufficient information to map aquifers.

The majority of unconsolidated aquifers identified within the project area are located along the main river valleys. The highest capacity wells are completed in glaciofluvial deposits underlying lacustrine deposits and more recent alluvial or fluvial deposits. The most productive aquifers, yielding over 3 L/s (50 USgpm) are found in the following places: two aquifers in the Tumbler Ridge community (aq. n° 0635 and 0640); one aquifer in the south of Fort St John and west of Taylor (aq. n° 0442); one aquifer in the village of Pouce Coupe (aq. n° 0598) and one aquifer in the Pine Valley (aq. n° 0930). Tumbler Ridge municipal production wells can yield in excess of 300 L/s (4755 Usgpm) each, (Lowen, 1984).

Well records (over 1000 reviewed) indicate that the highest capacity bedrock wells are from what appear to be the Dunvegan Formation, Upper Cretaceous Period with yields up to 15.8 L/s (250 USgpm). The Puswaskau Formation sandstones of the Upper Cretaceous Period also produce higher capacity wells up to 7.9 L/s (125 USgpm).

Groundwater quality analyses obtained during the period 2000 to 2003 and updated from 2003 to 2011 by the Northern Health Authority for a number of water supply systems in the region were examined. These illustrate the variable nature of groundwater quality found in the region. Groundwater ranges from the calcium-magnesium bicarbonate and sodium bicarbonate types with low to moderate levels of dissolved minerals (TDS generally ranging from 100 to 500 mg/L) to the more complex and more mineralized sodium bicarbonate, and sodium-calcium-magnesium sulphate-bicarbonate types (TDS ranging from 500 to 2000+ mg/L). Most wells in the study area produce potable drinking water or produce water that can be made potable with simple treatment.

Locally, natural groundwaters in the region may contain elevated concentrations of barium, boron, sodium and fluoride that exceed the 2010 Guidelines for Canadian Drinking Water Quality (GCDWQ). Iron and manganese are reported to often exceed guidelines. From a cursory examination of the quality data, elevated concentrations of barium and fluoride appear associated with soft, sodium bicarbonate type groundwaters.

There are significant untapped groundwater resources in the BC Peace River region that should be investigated. Geophysical surveying, followed by test drilling is recommended to assess the potential of selected buried river channel type aquifers

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[2] 1:20,000 scale, British Columbia Geographic System (BCGS)

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1. BACKGROUND

This report summarizes the results of hydrogeologic work carried out in two phases: one from 2002 to 2004 and the second one in 2010-2011. The purpose of this work was to identify, delineate and classify developed aquifers in the area of the Montney Gas Play (Peace River Region) of British Columbia for Geoscience, BC. The project provides key information on the region's groundwater resources to assist water management and development activities in the area. Funding for the project was provided by Geoscience BC and its sponsors. A map of the overall study area is provided in Figure 1.

This report includes information on aquifers identified in previous studies and an examination of available hydrogeologic data to identify and classify additional developed aquifers for the region. Principle data examined for this project included well records, well location maps, geologic maps, groundwater reports and water quality records. Additional data sources included reports and records provided by the Peace River Regional District, the Northern Health Authority, the PFRA and The District of Tumbler Ridge. A glossary of technical terms used in this report is provided in Appendix A.

2. ACKNOWLEDGEMENTS

Lowen Hydrogeology Consulting Ltd. and project team members: Dennis Lowen, William Hodge, Alan Kohut, Marion Dardare and Heliana Roggia wish to acknowledge the cooperation and assistance of several individuals who provided access to reports and information namely: Kevin Ronneseth, MOE, the PFRA Dawson Creek office (2004), Geoscience BC, Adrian Hickin (MEM) and the Northern Health Authority.

3. PROJECT OBJECTIVES AND SCOPE OF WORK

The principle objectives for this project were:

- To identify, delineate and classify developed aquifers and aquifer systems in the Peace River Region according to the British Columbia Aquifer Classification System (BCACS) as outlined in Berardinucci and Ronneseth (2002);
- To review aquifers previously defined and classified in the region by other investigators to ensure these previously classified aquifers and the newly classified aquifers are congruent in how they are classified, delineated and presented;
- To identify and delineate the buried river channels in the region;
- To produce three to four geologic cross sections that illustrate the different aquifers and hydrogeologic environments identified, and;
- To produce a brief report describing the aquifers, aquifer systems and general hydrogeological regimes found in the Peace River Region.

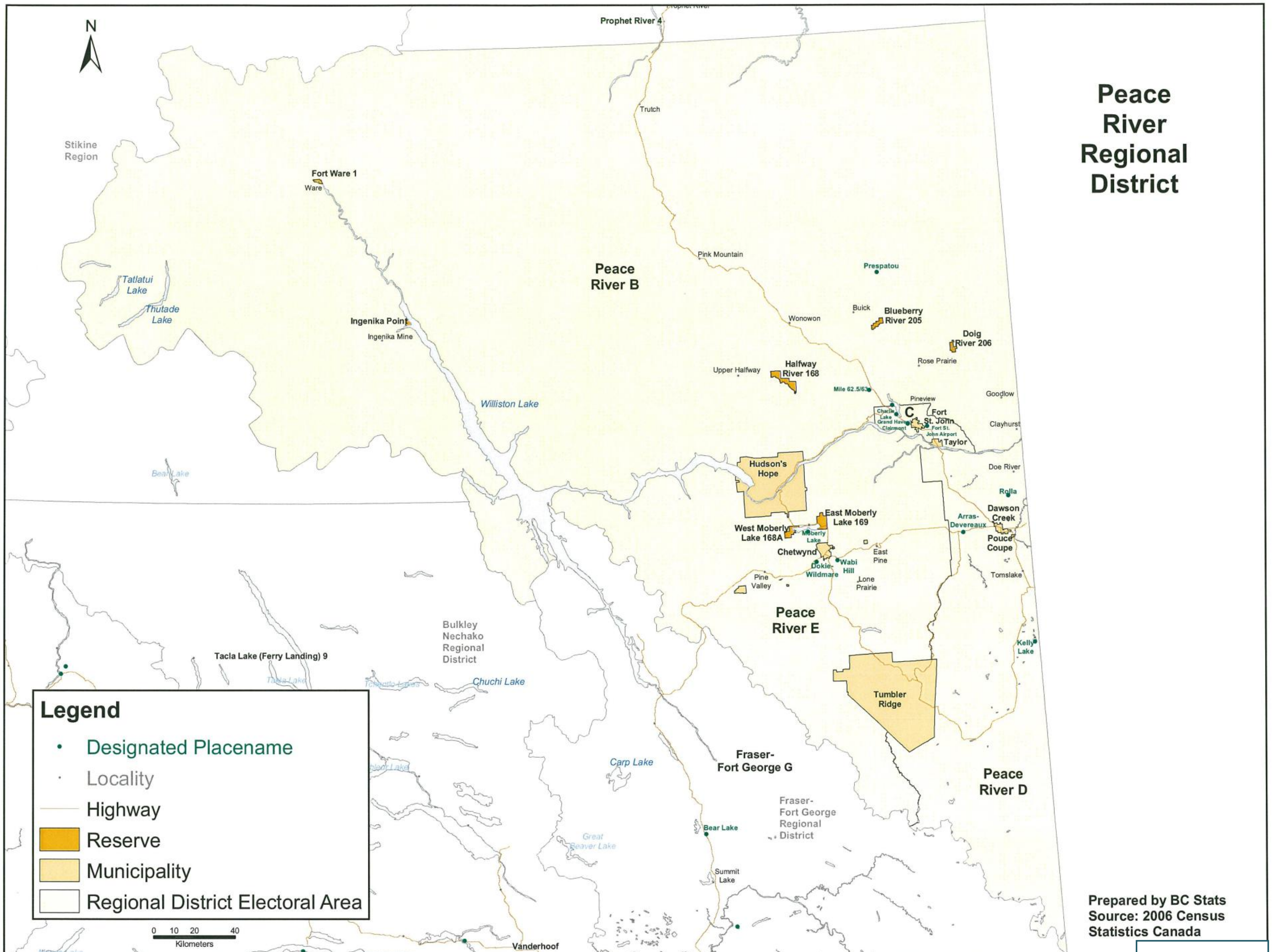

Peace River Regional District
N
Prophet River 4
Truch
Stikine Region
Fort Ware 1
Ware
Tatlatui Lake
Thutade Lake
Ingenika Point
Ingenika Mine
Williston Lake
Peace River B
Pink Mountain
Prespatou
Wonowon
Buick
Blueberry River 205
Doig River 206
Rose Prairie
Upper Halfway
Halfway River 168
Mile 62.5/63
Pineview
Goodlow
C
Fort St. John
Clayhurst
Taylor
Hudson's Hope
Doe River
Rolla
East Moberly Lake 169
West Moberly Lake 168A
Moberly Lake
Dawson Creek
Arras-Devereaux
Pouce Coupe
Chetwynd
East Pine
Wabi Hill
Tomslake
Pine Valley
Lone Prairie
Peace River E
Kelly Lake
Bulkley Nechako Regional District
Tacla Lake (Ferry Landing) 9
Chuchi Lake
Tumbler Ridge
Carp Lake
Fraser-Fort George G
Peace River D
Fraser-Fort George Regional District
Bear Lake
Summit Lake
Vanderhoof
Legend
Designated Placename
Locality
Highway
Reserve
Municipality
Regional District Electoral Area
0 10 20 40
Kilometers
Prepared by BC Stats
Source: 2006 Census
Statistics Canada

Figure 1

Scope of the work included:

- Compiling relevant technical data and information on geologic and groundwater conditions;
- Examining and interpreting well records, well locations, water level and flow conditions, nature of water bearing zones and their productivity;
- reviewing and interpreting available groundwater quality data, and;
- Reviewing the findings of previous groundwater investigations in the region and identifying any quantity and quality concerns.
- To conduct the work described above within the 104 trim map sheets (1:20,000 scale) containing sufficient well information for analysis. Map sheets are listed as follows:

  BCGS Map sheets with well information:

  093 O – 059, 069, 070.

  093 P – 015, 016, 030, 050, 053, 054, 058, 060, 061, 062, 063, 064, 067, 068, 069, 070, 072, 073, 074, 075, 076, 077, 078, 079, 080, 082, 083, 086, 087, 088, 089, 090, 092, 093, 097, 098, 099, 100.

  093 I – 086, 096

  094 A – 001, 007, 008, 009, 010, 011, 012, 013, 017, 018, 019, 020, 021, 023, 025, 026, 027, 028, 029, 030, 032, 033, 034, 035, 036, 037, 038, 039, 040, 041, 043, 044, 045, 046, 047, 048, 049, 051, 054, 055, 056, 057, 058, 062, 063, 064, 065, 066, 067, 068, 071, 072, 074, 075, 076, 077, 078, 084, 085, 086, 087, 088, 093, 094, 095, 096, 097, 098, 099.

  094 B – 010, 050, 059, 060.

Appendix B summarizes the main characteristics of the 55 aquifers mapped in the Peace River Region with reference to their respective map sheets.

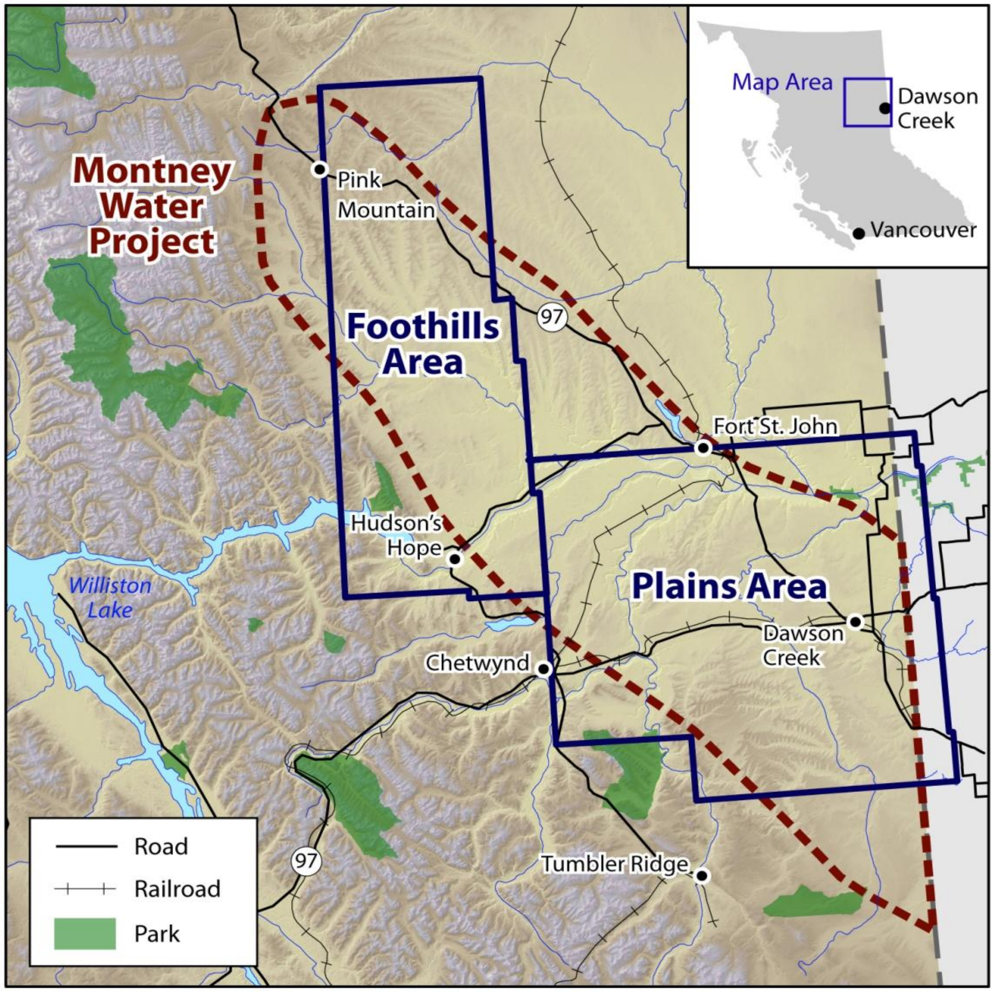
4. STUDY REGION AND GEOLOGIC SETTING

The Peace River Region is situated in the north-eastern part of British Columbia between the Rocky Mountain Foothills and the Alberta border. For purposes of this project, the study included map areas in the drainage area of the Peace River between the east arm of Williston Lake in the west, to the Alberta border in the east and from the upper reaches of the Beatton River in the north, latitude 57°, to the community of Tumbler Ridge in the south, latitude 55°. The area lies within National Topographic System (NTS), 1:250 000 scale map sheets 94 A (Charlie Lake) 94 B (Williston Lake), 93 O (Pine Valley), 93 P (Dawson Creek) and 93 I (South of Tumbler Ridge). Figure 2 is a key plan showing the Peace River and Montney Gas Play area.

The study area is situated primarily within the Alberta Plateau region of the Interior Plains physiographic subdivision of British Columbia (Holland, 1964). This region also includes, below the 2000 foot (610 m) elevation, the Peace River Lowland, which occupies a small digitate area along the main river and its tributaries. The overall region is of low relief with flat to gently rolling terrain. The south-western portion of the study area near the community of Tumbler Ridge captures a small portion of the Rocky Mountain Foothills physiographic region (Holland, 1964).

Figure 2

Montney Region

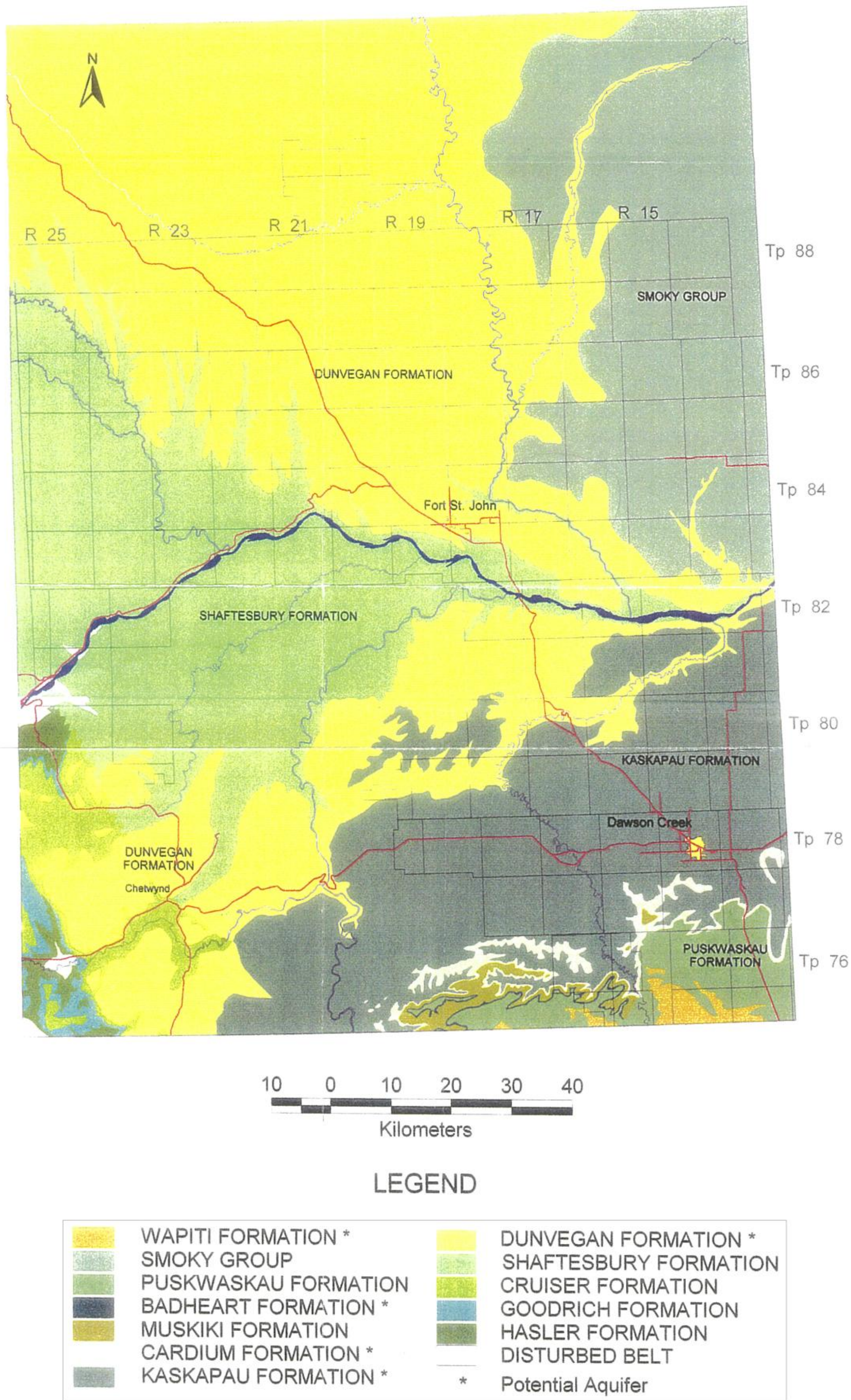


A brief synopsis of the general geology and glacial history of the area as reported by Holland is outlined below. More detailed descriptions of the bedrock geology and glacial deposits are provided in following sections of the report.

The Alberta Plateau region is underlain for the most part by flat or gently dipping shales and sandstones of Cretaceous age (Figure 3). Low topographic relief generally reflects gentle bedrock structures in the underlying rocks. In the Rocky Mountain Foothills region, the rocks are folded along north-westerly trending axes and cut by southwesterly dipping thrust faults.

During the Pleistocene epoch, the study area was covered by the Keewatin sector of the Laurentide continental icesheet. Ice moved westward and southwestward across the area depositing a veneer of glacial till over the area. After maximum expansion of Keewatin ice and its retreat, piedmont and valley glaciers flowing eastward from the Rocky Mountains moved outward onto the plateau depositing moraines in a narrow belt along the eastern edge of the foothills. During melting of the ice, channels discharged glacial meltwater into valleys, some of which were blocked by ice creating glacial lakes such as Lake Peace, a preglacial lake that occupied the Peace River Valley. Also during the glacial events preglacial and interglacial channels were backfilled with glacial deposits. These buried channels are discussed further in Section 7.

B.C. PEACE REGION GROUNDWATER INITIATIVE
BEDROCK GEOLOGY



PFRA

Geology data modified from 1:250,000 BC Government digital maps

Figure 3

5. BEDROCK GEOLOGY AND POTENTIAL AQUIFERS

A brief discussion of the general stratigraphic succession and distribution of the main Cretaceous bedrock units found within economical water well drilling depths in the region is warranted as it provides a framework for understanding the location and distribution of permeable aquifer zones that are capable of storing and transmitting groundwater. Table 1 outlines the general stratigraphic succession and brief descriptions of the major rock types in the region primarily based on Stott (1982). While the rocks are predominantly flat lying or gently dipping the main portion of the study area, northwesterly trending thrust faults have disrupted the strata to the west in the vicinity of Hudson Hope and Chetwynd (Cowen, 1998). Older bedrock strata are found at depth in the region and to the west in the Rocky Mountain Foothills but are not considered in this report.

Table 1
Bedrock Stratigraphy and Potential Aquifers, Peace River Region

Period	Group	Formation	Descriptions (from Stott, 1982 except where noted)	Potential Aquifers	Comments
Upper Cretaceous		**Wapiti**	Sandstone, mudstone, coal	Cowen (1998)	South of Dawson Creek
Upper Cretaceous	Smokey	**Puskwaskau**	Dark Marine shale and siltstone		South of Dawson Creek
Upper Cretaceous	Smokey	**Badheart** / **Marshybank**	Fine-grained sandstone. Sandstone, carbonaceous shale (McMechan, 1994)	Cowen (1998)	South of Dawson Creek
Upper Cretaceous	Smokey	**Muskiki**	Dark marine shale		South of Dawson Creek
Upper Cretaceous	Smokey	**Cardium**	Fine-grained, grey sandstone	Cowen (1998)	Inferior water quality south of Dawson Creek (Cowen, 1998)
Upper Cretaceous	Smokey	**Kaskapau including Pouce Coupe and Doe Creek sandstone members**	Dark marine shale. Shale and sandstone (Cowen, 1998)	Pouce Coupe Sandstone (Cowen, 1998)	Fair quality groundwater in the Kilerran/Doe River area but poor quality south of Dawson Creek (Cowen, 1998)
Upper Cretaceous	**Dunvegan Formation**		Carbonaceous sandstone, massive conglomerate, dark shale, siltstone	Cowen (1998)	Fair to good potential (Callan, 1973), fair to poor quality, aquifers not laterally extensive (Cowen, 1998)
Lower Cretaceous	Fort St John	**Sulley** *(north of Peace River)* / **Shaftesbury** *(south of Peace River*	Dark grey, sideritic shale Sideritic, dark marine shale and siltstone		Unfavorable as an aquifer, poor water quality where fracture porosity exists (Cowen, 1998). Well logs indicate low to moderate yields

Potential bedrock aquifers as reported by Cowen (1998) are indicated in Table 1. Regionally, permeable zones within the Dunvegan Formation and overlying formations dominated by competent sandstone strata such as the Kaskapau Formation, for example, comprise the main bedrock aquifers. Mathews (1955b) reported the best prospects for obtaining good quality groundwater at shallow depths were in the Pouce Coupe, Cardium and Dunvegan sandstone units. A schematic cross-section normal to the Peace River Valley (Figures 4 and 5) and running from the Blueberry River in the northwest to the upper reaches of the Kiskatinaw River in the southeast, illustrates the relationship of the bedrock formations to topography and major drainage features.

While the Dunvegan Formation is extensive in area and can be considered a major aquifer system, drainage systems have dissected the aquifer into a number of aquifers zones. Callan (1973) reports the Dunvegan Formation to have the greatest potential to contain aquifers with potable water quality because it contains sandstones of non-marine origin with both evidence of primary porosity and vertical fracturing. In the area north of Ft. St. John, Callan (1973) recognized three major sandstone aquifer units in the Dunvegan Formation. Cowen (1998) reports that the aquifers found in the Dunvegan Formation are not laterally extensive and are often greatly separated vertically.

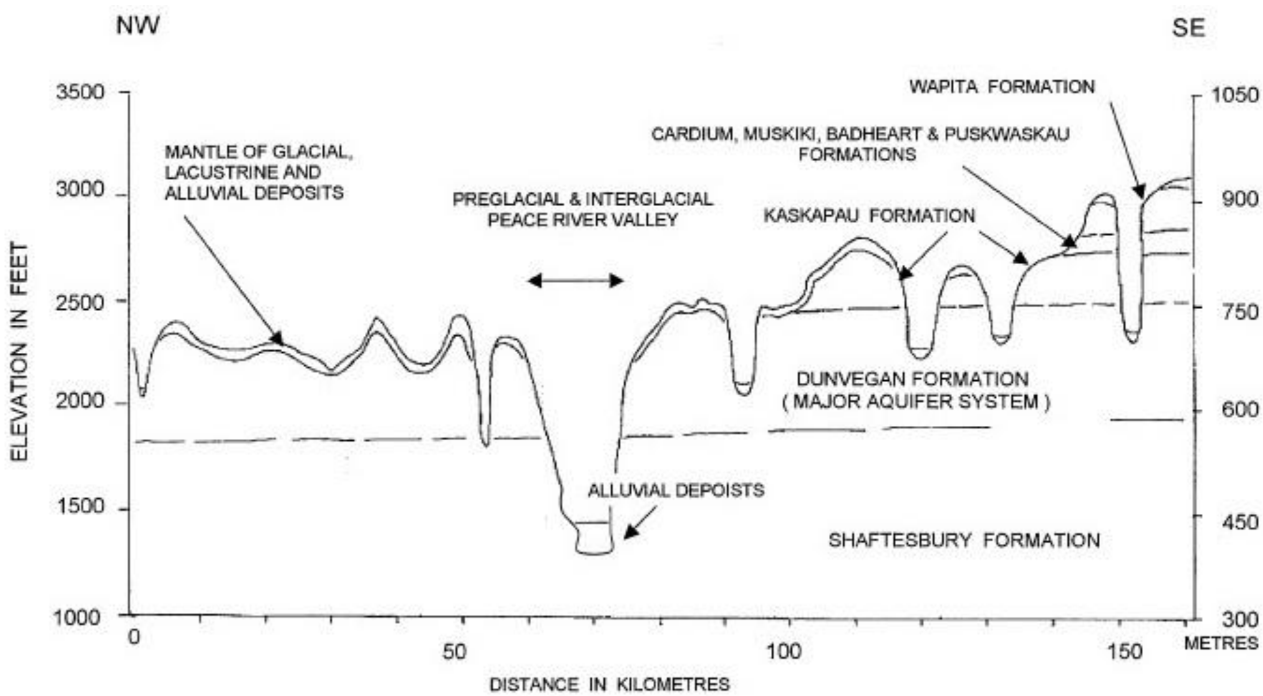


Figure 4 - Schematic Cross Section NW-SE

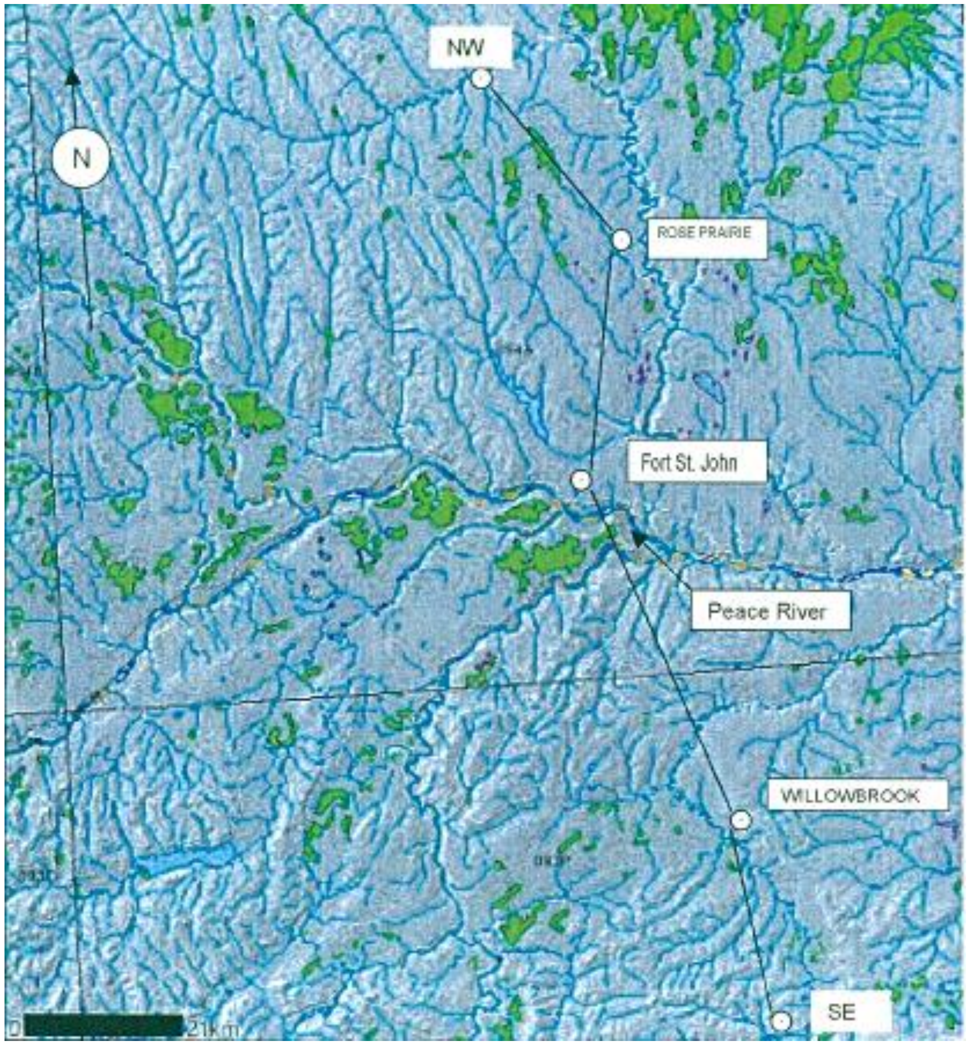
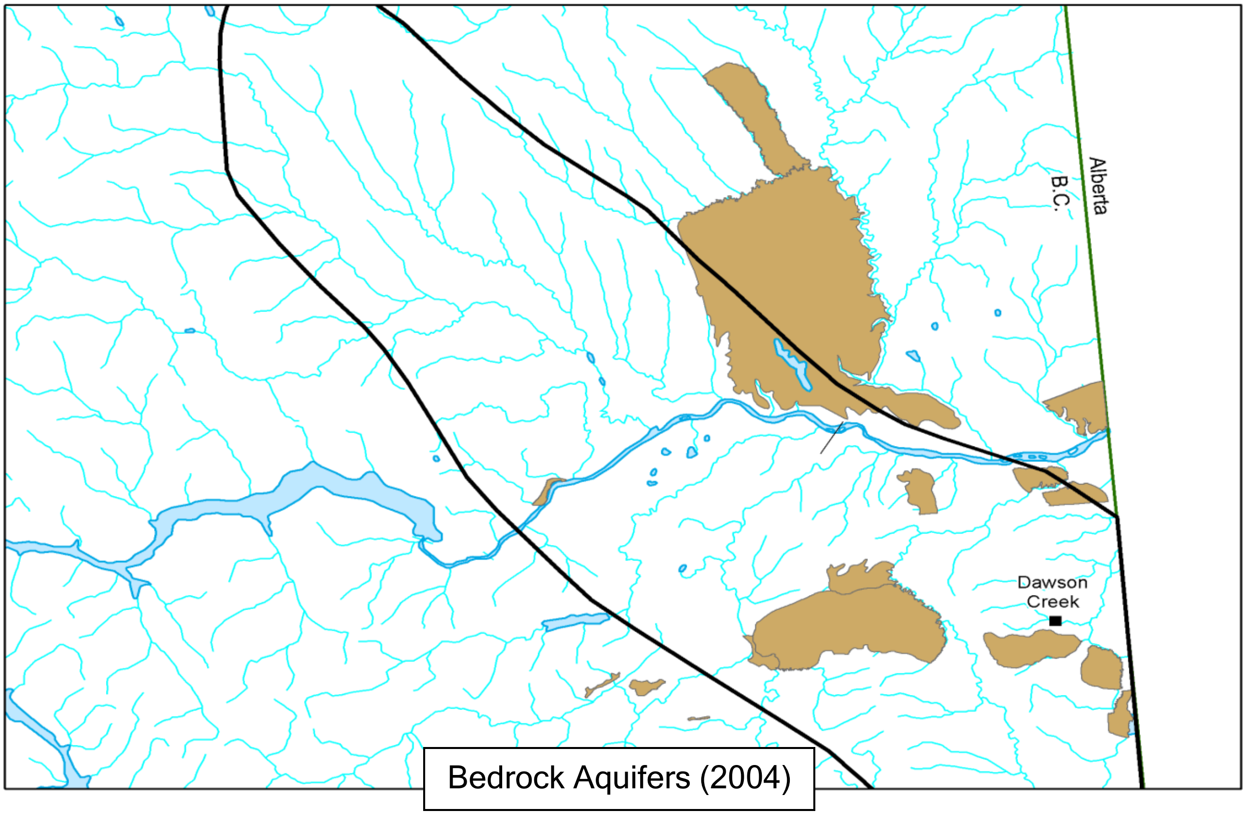


Figure 5 – Location of cross section NW-SE showing bedrock formation in Peace River Region

Both primary (intergranular) and secondary (fracture and bedding plane) porosity are likely important in controlling groundwater storage and movement in the bedrock formations. Callan (1973) reported that locally, vertical fracturing is significantly developed in outcrops of the Dunvegan Formation and that drilling programs in 1971 encountered several zones of lost circulation attributed to high angle fracture porosity and permeability. Contact zones between individual rock units and formations may also be important zones for preferential groundwater movement. Variations in degree of cementation and consolidation may also control groundwater storage and movement. Since the 1970s, advancements in drilling methods and pump technology have enabled individuals to explore and develop the potential of the bedrock formations to greater depths.

From an examination of several hundred well records the Ministry of Environment (1983) reported an average well yield of 0.6 L/s for wells completed in the Dunvegan Formation. Wells completed in sandstone units are reported to produce about 50% more water than wells drawing groundwater from shale units (Ronneseth, 1994). One bedrock well completed to a depth of 112 m in a fractured sandstone unit in the Dunvegan Formation near Chetwynd has a rated production capacity of 14.3 L/s. Transmissivity for this aquifer is reported to range from 23 to 45 m^2/day with a storativity of 8.3 x 10^{-4} (Hydrogeological Consultants Ltd, 1991). A map showing bedrock aquifers mapped in 2004 and revised in 2011 is attached as Figure 6.



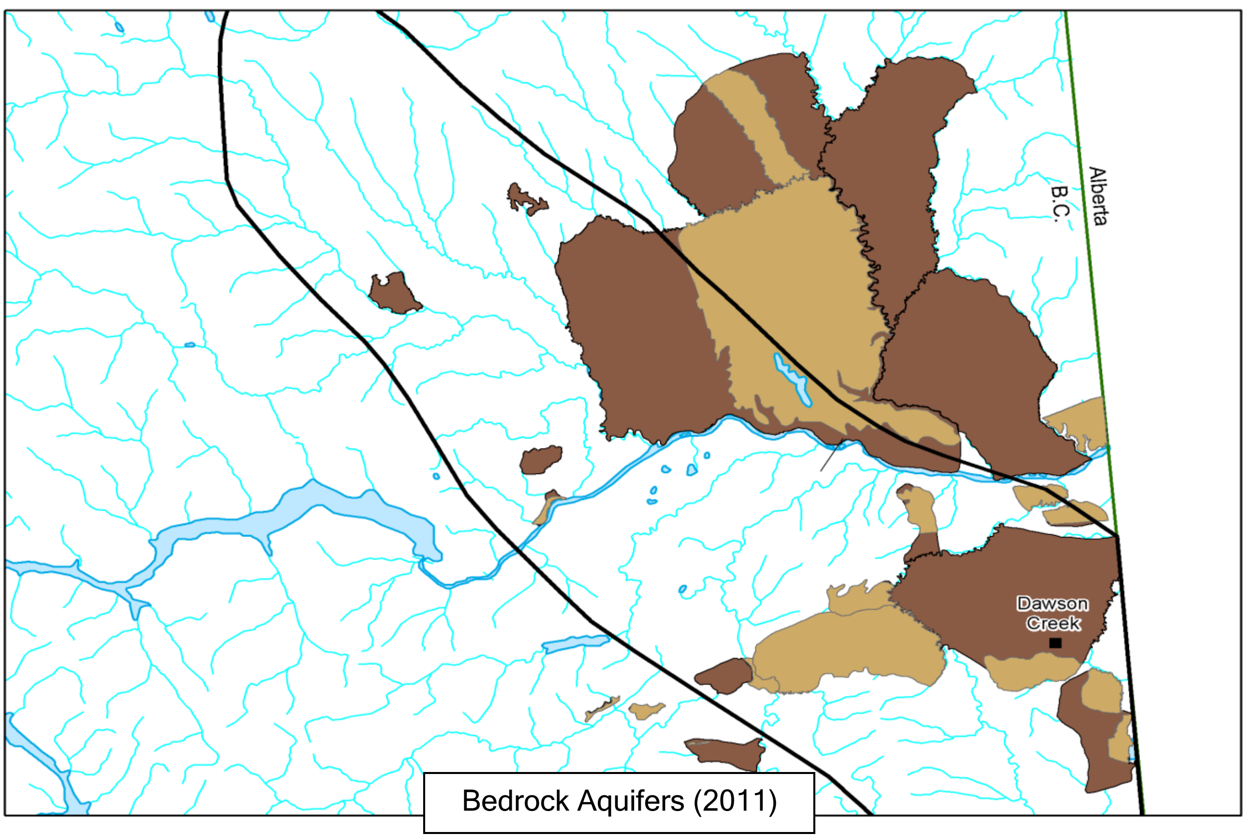


Figure 6 - Bedrock Aquifer Mapping 2004 and 2011 updated

6. UNCONSOLIDATED DEPOSITS AND POTENTIAL AQUIFERS

Mathews (1978), Reimchen (1980) and Rutter (1966) have mapped the distribution of surficial unconsolidated deposits in the Charlie Lake (94A), Dawson Creek (93P) and Williston Lake (94B) map areas respectively. Catto (1998) has also described the Quaternary geology and landforms of the Peace River Region and implications for water supply.

A complex succession of preglacial, glacial, interglacial and postglacial deposits are found in the region. During the Quaternary Period, the Laurentide Ice Sheet reached the area from the east on at least three separate occasions and ice from the mountains to the west also reached the area (Mathews, 1978).

Mathews (1978) describes three general topographic and physiographic settings that govern the distribution, type and thickness of unconsolidated deposits in the Charlie Lake map area namely:

1. Rolling uplands, where bedrock is typically within 15.2 m (50 feet) of the land surface,
2. Trenches occupied by main streams and their tributaries, and
3. Intervening platforms characterized by gentle slopes and thick deposits of unconsolidated deposits.

Mathews (1978) reports that the rolling uplands are generally covered by glacial till and stony silty clay from the last glaciation and in places by glaciolacustrine clay, silt and sand. Stream cut trenches vary from being narrow to broad such as the Peace River trench. Platforms extend up from the rims of the trenches to the base of uplands and may be filled with unconsolidated deposits from 50 to 600 feet (15.2 to 184 m) in thickness. The platform areas contain the greatest thicknesses of unconsolidated deposits in the region and offer some prospects for locating aquifers within the more permeable units where present. Thick sections of glacial till and fine-grained lacustrine deposits, however, appear to dominate the platform areas. Locally, shallow permeable deposits of sand and gravel may comprise suitable aquifers in the trench areas.

Mathews (1955a) distinguished 6 natural settings (e.g. river flats, terraces and rolling uplands) to describe possibilities for locating relatively shallow groundwater supplies in the Peace River area. Mathews (1963) also grouped the unconsolidated deposits in the Fort St. John area into a number of units on the basis of age and environment of deposition as summarized in Table 2. Mathews (1978) has also provided a more expanded discussion of the various units recognized in the region. These studies provide a good representation of the type, variability and setting of unconsolidated units found in the study region and indication where aquifers may exist.

Potential unconsolidated aquifers in the region are likely to be associated with the following geologic units from youngest to oldest:

Type 1. Sand and gravel deposits at or near present stream levels associated with modern alluvium along major creeks and rivers;

Type 2. Glaciofluvial deposits at or near surface formed by glacial melt waters at the end of the last glaciation;

Type 3. Glaciofluvial and fluvial interglacial sand and gravel units deposited during advance and retreat of ice sheets, including those deposited in preglacial and interglacial valleys;

Type 4. Preglacial sand and gravel deposits, including those deposited in preglacial valleys.

The unconsolidated aquifers mapped in 2004 and revised in 2011 are shown in Figure 7.

Table 2.

Unconsolidated Deposits and Potential Aquifers, Fort St. John Area

Age	Unit (Mattews, 1963)	Descriptions (Mattews, 1963)	Potential Aquifers	Comments
Youngest	**Postglacial deposits**	Stream and terrace gravels, alluvial fan deposits, pond silts, peat and swamp deposits, cliff-head and parabolic dunes	Permeable alluvial sand and gravel units	Limited in extent and volume
	Late glacial deposits	Lacrustine clay and silt, near shore sand and gravel, and in the west sand and till (?) attributable to the Cordilleran ice sheet; related to retreating stages of the Laurentide ice sheet when ice-dammed lakes persisted	Permeable sand and gravel units	Generally thin
	Glacial Till	Till attributable to the last major ice advance, massive and clay rich	Generally not an aquifer	Extensive but varies in thickness
	Interglacial and early Wisconsin (?) river and lake deposits	River and lake deposits relating to stream transport, aggradation and ponding, consisting of gravel with minor sand, overlain conformably by silt and clay	Permeable sand and gravel units	Generally along major river valleys
	Old glacial till	Till attributable to an early advance of Laurentide ice	Generally not an aquifer	Variable extent and thickness
Oldest	**Early interglacial or preglacial river and lake deposits**	Buried gravels and sands, silts and clays exposed along the north wall of the Peace River overlying Cretaceous shale southeast of Tea Creek	Permeable sand and gravel units	Generally along major river valleys

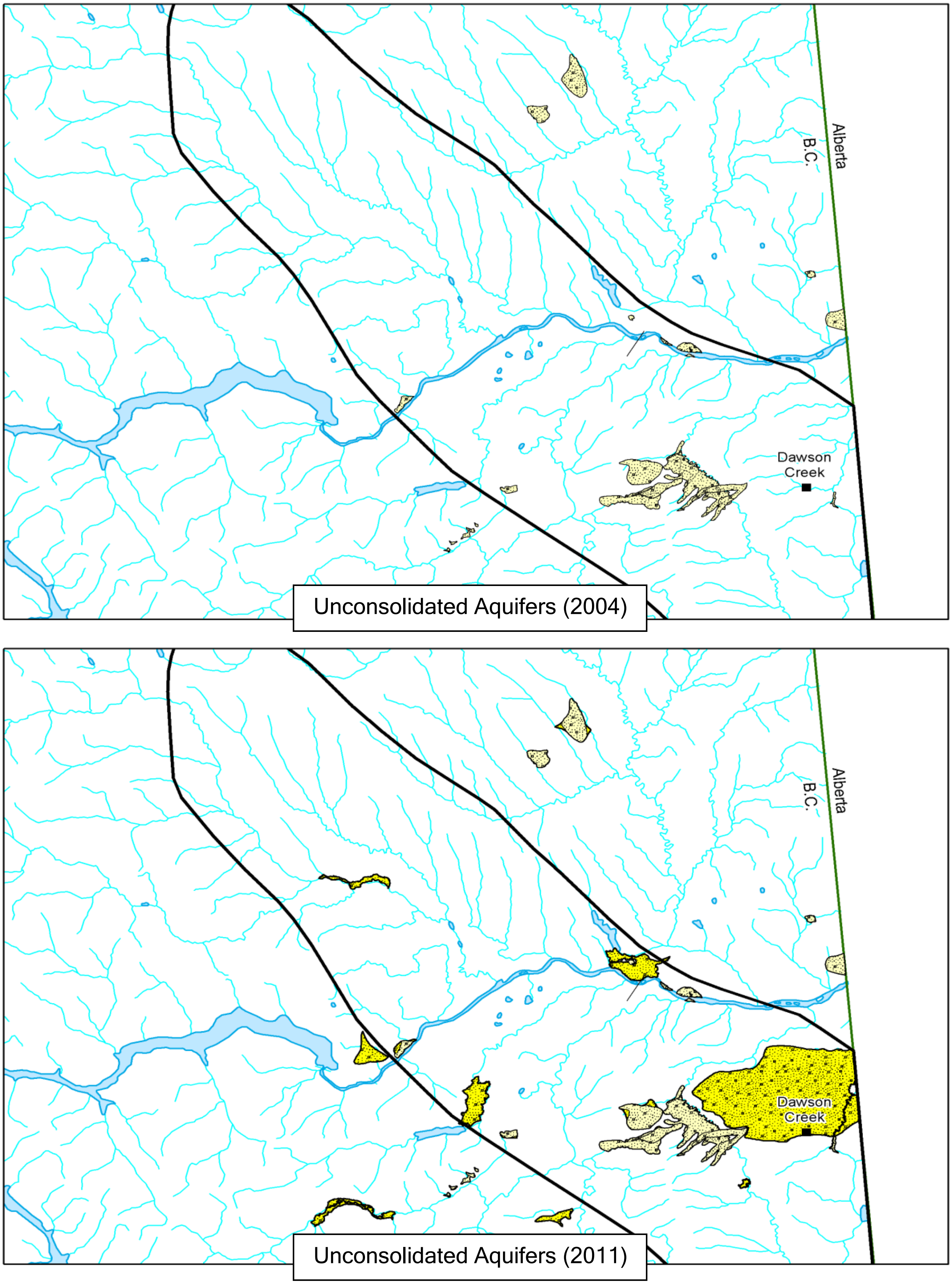


Figure 7 - Unconsolidated Aquifer Mapping 2004 and 2011 updated

Catto (1998) indicates that the pre-Late Wisconsin fluvial sands and gravels, and the glaciofluvial sands and gravels (Type 2 and 3) have the greatest potential for aquifer development. Further discussion on the types of unconsolidated aquifers found in the region based on the results of aquifer mapping carried out under this project is provided in Section 8. Interglacial aquifers found in preglacial and interglacial valleys are of special significance and these are discussed below. Figures 8 and 9 show cross-sections through typical unconsolidated deposits and aquifers.

7. PREGLACIAL AND INTERGLACIAL VALLEYS

Major drainage systems that existed prior to or during the last glaciation of the Interior Plains Region have been reconstructed in part from subsurface drilling information and geomorphologic features where evident (Meyboom, 1967). These bedrock-channel systems are made up of valleys that existed prior to glaciation (preglacial valleys) and those that were cut into bedrock during the Pleistocene epoch (glacial or interglacial bedrock valleys). Both types of valleys occur in the region and may be either partly or completely filled with glacial drift. Some of these buried valleys may contain sand and gravel aquifers hence they are important targets for groundwater exploration. Callan (1970), for example, reported up to 650 feet (198 m) of unconsolidated deposits with possible aquifer zones being encountered in a buried channel incised into the Cretaceous bedrock in the Sunset Prairie-Groundbirch area. A cross-section of a buried channel east of Sunset Prairie is provided in Figure 10.

Cowen (1998) has identified a number of the main buried valleys in the region where the PFRA conducted test drilling to investigate groundwater potential. Others, including Mathews (1963), Callan (1970), Mathews (1978), Ministry of Environment (1983) and Ministry of Energy and Mines (2011) also report the existence of these valleys in the region. Catto (1998) has also mapped the former channel systems in the region at a scale of 1:250 000. Figure 11 summarizes available information on the distribution of preglacial and interglacial valleys in the region based on these reports.

8. AQUIFER CLASSIFICATION MAPPING – METHODOLOGY AND LIMITATIONS

The British Columbia Aquifer Classification System (BCACS) was developed to identify and classify developed aquifers in British Columbia to provide information to assist with management of groundwater. Developed aquifers are aquifers wherein wells have been completed to utilize groundwater or investigate groundwater or subsurface geologic conditions. Well drilling and well testing records provide the prime source of data for confirming the presence of an aquifer.

Information from geologic mapping studies, soils, topography, and drainage data also assist in the identification of aquifers and location of their boundaries. Background information on the BCACS is provided in Appendix C.

Previous aquifer classification studies in the area have been completed by EBA Engineering Consultants Ltd (2003), Lowen Hydrogeology Consulting (2004) and Dave Thompson (2002). These studies identified 40 aquifers, some which have been revised by Lowen Hydrogeology Consulting Ltd. under this project. All of the 55 aquifers identified are listed in Table 3 and mapped in Figures 6 and 7. Worksheets outlining these aquifers are provided in Appendices D. Aquifer mapping can be viewed online at two BC Government Websites:

- BC Water Resources Atlas – http://www.env.gov.bc.ca/wsd/data_searches/wrbc/index.html
- iMap BC – http://webmaps.gov.bc.ca/imfx/imf.jsp?site=imapbc

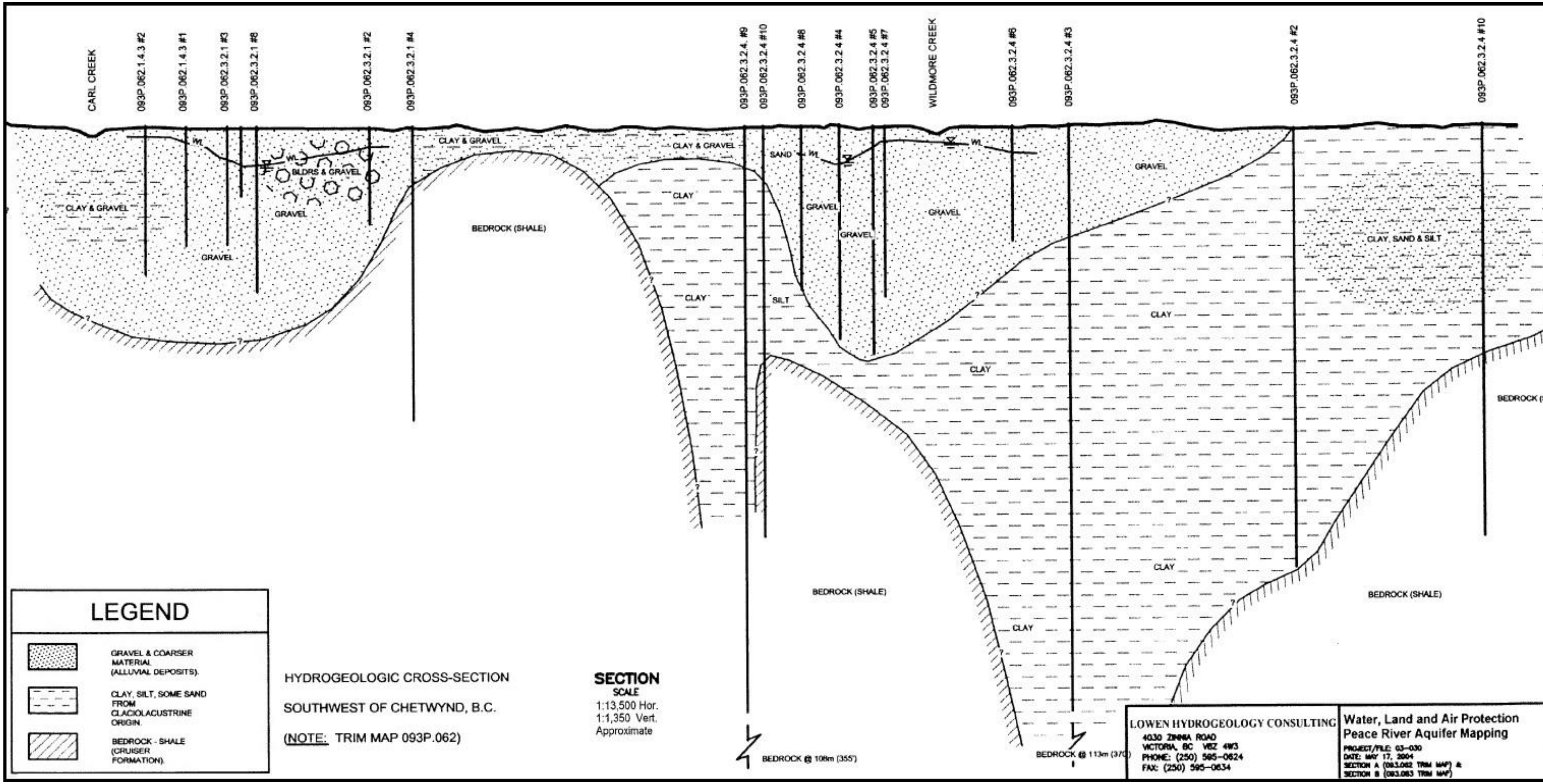


Figure 8

Hydrogeological Cross Section A-A'

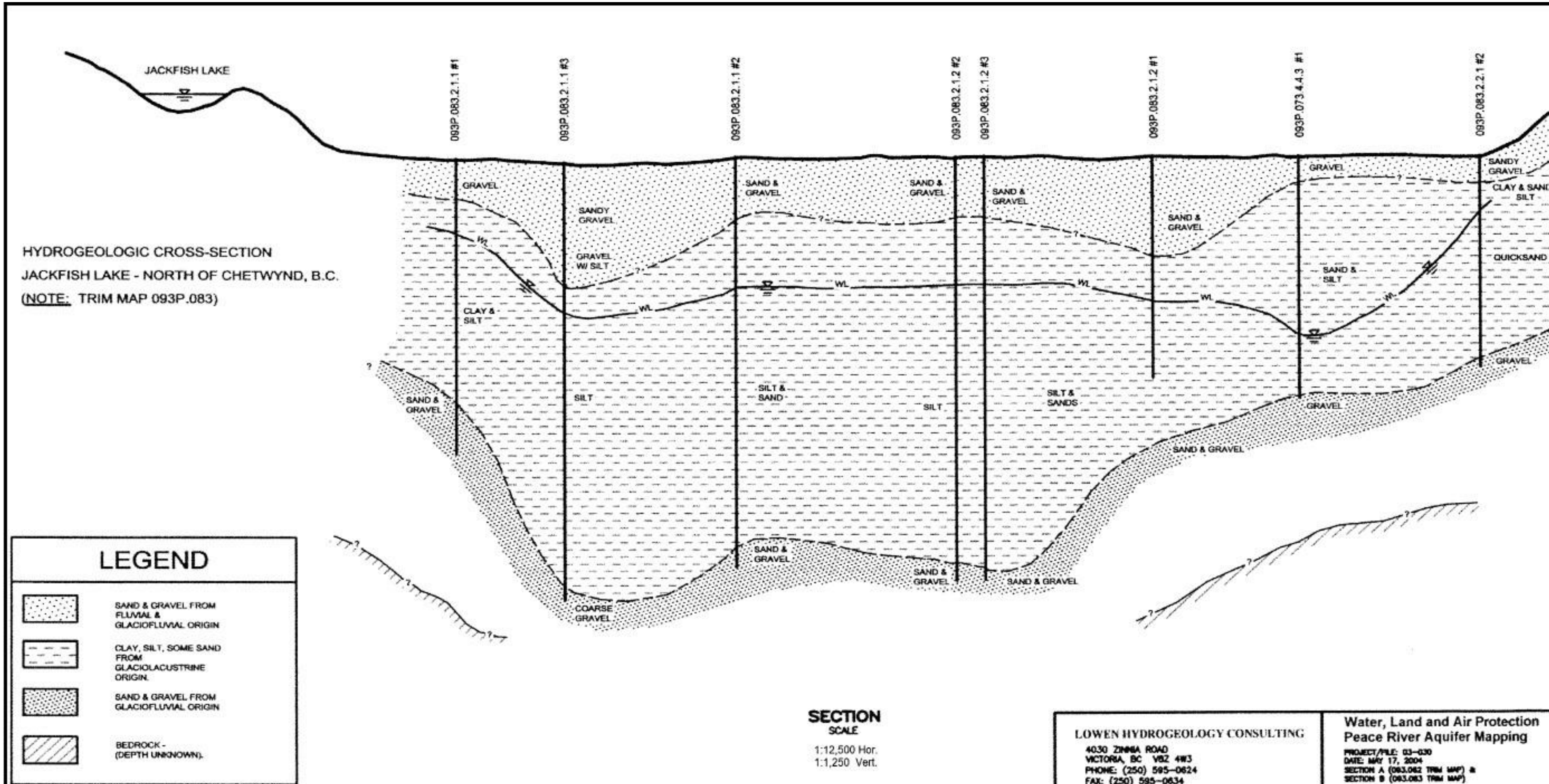


Figure 9

Hydrogeological Cross Section B-B'

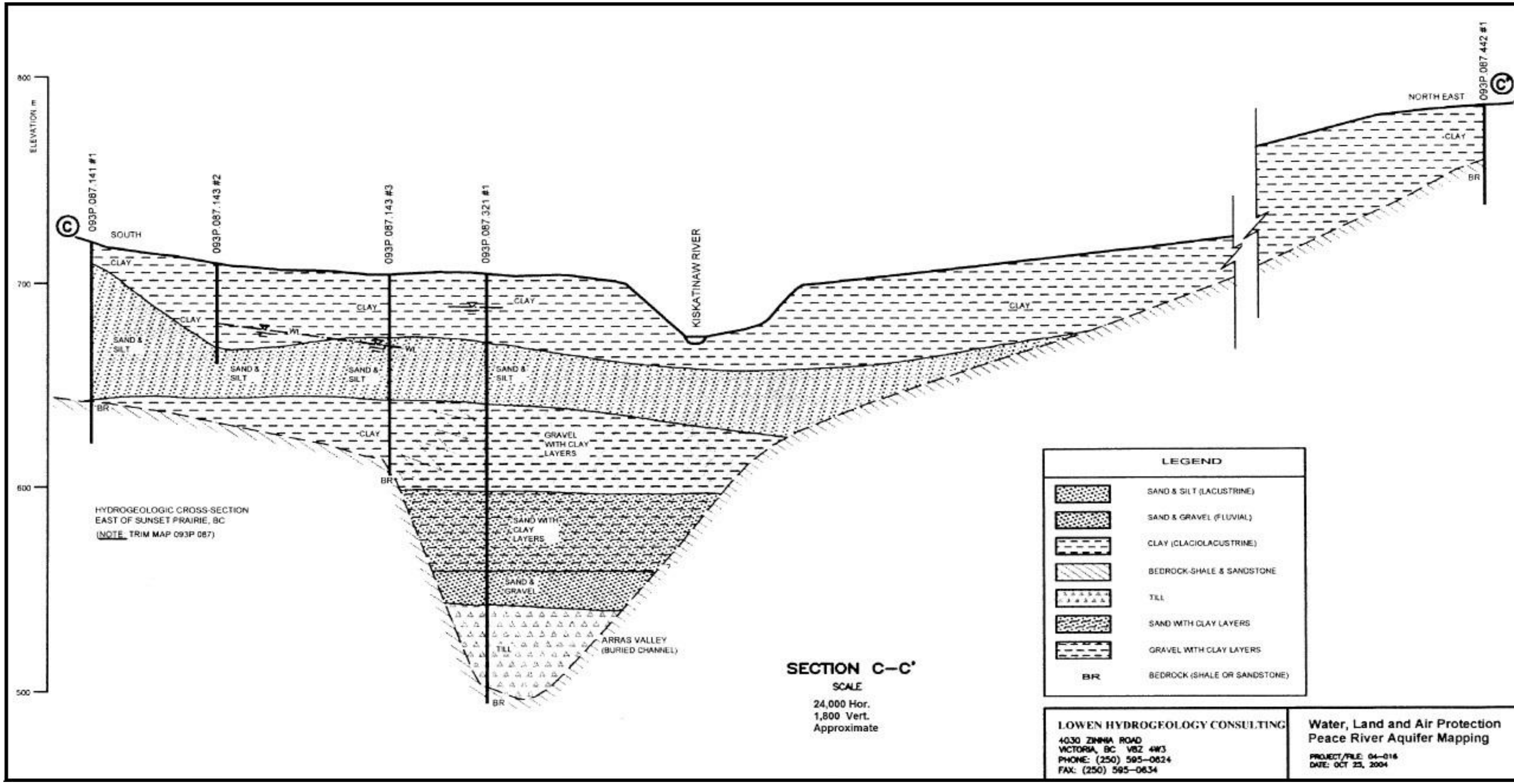


Figure 10

Hydrogeological Cross Section C-C'

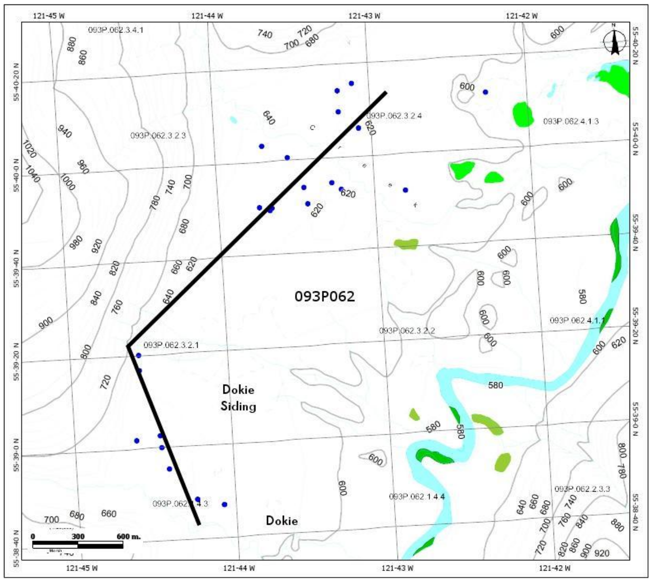


Figure 8A - Location of cross-section in Figure 8

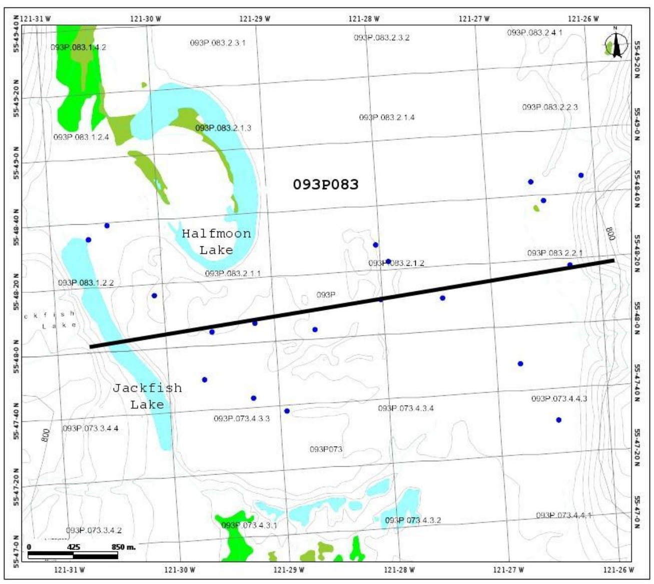


Figure 9A - Location of cross-section in Figure 9

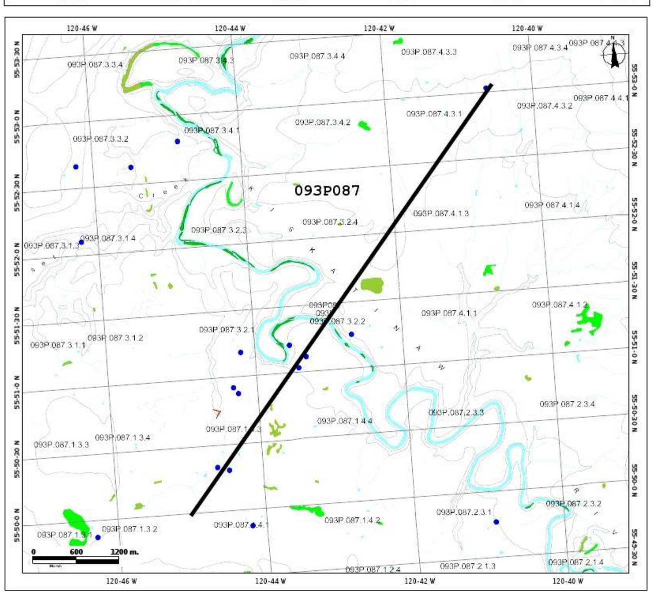


Figure 10A - Location of cross-section in Figure 10

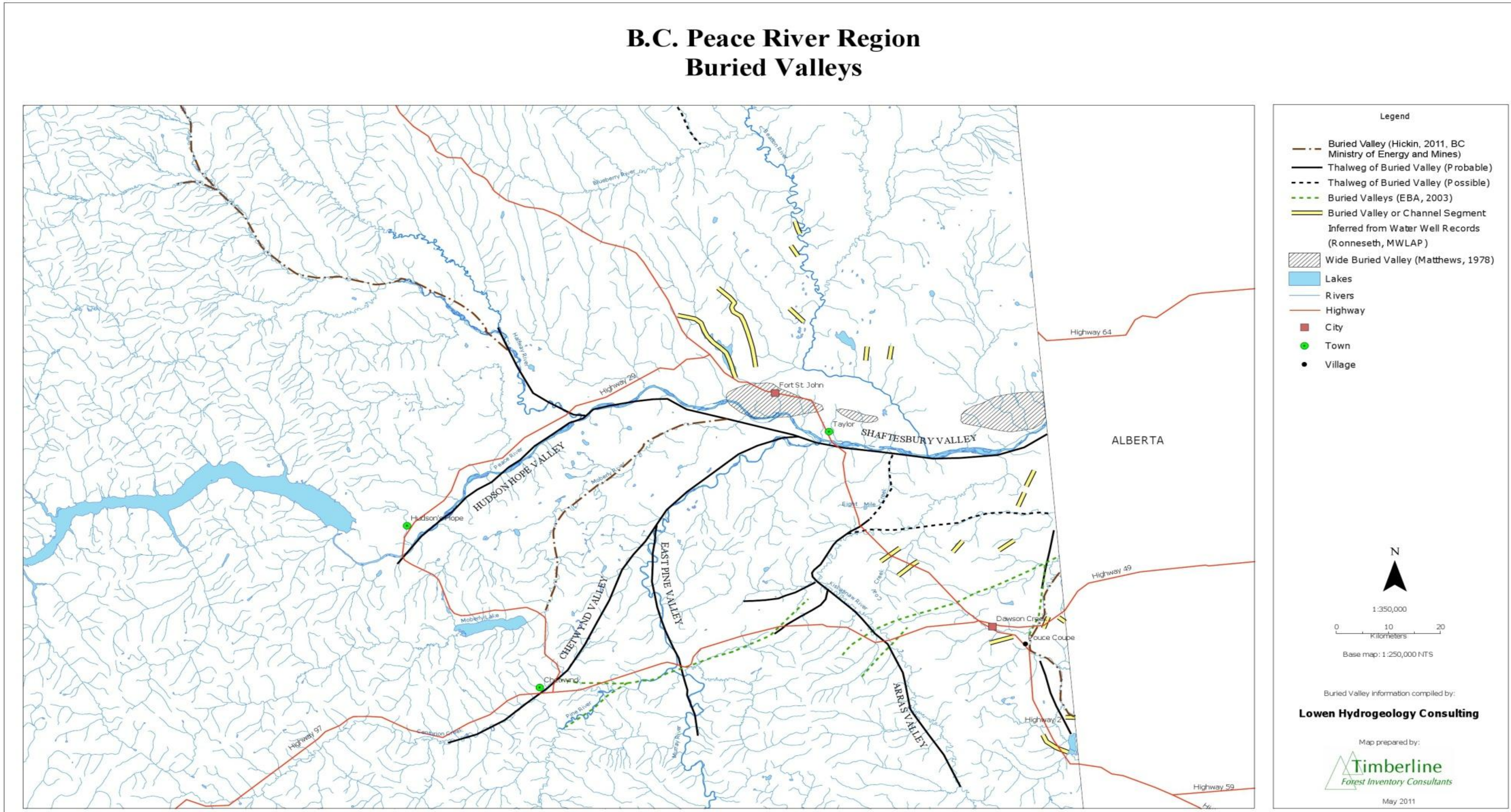


Figure 11

Preglacial and Interglacial Valleys

Table 3
List of Classified Unconsolidated and Bedrock Aquifers

Aquifer Number	Aquifer Classification & Ranking	Aquifer Type	Aquifer Size 2004 (km2)	Aquifer Size 2011 (km2)	Aquifer Location and Description	Level of Confidence (*Aquifer Delineation*)
440	III B - 9	Unconsolidated	9.0	13.2	Hudson Hope	High
441	III B - 10	Bedrock	10.2	13.6	7 km NE of Hudson Hope	Medium
442	II A - 12	Unconsolidated	1.9	1.9	3.5 km. West of Taylor	High
443	III B - 6	Unconsolidated	11.9	11.9	Taylor	Medium
444	II B - 12	Unconsolidated	1.5	75.5	Fort St. John	Medium
448	III C - 11	Bedrock	90.1	90.1	Clayhurst	Medium
451	III C - 12	Bedrock	1,635	3,286	North of Fort St. John	Medium
589	II C - 7	Bedrock	19.1	19.1	Pine and Murray Rivers	Medium
590	III C - 11	Unconsolidated	49.3	49.3	Groundbirch	Medium
591	III C - 12	Bedrock	519.7	519.7	Groundbirch - Progress	Medium
592	III C - 11	Unconsolidated	56.5	63.9	Willow Valley/Groundbirch	Medium
593	III C - 9	Bedrock	114.0	1146.9	Dawson Creek / Arras	Medium
594	III C - 10	Unconsolidated	53.8	53.8	Groundbirch-Sunset Prairie	Medium
595	III C - 10	Bedrock	67.0	69.6	Willow Valley	Medium
596	III C - 14	Unconsolidated	125.6	125.2	Progress-Sunset Prairie	Medium
597	III C - 10	Unconsolidated	40.5	40.5	Arras - Dawson Creek	Medium
598	III A - 10	Unconsolidated	2.5	3.15	Pouce Coupe	Medium
621	III B - 10	Bedrock	27.5	27.5	Kelly Lake southwest of Dawson Creek	Medium
622	III C - 12	Bedrock	100.13	280.2	South of Pouce Coupe - North of Tate Creek	Low
623	II B - 10	Unconsolidated	n/a	17.9	Lone Prairie	Low
624	II B - 9	Unconsolidated	0.86	1.1	Chetwynd area	Medium
625	II B - 9	Unconsolidated	0.84	0.92	Chetwynd area	Medium
626	II C - 8	Unconsolidated	2.9	2.9	Chetwynd area - north of Pine River	Medium
627	III B - 10	Bedrock	6.45	7.8	Chetwynd area - west of Dokie Siding	Medium
628	II B - 8	Unconsolidated	1.6	1.5	Chetwynd area - north of Pine River	Medium
629	II B - 8	Unconsolidated	0.53	0.53	Chetwynd area - north of townsite	Medium
630	III C - 8	Unconsolidated	7.02	8.25	Jackfish Lake area - northeast of Chetwynd	High
631	III C - 10	Bedrock	43.72	43.72	South of the Peace River	Low

Table 3. - Continued

Aquifer Number	Aquifer Classification & Ranking	Aquifer Type	Aquifer Size 2004 (km^2)	Aquifer Size 2011 (km^2)	Aquifer Location and Description	Level of Confidence (*Aquifer Delineation*)
633	III C - 9	Bedrock	47.99	44.89	South of the Peace River	Low
634	III C - 9	Bedrock	51.3	83.76	South of the Peace River	Medium
635	II A - 15	Unconsolidated	1.71	0.87	SW. of Tumbler Ridge	High
636	III C - 8	Unconsolidated	3.9	3.9	East of Fort St. John	Low
637	III C - 10	Unconsolidated	48.54	83.8	North of Fort St. John	Low
638	III C - 8	Unconsolidated	20.35	20.35	North of Fort St. John	Low
639	III C - 10	Bedrock	196.5	844.84	South of Prespatou	Low
640	III A - 11	Unconsolidated	2.55	2.55	East of Tumbler Ridge	High
687	II B - 10	Unconsolidated	1.0	1.0	Taylor Flats, S.of the Peace River and SE.of F.St. John	Medium
688	II C - 9	Bedrock	15.10	15.20	East of Chetwynd and N. of the Pine River	Low
689	II C - 9	Bedrock	1.80	75.1	Lone Prairie	Low
690	III B - 9	Unconsolidated	23.80	23.80	Clayhurst Area-extending East to the Alberta Border	Medium
765	II B - 7	Bedrock	n/a	2.33	South of Tumbler Ridge	Low
850	II C - 6	Unconsolidated	n/a	4.10	Fellers Heights	Low
851	II C - 10	Unconsolidated	n/a	866.44	Dawson Creek	Low
903	II B - 9	Unconsolidated	n/a	33.90	East of Dawson Creek	Low
908	II B - 9	Unconsolidated	n/a	22.90	North Bank Halfway River	High
910	II B - 11	Unconsolidated	n/a	36.10	East Williston Lake	Low
917	II B - 9	Bedrock	n/a	58.40	Near East Pine	Medium
923	II C - 11	Unconsolidated	n/a	61.80	Moberly Lake	High
928	II C - 9	Bedrock	n/a	37.40	Lynx Creek and Peace River	Low
929	II B - 9	Unconsolidated	n/a	10.40	North Pine River at Nelson Creek	High
930	III A - 12	Unconsolidated	n/a	16.70	South Pine River at Nelson Creek	High
931	II B - 10	Bedrock	n/a	964.40	North Fort St. John	Medium
932	II B - 10	Bedrock	n/a	23.00	Between Blueberry and Cameron Rivers	Low
933	II B - 13	Bedrock	n/a	1119.60	Cecil Lake, North Peace River	Medium
934	II A - 10	Bedrock	n/a	58.30	Between Halfway and Cameron Rivers	Low
		Total	**3,413.7**	**10,491.5**		

Thirty-two (32) of the aquifers are unconsolidated (surficial) aquifers and twenty-three are consolidated (sedimentary bedrock). The level of vulnerability of an aquifer is a measure of its vulnerability to a contaminant that is introduced at land surface (Berardinucci and Ronneseth, 2002). Groundwater vulnerability is a function of the groundwater flow system. The confined or unconfined nature of the aquifer indicates its intrinsic vulnerability to contaminants introduced at surface. It should be noted that the rating for vulnerability, development and productivity is for the aquifer as a whole. There may be variation (e.g. in vulnerability) across an aquifer. For more site specific information further characterization of an aquifer would be required.

Six aquifers have been identified as highly vulnerable (A) to surface contamination, twenty-seven aquifers have been identified as moderately vulnerable (B) and twenty-two aquifers have been identified as low with respect to vulnerability (C). Aquifers range in size from 0.53 km^2 to approximately 3286 km^2.

The majority of surficial aquifers within the project area are located along the main river valleys (Peace, Pine and Halfway Rivers). The highest capacity wells are completed in glaciofluvial deposits underlying lacustrine deposits and alluvial or fluvial deposition. The most productive aquifers, yielding over 3 L/s (50 USgpm) are found in the following places: two aquifers in the Tumbler Ridge community (aq. n° 0635 and 0640); one aquifer in the south of Fort St John and west of Taylor (aq. n° 0442); one aquifer in the village of Pouce Coupe (aq. n° 0598) and one aquifer in the Pine Valley (aq. n° 0930),

Well records indicate that the highest capacity bedrock wells are from what appear to be the Dunvegan Formation sandstones of the Upper Cretaceous Period. Aquifer boundaries, classifications and rankings are preliminary and subject to revision as more hydrogeological information become available. Characteristics of the unconsolidated and bedrock aquifers are summarized in Tables 4 and 5, respectively.

The sub-aquifer types identified in Tables 4 and 5 were developed (Wei et al., 2009) to further characterize different aquifer types based on their geology and geomorphology.

Aquifers within the project area have been classified or characterized based on their reported level of development and their assessed vulnerability to contamination. The level of development is determined subjectively by assessing well density, water use and aquifer productivity and sources of recharge (Berardinucci and Ronneseth, 2002). In using this methodology, it is assumed that all water wells reported are utilized (unless indicated otherwise on the well record) and the estimated yield reported on the well record is the amount of water utilized. Well yields reported on well records are usually estimated by the water well contractor based on short-term bail or air tests and not long-term pumping tests which are generally more reliable (pumping test yields are used for classification when available). As the MWLAP does not track the status of water wells after construction, it is not known whether these wells are used or have since been abandoned. As water usage is normally not metered, water usage is also not known. For these reasons, the assessment of development for this project may be conservative.

Table 4
Summary of Aquifer Characteristics, Unconsolidated Aquifers

Aquifer Number	Aquifer Type	Aquifer Sub-Type	Deposit	Materials	Confining Deposits	Well Depths *(m. below ground)*	Well Yields *(L/s)*	Water Levels *(m. below ground)*	Comments
440	Surficial	1a	Glaciofluvial	Sand and gravel	Silt and clay	24.4 - 138.7	0.31 - 6.3	21.3 - 39.6	-
442	Surficial	1a	Alluvial Terrace	Sand and gravel	Clay	6.4 - 23.5	6.3 - 15.1	1.8 - 7.3	-
443	Surficial	4b	Fluvial gravel	Gravel	Clay and silty sand	Test holes only	*No data*	*No data*	-
444	Surficial	4b	Buried Valley - glaciofluvial	Gravel, sand, silt	Clay and till	12.2 - 167.6	0.06 - 1.89	3 - 36.6	-
590	Surficial	4b	Glaciofluvial	Sand, gravel, silt	Clay	22 - 66.7	0.06 - 3.8	2.4 - 30.5	-
592	Surficial	4b	Glaciofluvial	Sand, gravel, silt	Clay	8.5 - 53.3	0.32 - 2.52	1.2 - 16.8	-
594	Surficial	4b	Buried Valley	Sand and gravel	Clay	13.7 - 207.3	0.25 - 1.26	12.2 - 53.9	-
596	Surficial	4b	Glaciofluvial	Sand, gravel, silt	Clay	6.7 - 65.5	0.32 - 4.7	3.3 - 36.6	-
597	Surficial	4b	Buried Valley	Coarse sand and gravel	Clay	98.7 - 140.2	1.1 - 4.73	4.5 - 42.7	-
598	Surficial	1c	Fluvial	Sand gravel and silt	Silt	3.6 - 45.1	10.1 (one only)	0.61 - 3.0	-
623	Surficial	4b	Glaciofluvial	Sand and gravel	Clay	22.8 - 150.9	0.19 - 2.21	3 - 73.1	-
624	Surficial	4b	Alluvial fan and glaciofluvial intermixed	Gravel and some sand	Clay, silty and sandy clay, till	12.2 - 116.7	1.2 - 1.9	4.5 - 30.5	May be in hydraulic continuity with Wildmore Creek
625	Surficial	3a	Alluvial fan and glaciofluvial intermixed	Gravel	Clay and till	7.3 - 18.3	0.4 - 2.5	3 - 12.2	May be in hydraulic continuity with Bissett Creek
626	Surficial	4b	Glaciofluvial	Sand and gravel?	Sandy silt, clay and till	9.4 - 78.6	0.06 - 3.8	1.8 - 26.5	May be in hydraulic continuity with Windrom Creek, gas reported on one well
628	Surficial	3a	Alluvial fan	Sand and gravel	Clay and sandy clay	3.6 - 50.3	0.9 (one only)	1.5 - 7.9	May be in hydraulic continuity with Windrom Creek
629	Surficial	3a	Alluvial fan	Gravel and sand	Clay	4.2 - 10.7	*No data*	0.6 - 2.4	-

Table 4 - Continued

Aquifer Number	Aquifer Type	Aquifer Sub-Type	Deposit	Materials	Confining Deposits	Well Depths (m. below ground)	Well Yields (L/s)	Water Levels (m. below ground)	Comments
630	Surficial	4b	Buried Valley Glaciofluvial	Sand and gravel	Silt and clay	61.3 - 149.3	0.06 - 4.4	18.3 - 62.5	Buried valley, water quality reported good
635	Surficial	3a	Alluvial fan	Gravel	Sand and gravel and till	9.1 - 89.3	0.9 - 312	1.5 - 23.5	Transmissivities range from 8.7 x 10^{-3} to 8.3 x 10^{-2} m^2/s, likely recharged from Flatbed Creek
636	Surficial	4b	Glacio lacustrine	Sand and gravel	Clay and silt	44.2 - 86.6	0.32 - 2.6	12.2 (one well)	High soda reported
637	Surficial	4b	Glacial	Till with sand and gravel	Stony silty clay and silt	6.4 - 78.6	0.1- 1.3	5.5 - 29.6	High soda reported
638	Surficial	4b	Glacial	Till with sand and gravel	Stony silty clay and silt	13.1 - 48.1	0.2 - 1.1	8.5 - 9.4	High soda reported
640	Surficial	4a	Glaciofluvial	Sand and gravel	Sand, gravel, silt, clay	9.1 - 45.7	6.3 - 11.9	6 - 26.8	Perched aquifer
687	Surficial	3a	Alluvial Fan	Sand and gravel	Clay and till	8.5 - 41.5	0.3 - 12.6	4.6 - 37.2	-
690	Surficial	4b	Glaciofluvial	Sand and gravel	Clay, silt and till	12.2 - 54.8	0.4 - 1.3	6 - 45.7	-
850	Surficial	4b	Alluvial Lacustrine	Clay with sand layers to coarse gravel	Clay and silt	125 - 123.4	0.63 - 3.15	2.4 - 21.3	-
851	Surficial	4b	Glacio lacustrine	Sand boulders and gravel	Clay	6.7 - 121.9	0.06 - 1.89	1.2 - 57.9	-
903	Surficial	4b	Glacio lacustrine	Sand boulders and gravel	Clay	6 - 36.5	*No data*	1.5 - 30.5	Extends in Alberta
908	Surficial	4a/4b	Terrace and alluvium	Gravel and sand	Clay	4.6 - 28.3	0.63 - 0.95	4.9 - 22.6	-
910	Surficial	4b	Lacustrine Fluvial	Sand and gravel	Clay and silt	12.5 - 115.9	0.13 - 1.89	8.5 - 73.1	-
923	Surficial	4b	Morainal Alluvial fan	Sand gravel and silt	Clay silt and till	14.9 - 147.2	0.32 - 2.52	6 - 21.3	-
929	Surficial	4b	Terrace	Gravel sand and silt	Clay and silt	4.9 - 40.2	0.32 - 2.52	3 - 5.5	-
930	Surficial	4a/4b	Terrace	Gravel sand and silt	Clay and silt	8.5 - 138.7	0.5 - 5	1.8 - 6.7	-

Table 5
Summary of Aquifer Characteristics, Bedrock Aquifers

Aquifer Number	Aquifer Type	Aquifer Sub-Type	Deposit	Materials	Well Depths (m. below ground)	Well Yields (L/s)	Water Levels (m. below ground)	Comments
441	Bedrock	5a	Gates Sandstone (Sedimentary bedrock)	Layered sandstone and shale	7.9 - 91.4	0.06 - 1.8	4.6 - 45.1	-
448	Bedrock	5a	Wapiti (Sedimentary bedrock)	Sandstone, shale and conglomerate	32.6 - 146.3	0.25 - 3.15	18.3 - 61	-
451	Bedrock	5a	Dunvegan (Sedimentary bedrock)	Shale and sandstone	8.5 - 305	0 - 15.8	1.2 - 121.6	Large Bedrock Aquifer System
589	Bedrock	5a	Dunvegan (Sedimentary bedrock)	Shale and sandstone	33.5 - 103.6	0.03 - 0.50	9.1 (one only)	-
591	Bedrock	5a	Kaskapau (Sedimentary bedrock)	Shale and sandstone	8.2 - 182.9	0 - 3.15	0.6 - 45.7	-
593	Bedrock	5a	Kaskapau (Sedimentary bedrock)	Shale and sandstone	9.7 - 824.5	0 - 3.15	0.3 - 97.8	-
595	Bedrock	5a	Dunvegan (Sedimentary bedrock)	Shale and sandstone	22.2 - 128	0.06 - 1.4	8.2 - 26	-
621	Bedrock	5a	Wapiti (Sedimentary bedrock)	Layered sandstone, shale	17.1- 48.8	1.3 - 1.9	0.3 - 8.8	Recharge from direct precip. and Kelly Lake, good water quality
622	Bedrock	5a	Dowling,Thistle and Hanson Members of Puskwaskau formation (Sedimentary bedrock)	Layered sandstone, shale	27.4 - 140.2	0.06 - 6.3	1.2 - 89	TDS 3684 mg/L, hardness 2000+ mg/L, alkalinity up to 1020 mg/L
627	Bedrock	5a	Cruiser (Sedimentary bedrock)	Black shale and sandstone	9.1 - 123.1	0.1 - 4.4	0.3 - 36.6	-
631	Bedrock	5a	Dunvegan (Sedimentary bedrock)	Sandstone and shale	27.4 - 195	0.6 - 1.6	85.3 (one well)	-
633	Bedrock	5a	Dunvegan (Sedimentary bedrock)	Shale and sandstone	6 - 122	0.06 - 1.9	3 - 79.2	-

Table 5 - Continued

Aquifer Number	Aquifer Type	Aquifer Sub-Type	Deposit	Materials	Well Depths (m. below ground)	Well Yields (L/s)	Water Levels (m. below ground)	Comments
634	Bedrock	5a	Dunvegan (Sedimentary bedrock)	Shale with sandstone layering	10.7 - 158.5	0.06 - 9.5	5.5 - 85.3	-
639	Bedrock	5a	Dunvegan (Sedimentary bedrock)	Sandstone and shale	14.6 - 194.5	0.1 - 15.8	0.6 - 61.8	-
688	Bedrock	5a	Dunvegan (Sedimentary bedrock)	Shale and sandstone	28.9 - 121.9	0.06 - 6.6	1.8 - 39.1	-
689	Bedrock	5a	Dunvegan (Sedimentary bedrock)	Shale and sandstone	19.2 - 94.5	0.1 - 3.8	6 - 38.1	-
765	Bedrock	5a	Fort St John (Sedimentary bedrock)	Shale interbedded with sandstone	86.7 - 149.3	0.8 - 4.7	12.5 - 21.9	-
917	Bedrock	5a	Dunvegan (Sedimentary bedrock)	Shale and sandstone	41.1 - 153	0 - 9.46	7 - 99	-
928	Bedrock	5a	Fort St John (Sedimentary bedrock)	Shale interbedded with sandstone	31 - 71	0.06 - 18.9	1.5 - 34.7	-
931	Bedrock	5a	Dunvegan (Sedimentary bedrock)	Shale and sandstone	28.3 - 262.1	0.1 - 1.3	26.2 - 115.8	-
932	Bedrock	5a	Dunvegan (Sedimentary bedrock)	Shale and sandstone	6 - 146.3	0 - 1.14	1.2 - 79.2	-
933	Bedrock	5a	Dunvegan / Smokey (Sedimentary bedrock)	Shale and sandstone	7.6 - 370.6	0.1 - 1.6	3.6 - 84.1	The two bedrock units are considered to be hydraulically connected
934	Bedrock	5a	Fort St John (Sedimentary bedrock)	Shale interbedded with sandstone	12.5 - 70	0.32 - 0.44	5.5 - 12.5	-

Because of the lack of information available at the time of this assessment, a clear scientific understanding and interpretation of the groundwater flow systems is generally not possible in this assessment. The “direction of groundwater flow” has not been established for the mapped aquifers and is generally described on the worksheets as:

Unknown, insufficient data available to determine with certainty but ignoring geologic complexities, likely from areas of higher elevation towards areas of lower elevation.

However, some small surficial (unconsolidated) aquifers stand along major rivers (Pine, Halfway, Moberly or Peace Rivers). In this case, the direction of the flow is considered to follow the topographic gradient.

“Recharge” has generally been described on the worksheets as:

Direct infiltration of precipitation (rain or snow) at ground surface.

Several cases report infiltration from the rivers or lake if the aquifers are located close by. Also infiltration from runoff water has been reported a few times in the case where small streams can be observed to terminate above an aquifer.

Knowledge of the groundwater flow system and in turn the aquifer vulnerability depends on the aquifers properties (hydraulic conductivity, porosity, hydraulic gradients) and the associated sources of water and stresses for the system (recharge, interaction with surface water, travel through the unsaturated zone and well discharge). These properties have generally not been determined in this assessment because of a lack of hydrogeological information. Assessing the level of vulnerability of an aquifer in this assessment has been based mainly on the thickness and type of geologic formation (clay, till, silt, etc.) overlying the aquifer at the well head and reported depth to groundwater. Reported depth to groundwater can be misleading as reported groundwater levels are generally measured only once (at or shortly after the time of well construction). Construction of geologic cross-sections where sufficient water well data exists, has allowed a better understanding of the extent and thickness of these overlying deposits away from the well head at only a few locations.

The *level of confidence* in delineating, classifying and ranking these aquifers with respect to development and vulnerability is directly proportional to the amount and quality of groundwater information available for review. The level of confidence (low, medium, and high) for each aquifer delineated has been shown in Table 3. The level of confidence also dictates whether dashed or solid lines are used in drawing the aquifer boundaries on the aquifer classification maps. Because information is often unavailable to delineate the aerial extent of the aquifer, the location of the aquifer is less certain and a dashed line indicates the aquifer boundary on the aquifer classification map. For example, if limited water well and other hydrogeological information are available and the aerial extent of the aquifer is delineated on well development alone, a low level of confidence is apparent and a dashed line is drawn to indicate the aquifer boundary. When there is a reasonable degree of certainty or confidence associated with the location of the aquifer boundary, a solid line is used to define the boundary.

At present, aquifer classification maps and worksheets are used at the provincial, regional and local planning and management levels. They are used to identify highly developed and vulnerable aquifers for groundwater protection, identify aquifers where groundwater quality issues are apparent and determine potential new sources of drinking water supplies among many other uses. There is concern, however, that in time, those aquifers, especially those aquifers mapped several years ago and based on very limited data (low level of confidence) may mislead users of this data.

At some point in the future, as areas in British Columbia become increasingly developed and more well record data and other hydrogeological information becomes available, aquifers (maps and worksheets) should be systematically reviewed and updated. In this manner, the quality of aquifer classification mapping is continuously being improved for specific users (provincial and federal governments, the general public, consultants, universities and industries etc.). This is particularly important where some aquifers need improved definition, having been delineated in the past based on minimal hydrogeological information resulting in a low level of confidence with respect to determining aquifer boundaries.

9. GROUNDWATER QUALITY

Information on groundwater quality was obtained from previous reports noted below and augmented by an examination of 252 groundwater quality analyses available from the Northern Health authority (2003 and 2011), covering 79 water supply systems in the region. The analyses for the water systems are historic, spanning the years 1977 to 2010 and probably represent the most comprehensive source of groundwater quality information in the region. Water supply systems include various municipal sources, trailer parks, camps, motels, recreational parks, resorts, compressor stations, water districts, industries, airports, schools, marinas and restaurants. Some systems may no longer be in service. Table 8 provides a representative listing of 31 of the 79 water systems and extraction points compiled. Sixty-two (62) of these systems have specific location information as shown in Figure 12. The location of active drinking water systems can also be viewed at the British Columbia Water Resources Atlas (Ministry of Environment, 2011).

Bedrock Aquifers

Ministry of Environment (1983) and Ronneseth (1994) report that groundwater quality from aquifers in the Alberta Plateau region is highly variable. According to Ronneseth (1994) groundwater found in bedrock may range from the calcium and magnesium bicarbonate types to calcium and magnesium sulfate and sodium bicarbonate types. A general summary of groundwater quality based on Ministry of Environment (1983) is provided in Table 6. Groundwater can be categorized as very hard to extremely hard north of Township 84 and in the Dawson Creek – Swan Lake area, commonly ranging from 1,000 to 2,500 mg/L. Elsewhere groundwater may be considered moderately hard to hard, with hardness ranging from about 100 to 500 mg/L. Elevated concentrations of iron and manganese are common.

Unconsolidated Aquifers

Ministry of Environment (1983) and Ronneseth (1994) reported that limited data on chemical analyses for groundwater in the unconsolidated deposits showed total dissolved solids content ranging from about 1,000 mg/L to about 2,500 mg/L north of the Peace River and from about 1,000 to 5,000 mg/L south of the Peace River (Table 6). Groundwater quality is described mainly as calcium and magnesium or sodium bicarbonate types with some sulphate types in the Dawson Creek – Swan Lake area and near Groundbirch. Groundwater in the unconsolidated deposits is often less hard than in the bedrock. Iron concentrations are reported to range from about 1 to 10 mg/L south of the Peace River and up to 0.6 mg/L north of the Peace River.

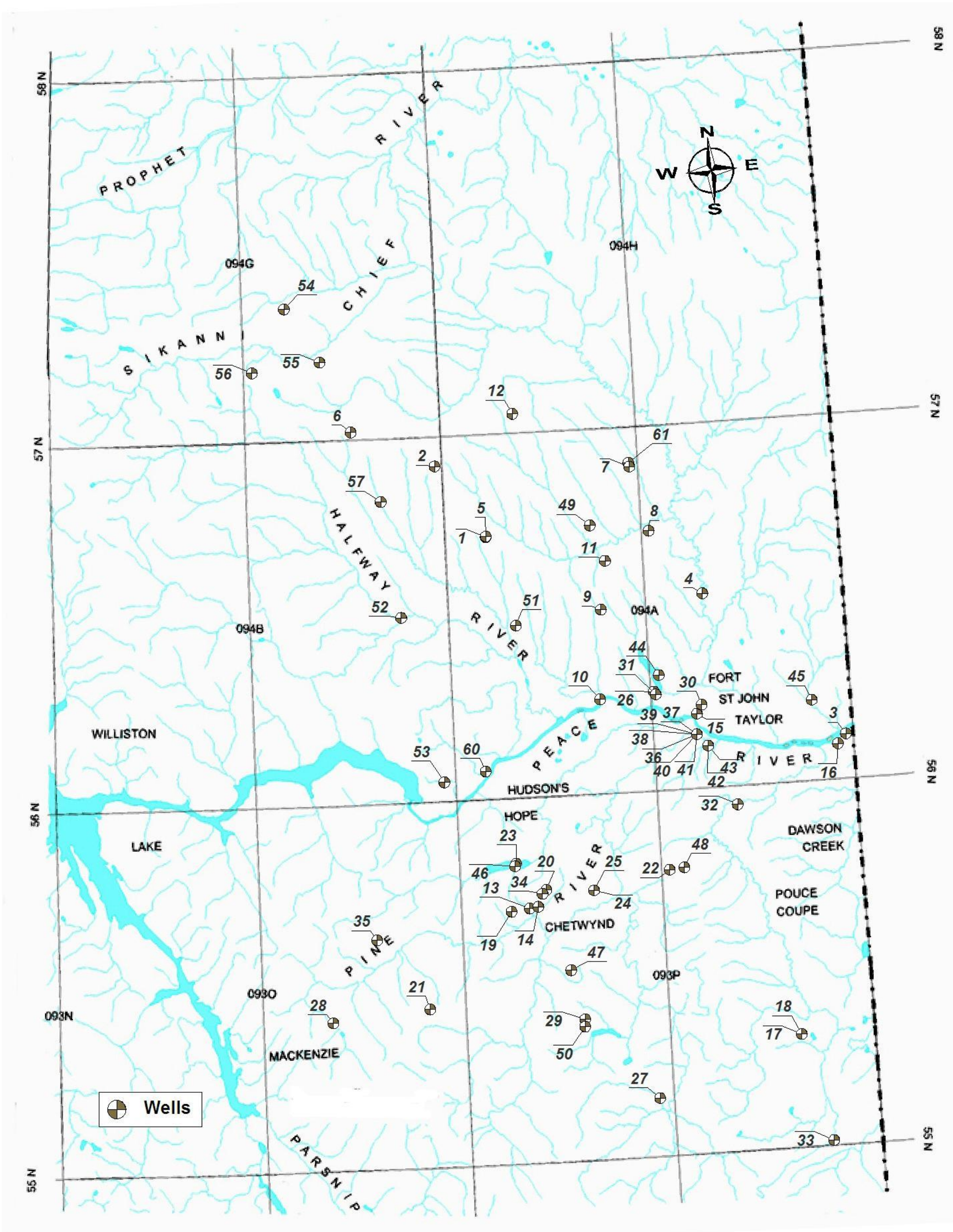


Figure 12

Location of 62 Water Systems

Table 6.

General Summary of Groundwater Quality, Peace River Region

Area	Aquifer Type	TDS (mg/L)	Hardness (mg/L)	Type	Other Parameters	Reference
TWPs 85-87, Rges 17-20 North of Peace River in vicinity of Fort St John	Bedrock	2000 - 6600	Very hard to extremely hard 1000 - 2500	Calcium-magnesium bicarbonate Calcium-magnesium sulphate Sodium bicarbonate	Iron < 0.6 mg/L (north of Twp 84)	Ministry of Environment (1983)
South of TWP 85 to BC-Alberta border	Bedrock	900 - 3300	Very hard to extremely hard 1000 - 2500	Calcium-magnesium bicarbonate Calcium-magnesium sulphate near Dawson Creek	Locally Iron > 1.0 mg/L	Ministry of Environment (1983)
TWPs 85-87, Rges 17-20 North of Peace River in vicinity of Ft. St. John	Unconsolidated	1000 - 2500		Calcium-magnesium or sodium bicarbonate	Iron up to 0.6 mg/L (north of Peace River)	Ministry of Environment (1983)
South of TWP 85 to BC-Alberta border	Unconsolidated	1000 - 5000		Calcium-magnesium or sodium bicarbonate, sulphate types in the Dawson Creek-Swan Lake and Groundbirch areas	Iron from 1 to 10 mg/L (south of Peace River)	Ministry of Environment (1983)
Moberly Lake, East Pine and Lone Prairie	Unconsolidated		140 - 375	High bicarbonate, 1000 - 1500 mg/L	Iron 0.3 - 0.8 mg/L	Ministry of Environment (1983)
Chetwynd	Bedrock and Unconsolidated		260 - 460	Calcium-magnesium bicarbonate, bicarbonate 300-1350 mg/L	Iron .3 - 4.0	Ministry of Environment (1983)
Tumbler Ridge	Unconsolidated	130 - 1125	30 - 345	Calcium-magnesium bicarbonate, bicarbonate 20-450 mg/L	Iron 0.04 - 4.0	Ministry of Environment (1983)

Quality Concerns

Locally, natural groundwaters in the region may contain elevated concentrations of a number of constituents that exceed the 2011 Guidelines for Canadian Drinking Water Quality (GCDWQ) prepared by the Federal-Provincial-Territorial Committee on Drinking Water. Cui and Wei (2000) examined several hundred analyses from domestic wells under the provincial Water Quality Check Program (WQCP), which operated between 1977 and 1993. They found that in addition to elevated concentrations of iron and manganese, the following parameters may be elevated locally in the region (Table 7). The range in percentages shown in Table 7 covers different 1: 50,000 NTS map sheet areas within the Peace River region.

Table 7-

Parameters that may exceed drinking water guidelines:

Parameter	Concentrations mg/L	% of samples	GCDWQ (maximum acceptable concentration mg/L)
Barium	> 1	1 to 34 %	1
Boron	> 5	1 to 10 %	5
Hardness	50 - 2800	-	80 - 100 mg/L Aesthetic objective only
Sodium	> 200	10 to 100 %	< or = 200 mg/L Aesthetic objective only
Fluoride	> 1.5	1 to 20 %	1.5
Total Dissolved Solids (TDS)	> 500	-	< or = 500 mg/L Aesthetic objective only

Note: Iron and manganese commonly exceed guidelines. Data from Cui and Wei (2000).

Table 8 summarizes results of a number of representative groundwater quality analyses from 1990 to 2009 by Northern Health for those water systems where there was sufficient analytical data information to determine groundwater types. Groundwater types are defined on the basis of the most dominant percentages of cations and anions present in equivalents per million (epm). These illustrate the variable nature of groundwater quality found in the region ranging from the calcium bicarbonate type to the calcium-magnesium bicarbonate type with low to moderate levels of dissolved minerals (TDS generally ranging from 100 to 500 mg/L) to the more complex and more mineralized sodium bicarbonate, and sodium-calcium-magnesium sulphate-bicarbonate types (TDS ranging from 500 to 2000+ mg/L). From a cursory examination of the data, elevated concentrations of barium and fluoride appear associated with soft, sodium bicarbonate type groundwaters. Table 9 shows concentration ranges of a number of common parameters for the water systems tested by Northern Health. These results confirm the ubiquitous presence of elevated iron and manganese (median 0.98 and 0.02 mg/L) respectively in most samples, high hardness levels (median 202 mg/L), and moderately high total dissolved solids (median 428.5 mg/L). Cowen (1998) also reported a wide variation in groundwater quality for nine samples obtained from test holes in a number of buried valley aquifers in the region. Total dissolved solids for these latter samples ranged from 296 to 3090 mg/L.

Table 8

Representative Groundwater Quality Analyses from 1990 to 2009 by Northern Health

No.	Site	Date d/m/y	TDS mg/L	Hardness mg/L	pH ph units	Ca mg/L*	Mg mg/L	Na mg/L	HCO3 mg/L+	SO4 mg/L	Type	F mg/L	Iron mg/L	Mn mg/L	Ba mg/L
60	Lynx	05/02/01	319	317	7.36	103	14.4	1.9	359.9	21.5	Ca-HCO3	0.11	0.614	0.808	-
14	Wabi	09/01/02	526	168.3	-	42.9	14.5	201.2	614.76	5	Na-HCO3	0.5	0.034	0.011	0.947
79	J. Camp	14/03/01	-	48.3	8.29	11	4.7	185	589.26	0.25	Na-HCO3	0.83	0.249	0.011	1.14
4	K. Valley	29/06/00	1060	67.4	8.45	10.6	9	388	1129.7	2.5	Na-HCO3	0.8	1.18	0.02	1.12
19	Aspen	10/01/02	-	56.9	8.39	11.9	5.9	216	594.14	0.25	Na-HCO3	0.79	0.241	0.004	2.866
24	Tembec West	19/07/03	620	161	8.15	32.9	19.2	188	681	39.6	Na-HCO3	0.99	0.46	0.036	-
2	Highway Gas	18/03/09	465	-	8.01	31.8	17	134	465	53.8	Na-HCO3	0.02	0.01	0.0069	0.047
78	Silver Sands	14/03/01	220	181	8.15	54	11.1	2.7	222.04	18.6	Ca-Mg-HCO3	0.11	0.012	0.001	0.078
53	Beryl Prairie Spring	07/09/00	393	418	6.89	102	40.1	4	475	11.3	Ca-Mg-HCO3	0.2	0.18	0.185	0.172
72	Dokie	07/08/02	-	246.8	7.73	70.8	17	4.34	294.02	6.3	Ca-Mg-HCO3	0.05	0.017	0.186	0.262
35	Mount Lemoray Camp	08/02/95	390	315.8	7.35	95	19	14	360	2.9	Ca-Mg-HCO3	0.05	0.09	0.01	-
63	H. Camp	11/10/00	208	204	7.91	56.8	15.2	1.1	213.5	29.7	Ca-Mg-HCO3	0.1	0.01	0.0007	-
75	Kelly Lake	14/01/02	330	298	8.3	82.8	22.4	11	351.36	15.4	Ca-Mg-HCO3	0.1	0.022	0.003	-
27	Tumbler Ridge	08/10/02	-	205	8.1	59.4	13.8	-	224.48	25.6	Ca-Mg-HCO3	0.07	-	0.0541	0.015
20	Chetwynd FP	18/02/08	319	285	8.11	64.1	30.4	30.3	404	5.89	Ca-Mg-HCO3	0.35	1.24	0.026	1.84
16	Blackfoot Park	14/08/97	384	347	7.6	104	21.2	9	388	49	Ca-Mg-HCO3	0.09	0.069	0.067	-

Table 8 - Continued

No.	Site	Date d/m/y	TDS mg/L	Hardness mg/L	pH ph units	Ca mg/L*	Mg mg/L	Na mg/L	HCO3 mg/L+	SO4 mg/L	Type	F mg/L	Iron mg/L	Mn mg/L	Ba mg/L
52	Upper Halfway School	25/10/93	587.1	354.4	8.2	112.1	18.1	4.6	417	30.5	Ca-Mg-HCO3	0.3	0.03	-	-
13	Chetwynd Well #3	15/01/01	259	182	7.84	35.8	22.6	25.8	343	5	Mg-Ca-HCO3	0.02	0.01	0.021	0.511
77	Spectra Pine River	03/12/02	330	209	7.71	62.4	13	50	307.44	11	Ca-Na-Mg-HCO3	0.09	<0.03	<0.002	0.27
25	Tembec East	21/07/03	549	368	7.77	69.9	47.2	114	621	107	Na-Mg-Ca-HCO3	0.54	0.52	0.655	-
11	Bluehills	17/07/02	261	224	8.17	65.6	14.5	5	213.5	56	Ca-Mg-HCO3-SO4	0.7	0.16	0.034	0.13
73	Kobes	16/07/02	258	215	8.13	60.8	15.3	-	200.08	57	Ca-Mg-HCO3-SO4	0.7	1.57	0.205	0.11
33	Tim Hartnell	23/09/99	480	534	7.46	144	42.3	12.1	520	127	Ca-Mg-HCO3-SO4	0.02	1.39	0.4	-
45	Feye Spring	23/01/91	434	288	8.2	69	28	21.5	231	149	Ca-Mg-HCO3-SO4	0.28	1.2	0.02	0.03
64	Petro Canada J. Camp	02/11/98	275	267	7.4	76	18.7	3	247	53.7	Ca-Mg-HCO3-SO4	0.12	0.005	-	-
77	Spectra Pine River	03/12/02	330	209	7.71	62.4	13	50	307.44	11	Ca-Na-Mg-HCO3	0.09	<0.03	<0.002	0.27
74	Klahanie	16/07/01	960	585	7.68	168	40.2	55.8	342.82	326	Ca-Mg-SO4-HCO3	0.18	0.005	<0.001	0.078
68	Peace View	25/02/03	1180	698	7.22	156	74.9	115	502.64	420	Ca-Mg-Na-SO4-HCO3	0.12	0.215	1.46	0.009
67	South Helmet	02/06/09	763	709	7.36	198	51.9	35.6	190.32	326	Ca-Mg-SO4-Cl-HCO3	0.04	0.03	0.02	0.2
51	Rosco's Pub	05/11/93	3489.8	2399.6	7.5	350.8	370	161	805.2	2148	Mg-Ca-SO4-HCO3	0.1	0.11	-	-
15	Forest Lawn	22/01/02	2020	933	7.8	184	115	311	747.86	892	Na-Mg-Ca-SO4-HCO3	1.3	0.006	0.139	-

Note : All concentrations reported as total except for pH. HCO3 calculated from Total Alkalinity x 1.22. Site numbers where the locations are known are shown in Figure 11. Data from Northern Health (2003) and (2011).

Table 9

Range of concentrations found in 79 water systems tested by Northern Health

Parameter	Units	Number of Samples	Mean	Median	Max.	Min.	Comments
pH	-	112	7.86	7.82	8.9	6.89	
Calcium (total)	mg/L	221	59.95	58.1	350.8	-	Some analyses with low concentrations may be affected by water treatment
Magnesium (total)	mg/L	214	23.5	14.75	370	-	Some analyses with low concentrations may be affected by water treatment
Sodium (total)	mg/L	116	106	25.5	750	1.1	
Alkalinity (total)	mg/L	149	380	288	1280	44.8	
Sulphate (total)	mg/L	68	197	48.6	2148	<1	
Chloride (total)	mg/L	143	13.3	2.7	115	0.003	
Hardness (total)	mg/L	213	246	202	2399	-	some analyses with low concentrations may be affected by water treatment
Total Dissolved Solids	mg/L	132	639	428.5	3849.8	61	
Conductivity	µs/cm	106	999	678	3530	108	
Barium (total)	mg/L	200	0.4	0.1	7.59	<0.02	
Boron (total)	mg/L	130	0.15	0.1	1	<0.1	
Iron (total)	mg/L	197	0.533	0.098	17.5	<0.03	
Manganese (total)	mg/L	148	0.198	0.02	2.12	<0.001	
Fluoride (total)	mg/L	197	0.297	0.119	3	<0.01	

10. CONCLUSIONS

(a) Based on the available information for review, fifty-five unconsolidated and bedrock aquifers have been identified, delineated and classified within the 104, 1:20,000 scale map sheets investigated in this study. Five unconsolidated and one bedrock aquifer have been identified as highly vulnerable to any potential surface sources of contamination.

(b) Of the fifty-five (55) aquifers mapped, thirty-two (32) are unconsolidated (surficial) aquifers and twenty-three (23) are consolidated (sedimentary bedrock). The aquifers range in size from 0.53 km^2 to 3286 km^2.

(c) The majority of surficial aquifers identified are located along the main river valleys. The highest capacity wells are completed in glaciofluvial deposits underlying lacustrine deposits and recent alluvial or fluvial deposits. The highest capacity wells within the project area are located at Tumbler Ridge, Pine Valley, West of Taylor and Pouce Coupe.

(d) Well records indicate that the highest capacity bedrock wells are from the Dunvegan Formation sandstones of the Upper Cretaceous Period.

(e) Significant quantities of groundwater could be developed from buried river channels or buried alluvial fans generally located within the major valleys of the region. The wells found at Tumbler Ridge are a good example where an alluvial fan was deposited by a small creek (Flatbed Creek) in a much larger Valley (Murray River).

(f) Results of groundwater quality analyses obtained during the period 2000 to 2011 by the Northern Health Authority for a number of water supply systems in the region were examined. These illustrate the variable nature of groundwater quality found in the region. These range from the calcium-magnesium bicarbonate and sodium bicarbonate types with low to moderate levels of dissolved minerals (TDS generally ranging from 100 to 500 mg/L) to the more complex and more mineralized sodium bicarbonate, and sodium-calcium-magnesium sulphate-bicarbonate types (TDS ranging from 500 to 2000+ mg/L).

(g) Locally, natural groundwaters in the region may contain elevated concentrations of iron, manganese, barium, boron, sodium and fluoride that exceed the 2010 Guidelines for Canadian Drinking Water Quality (GCDWQ) prepared by the Federal-Provincial-Territorial Committee on Drinking Water.

(h) From a cursory examination of the data, elevated concentrations of barium and fluoride appear associated with soft, sodium-bicarbonate type groundwaters.

(i) Oil and Gas operations in the region require high capacity water supply sources. Fracing operations and camp use create a high water demand. The shallow bedrock aquifers have potential for significant water supply systems. For example the Dunvegan aquifers are widespread and can be quite productive. In selected areas individual wells can average 150 USgpm (818 m^3/d). Then a well field with 10 wells for example could produce 8,180 m^3/d, a significant supply. This type of development scenario is possible for much of the region. These well fields would require sufficient offsets from existing groundwater users to avoid conflict.

11. RECOMMENDATIONS

(a) Since much of the groundwater data used to identify and classify aquifers is based on water well records submitted to local, provincial and federal government agencies for various purposes, measures to improve the quality of information that is recorded and submitted is highly recommended. These measures could include for example both regulatory and non-regulatory programs, involving setting standards and developing training workshops for the recording and submission of water well and testhole records.

(b) Well records should be submitted to a single agency responsible for tracking and data processing to enable timely availability and distribution of the information to assist economic development, health protection and water services planning in the region. All well water records are submitted to the BC Ministry of Environment.

(c) Where local groundwaters, especially from bedrock formations, are known to be relatively soft (low in hardness), they should be checked for concentrations of barium and fluoride as concentrations of these parameters above the guidelines for drinking water quality are a health concern.

(d) A well and aquifer protection plan should be developed at the community level for the highly vulnerable surficial aquifer southwest of Tumbler Ridge and all other highly vulnerable (A) aquifers. Implementation of the Well Protection Toolkit (Province of British Columbia, 2000) is recommended for the management and protection of this important aquifer. These plans would also be a benefit to all communities relying upon aquifers for their water supplies and should be encouraged.

(e) A groundwater exploration program targeting buried river channels and buried alluvial fans should be undertaken. Recent geophysical work by oil and gas companies has shown aero-magnetic surveys to be useful in locating buried river channels, this method could be employed. Another source of useful data for delineating buried river channels is the oil and gas exploration drilling records available from the BC Oil and Gas Commission. Also earth resistivity or seismic surveys can help locate the buried channels. The geophysical work should be followed-up by test well drilling and pumping tests to assess the aquifers. A prime exploration target may be where two buried channels converge. See Figure 11 for interpreted locations of buried channels. There is a significant, untapped groundwater resource in the Peace River Region which could be developed to serve the local population.

(f) A groundwater quality sampling program should be undertaken. Data is sparse for such a large area.

(g) More groundwater monitoring wells should be established for water level and quality monitoring.

(h) Oil and gas wells should be logged through the overburden and shallow bedrock and information shared.

i) A regional hydrogeology study would be beneficial including:

- detailed hydrogeology cross-sections
- groundwater flow modelling
- groundwater age dating

This study could be carried out in one representative watershed within the region. A watershed with good surface water flow information would be best. The Kiskatinaw Valley may be ideal since the University of Northern BC is doing a stream gauging study there.

Respectfully Submitted,

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APPENDIX A

Glossary of Terms

This report refers to a number of key hydrogeological terms and concepts that are defined herein as follows:

AQUIFER – An aquifer is a formation, group of formations or part of a formation containing enough saturated permeable material to produce significant amounts of water to wells and springs. (See also confined aquifers or artesian aquifers and unconfined aquifers.)

BEDROCK – Rock underlying soil and other unconsolidated material.

CONFINED AQUIFER – Confined is synonymous with artesian. A confined aquifer or an artesian aquifer is an aquifer bounded both below and above by beds of considerably lower permeability than that existing in the aquifer itself. The groundwater in a confined aquifer is under pressure that is significantly greater than that existing in the atmosphere.

FLUVIAL DEPOSITS – Deposits related to a river or stream.

FRACTURE – A break or crack in the bedrock.

GLACIO-FLUVIAL DEPOSITS – Deposits related to the joint action of glaciers and melt water streams.

GROUNDWATER – Water in the zone of saturation underground, that is under a pressure equal to or greater than atmospheric pressure.

GROUNDWATER TABLE – That surface below which rock, gravel, sand or other material is saturated. It is the surface of a body of unconfined groundwater at which the pressure is atmospheric.

HYDRAULIC CONDUCTIVITY – Hydraulic conductivity is a measure of the ability of a fluid to flow through a porous medium determined by the size and shape of the pore spaces in the medium and their degree of interconnection and also by the viscosity of the fluid. Hydraulic conductivity can be expressed as the volume of fluid that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow.

HYDRAULIC GRADIENT – The slope of the groundwater level or water table.

HYDRAULIC HEAD – The level to which water rises in a well with reference to a datum such as sea level.

HYDROGEOLOGY – Study of groundwater in its geological context.

IMPERMEABLE – Impervious to flow of fluids.

INFILTRATION RATE – The rate at which water permeates the pores or interstices of the ground.

MARINE DEPOSITS – Mostly silt and clay materials deposited under a marine environment.

METAMORPHIC ROCKS – Any rock derived from pre-existing rocks by mineralogical, chemical, and/or structural changes, essentially in the solid state, in response to marked changes in temperature, pressure, shearing stress, and chemical environment, generally at depth in the earth's crust.

OVERBURDEN – The layer of fragmental and unconsolidated material including loose soil, silt, sand and gravel overlying bedrock, which has been either transported from elsewhere or formed in place.

PERCHED WATER TABLE – A separate continuous body of groundwater lying (perched) above the main water table. Clay beds located within a sedimentary sequence, if of limited aerial extend, may have a shallow perched groundwater body overlying them.

PERMEABILITY – The property of a porous rock, sediment or soil for transmitting a fluid, it is a test of the relative ease of fluid flow in a porous medium.

PERMEABLE – The property of a porous medium to allow the easy passage of a fluid through it.

POROSITY – The volume of openings in a rock, sediment or soil. Porosity can be expressed as the ratio of the volume of openings in the medium to the total volume.

POTENTIAL WELL YIELD – An estimate of well yield generally above the existing yield rate or test rate, but considered possible on the basis of available information, data and present well performance.

PUMPING TEST – A test conducted by pumping a well to determine aquifer or well characteristics.

QUATERNARY – The period of geologic time that follows the Tertiary. The Quaternary includes the Pleistocene and Recent Periods and is part of the Cenozoic Era.

SANDSTONE – A sedimentary rock composed of mostly sand sized particles.

SATURATED ZONE – The subsurface zone in which all voids are ideally filled with water under pressure greater than atmospheric.

SEDIMENTARY ROCKS–Rocks formed from consolidation of loose sediments such as clay, silt, sand, and gravel.

SHALE – A fine-grained sedimentary rock, formed by the consolidation of clay, silt, or mud. It is characterized by finely laminated structure and is sufficiently indurated so that it will not fall apart on wetting.

STATIC WATER LEVEL – The level of water in a well that is not being influenced by groundwater withdrawals. The distance to water in a well is measured with respect to some datum, usually the top of the well casing or ground level.

SURFICIAL DEPOSITS – Deposits overlying bedrock and consisting of soil, silt, sand, gravel and other unconsolidated materials.

TILL – Till consists of a generally unconsolidated, unsorted, unstratified heterogeneous mixture of clay, silt, sand, gravel and boulders of different sizes and shapes. Till is deposited directly by and underneath glacial ice without subsequent reworking by meltwater.

TOPOGRAPHY – The configuration of a surface including its relief and the position of its natural features.

TOTAL DISSOLVED SOLIDS (TDS) – Concentration of total dissolved solids (TDS) in groundwater expressed in milligrams per litre (mg/L), is found by evaporating a measured volume of filtered sample to dryness and weighing this dry solid residue.

TRANSMISSIVITY – Rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient. Transmissivity values can be expressed as square metres per day (m^2/day), or as square metres per second (m^2).

UNCONFINED AQUIFER–An aquifer in which the water table is free to fluctuate under atmospheric pressure.

UNCONSOLIDATED DEPOSITS – Deposits overlying bedrock and consisting of soil, silt, sand, gravel and other material which have either been formed in place or have been transported in from elsewhere.

WATER CENTRIC PLANNING - Planning with a view to water. The underpinning premise is that the resource, land use and community design decisions will be made with an eye towards their potential impact on the watershed.

WATERSHED – A catchment area for water that is bounded by the height of land and drains to a point on a stream or body of water, a watershed can be wholly contained within another watershed.

WATERSHED/LANDSCAPE - BASED APPROACH TO COMMUNITY PLANNING - A working paper produced by the GVRD Technical Advisory Committee with a view to balancing settlement (development) with ecology. This initiative evolved into “water-centric planning”.

WATER TABLE – See Groundwater Table.

WELL SCREEN – A cylindrical filter used to prevent sediment from entering a water well. There are several types of well screens, which can be ordered in various slot widths, selected on the basis of the grain size of the aquifer material where the well screen is to be located. In very fine grained aquifers, a zone of fine gravel or coarse sand may be required to act as a filter between the screen and the aquifer.

WELL YIELD – The volume of water discharged from a well in litres per minute (L/min), litres per second (L/s) or cubic metres per day (m^3/day).

APPENDIX B

Aquifers and BCGS Map sheets

Aquifer No.	Aquifer Class. & Ranking	Aquifer Type	Map Sheet(s)		Aquifer Location and Description	Status (2011)
440	III B - 9	UNC	094 A	001	Hudson Hope	Boundary Revised
441	III B - 10	BED	094 A	001; 011; 012	7 km NE of Hudson Hope	Boundary Revised
442	II A - 12	UNC	094 A	017	3.5 km. West of Taylor	No Change
443	III B - 6	UNC	094 A	017	Taylor	No Change
444	II B - 12	UNC	094 A	025; 026; 027	Fort St. John	Boundary Revised
448	III C - 11	BED	094 A	020; 030	Clayhurst	No Change
451	III C - 12	BED	094 A	025 to 028; 032 to 037; 043 to 047; 055 to 057; 062; 063; 066; 067; 075; 076	North of Fort St. John	Boundary Revised
589	II C - 7	BED	093 P	074; 075	Pine and Murray Rivers	No Change
590	III C - 11	UNC	093 P	075; 076	Groundbirch	No Change
591	III C - 12	BED	093 P	075; 076; 086; 087	Groundbirch - Progress	No Change
592	III C - 11	UNC	093 P	086	Willow Valley/Groundbirch	Boundary Revised
593	III C - 9	BED	093 P	069; 078 to 080; 088 to 090; 097 to 100	Dawson Creek / Arras	Boundary Revised
594	III C - 10	UNC	093 P	076; 077; 087	Groundbirch-Sunset Prairie	Boundary Revised
595	III C - 10	BED	093 P	086; 087; 097	Willow Valley	Boundary Revised
596	III C - 14	UNC	093 P	077; 078; 086; 087	Progress-Sunset Prairie	No Change
597	III C - 10	UNC	093 P	067; 077; 078	Arras - Dawson Creek	No Change
598	III A - 10	UNC	093 P	080	Pouce Coupe	Boundary Revised
621	III B - 10	BED	093 P	030	Kelly Lake southwest of Dawson Creek	No Change
622	III C - 12	BED	093 P	050; 060; 069; 070; 080	South of Pouce Coupe - North of Tate Creek and W. Swan Lake	Boundary Revised
623	II B - 10	UNC	093 P	053; 054	Lone Prairie	New Aquifer
624	II B - 9	UNC	093 P	062	Chetwynd area	Boundary Revised
625	II B - 9	UNC	093 P	062	Chetwynd area	Boundary Revised
626	II C - 8	UNC	093 P	062	Chetwynd area - north of Pine River	No Change
627	III B - 10	BED	093 P	062; 072	Chetwynd area - west of Dokie Siding	Boundary Revised
628	II B - 8	UNC	093 P	062; 072	Chetwynd area - north of Pine River	No Change
629	II B - 8	UNC	093 P	072	Chetwynd area - north of townsite	No Change
630	III C - 8	UNC	093 P	073; 083	Jackfish Lake area - northeast of Chetwynd	Boundary Revised

Aquifer No.	Aquifer Class. & Ranking	Aquifer Type	Map Sheet(s)	Aquifer Location and Description	Status (2011)
631	III C - 10	BED	094 A 009; 010	South of the Peace River	No Change
633	III C - 9	BED	093 P 099; 100 094 A 010	South of the Peace River	Boundary Revised
634	III C - 9	BED	093 P 097; 098 094 A 007; 008	South of the Peace River	Boundary Revised
635	II A - 15	UNC	093 P 015	SW. of Tumbler Ridge	Boundary Revised
636	III C - 8	UNC	094 A 040	East of Fort St. John	No Change
637	III C - 10	UNC	094 A 085; 095	North of Fort St. John	Boundary Revised
638	III C - 8	UNC	094 A 074; 075; 084; 085	North of Fort St. John	No Change
639	III C - 10	BED	094 A 074 to 076; 084; 085; 093 to 096	South of Prespatou	Boundary Revised
640	III A - 11	UNC	093 P 016	East of Tumbler Ridge	No Change
687	II B - 10	UNC	094 A 017	Taylor Flats, S.of the Peace River and SE.of F.St. John	No Change
688	II C - 9	BED	093 P 063	East of Chetwynd and N. of the Pine River	Boundary Revised
689	II C - 9	BED	093 P 053; 054; 063; 064	Lone Prairie	Boundary Revised
690	III B - 9	UNC	094 A 020; 030	Clayhurst Area-extending East to the Alberta Border	No Change
765	II B - 7	BED	093 I 086; 096	South of Tumbler Ridge	New Aquifer
850	II C - 6	UNC	093 P 068	Fellers Heights	New Aquifer
851	II C - 10	UNC	093 P 078 to 080; 087 to 090; 098 to 100	Dawson Creek	New Aquifer
903	II B - 9	UNC	093 P 080; 090	East of Dawson Creek	New Aquifer
908	II B - 9	UNC	094 A 041; 051; 094 B 050; 060	North Bank Halfway River	New Aquifer
910	II B - 11	UNC	094 A 004 094 B 010	East Williston Lake	New Aquifer
917	II B - 9	BED	093 P 074	Near East Pine	New Aquifer
923	II C - 11	UNC	093 P 082; 092; 093	Moberly Lake	New Aquifer
928	II C - 9	BED	094 A 011; 021	Lynx Creek and Peace River	New Aquifer
929	II B - 9	UNC	093 O 069; 070	North Pine River at Nelson Creek	New Aquifer
930	III A - 12	UNC	093 O 059; 069; 070	South Pine River at Nelson Creek	New Aquifer
931	II B - 10	BED	094 A 047; 057; 058; 067; 068; 077; 078; 087; 088; 097; 098; 099	East of Blueberry River, North Fort St. John	New Aquifer
932	II B - 10	BED	094 A 071; 072	City of Wonowon	New Aquifer
933	II B - 13	BED	094 A 019; 020; 028; 029; 037; 040; 048; 049; 058	Cecil Lake, North Peace River	New Aquifer
934	II A - 10	BED	094 B 059	Between Halfway and Cameron Rivers	New Aquifer

Note: Aquifers 622 and 623 were combined to make one aquifer numbered 622. The number 623 was assigned to the new aquifer SE of Chetwynd.

APPENDIX C

THE BRITISH COLUMBIA AQUIFER CLASSIFICATION SYSTEM (BCACS)

The application of the British Columbia Aquifer Classification System on a province-wide basis would provide a comprehensive inventory of aquifers (**Figure 1**). The following sections describe how an aquifer classification is derived and how these classifications are to be interpreted. For further information on using and understanding the BCACS and on interpreting aquifer mapping, the publication entitled *A Guide to using the BC Aquifer Classification Maps for the Protection and Management of Groundwater* by Berardinucci and Ronneseth (2002) is recommended for reading.

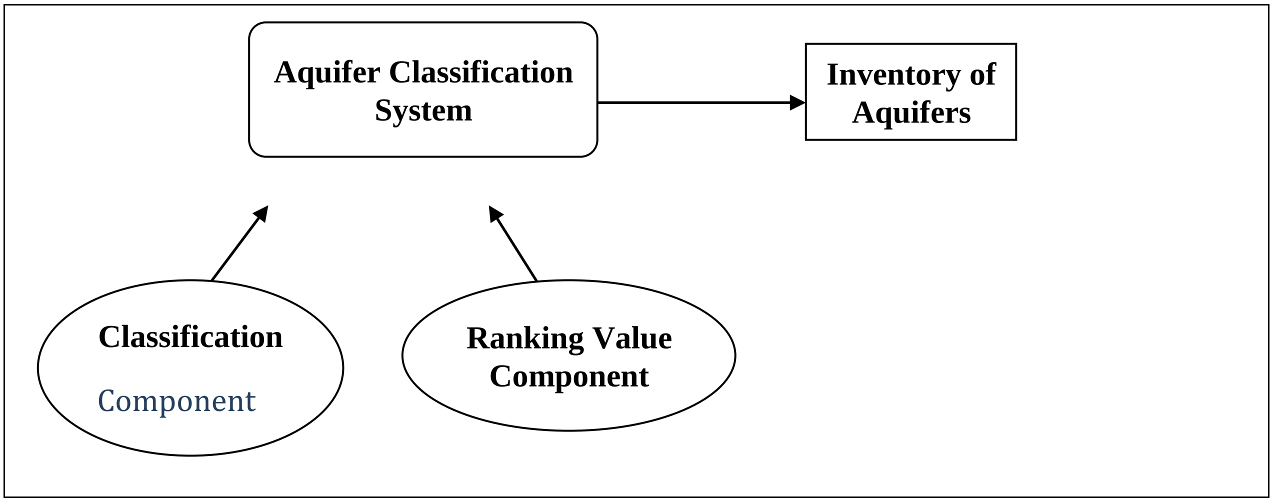

Figure 1. **Structure of the British Columbia Aquifer Classification System**

1. THE CLASSIFICATION SYSTEM

The aquifer classification system has two components: a *classification* component to categorize aquifers based on their current level of development (use), and vulnerability to contamination, and a *ranking value* component to indicate the relative importance of an aquifer.

The classification component categorizes aquifers according to level of development and vulnerability to contamination: *Level of Development* and *Vulnerability* categories are designated. The composite of these two categories is the *Aquifer Class* (**Table 1**). Classification and ranking values are determined for aquifers as a whole, and not for parts of aquifers.

Development category: The level of development of an aquifer is determined by assessing demand verses the aquifer's yield or productivity. A high (**I**), moderate (**II**), or low (**III**) level of development can be designated.

Vulnerability category: The vulnerability of an aquifer to contamination from surface sources is assessed based on: type, thickness and extent of geologic materials overlying the aquifer, depth to water (or top of confined aquifers), and the type of aquifer materials. A high (**A**), moderate (**B**), or low (**C**) vulnerability can be designated.

Aquifer Class: The combination of the three development and three vulnerability categories results in nine aquifer classes (**Table 1**). For example, a class **IA** aquifer would be heavily developed with high vulnerability to contamination, while a **IIIC** would be lightly developed with low vulnerability.

Table 1

Aquifer classification components.

Development Category

I	II	III
Heavy (demand is high relative to productivity)	Moderate (demand is moderate relative to productivity)	Low (demand is low relative to productivity)

Vulnerability Category

A	B	C
High (highly vulnerable to contamination from surface sources)	Moderate (moderately vulnerable to contamination from surface sources)	Low (not very vulnerable to contamination from surface sources)

Aquifer Class

	I		II		III	
A	IA	heavily developed, high vulnerability aquifer	IIA	moderately developed, high vulnerability aquifer	IIIA	lightly developed, high vulnerability aquifer
B	IB	heavily developed, moderate vulnerability aquifer	IIB	moderately developed, moderate vulnerability aquifer	IIIB	lightly developed, moderate vulnerability aquifer
C	IC	heavily developed, low vulnerability aquifer	IIC	moderately developed, low vulnerability aquifer	IIIC	lightly developed, low vulnerability aquifer

2. THE RANKING VALUE COMPONENT

A numerical measure of an aquifer's priority is provided by the aquifer's ranking value. The ranking value is determined by summing the point values for each of the following hydrogeologic and water use criteria: productivity, size, vulnerability, demand, type of use, quality concerns (that have health risk implications), and quantity concerns (**Table 2**). All criteria have arbitrarily been assigned equal weight. Values range from a minimum of “1” to a maximum of “3”, except for quality and quantity concerns which are assigned a minimum of “0” if concerns are not evident. Possible ranking scores range from a low of 5 to a high of 21; the higher the ranking score, the greater the aquifer’s priority.

Table 2. **Aquifer ranking component**

	Point Value			Rationale
Criteria	1	2	3	
Productivity	Low	Moderate	High	Abundance of the resource
Vulnerability	Low	Moderate	High	Potential for water quality degradation
Size	<5 km^2	5 - 25 km^2	>25 km^2	Regionality of the resource
Demand	Low	Moderate	High	Level of reliance on the resource
Type of Use	Non-drinking water	Drinking water	Multiple use/ drinking water	Variability/ diversity of the resource for supply
Quality Concerns	Isolated	Local	Regional	Actual concerns
Quantity Concerns	Isolated	Local	Regional	Actual concerns

The classification system is map-based with aquifers delineated at a scale of 1:20,000 or 1:50,000 (the classification system is only being applied in areas with well location mapping). An inventory database containing the attributes of each aquifer is built as aquifers are identified and classified. The maps and database can be readily incorporated into a geographical information system (GIS).

Much of the information upon which mapping and classification is based is office-derived, using existing and readily available data sources. These include well records (approximately 70,000 available across the province) provided by well drillers, published geologic mapping, and Ministry and consultants reports. Data availability and reliability constrain how technically rigorous the assessments can be (e.g., while transmissivity values provide the basis for assessing aquifer productivity, these values are rarely available; productivity can alternatively be assessed using typical well yields, type of well use, aquifer materials and other simpler, more subjective indicators). The data limitations are important to note as class designations strive for *reasonable assessments* based on the available data, not rigorous determinations. Given the broader management objectives of the system and the operational and data constraints, this approach is appropriate. The classification and ranking value of an aquifer is time dependent and could change with updated information.

3. DELINEATING AQUIFER BOUNDARIES

One of the primary tasks of classification is identification of an aquifer and delineation of its boundaries. As classification is based on existing information, aquifer boundaries range from reasonable assessments (where detailed information is available) to general approximations (scarce information availability). Only those aquifers that have sufficient groundwater development are delineated and classified. In cases where aquifers cannot be fully delineated, especially confined, unconsolidated aquifers and bedrock aquifers, boundaries are defined by the area of groundwater development. Aquifers with areas less than one square kilometre are generally not mapped. Guidelines for determining level of development, vulnerability to contamination and ranking values are detailed in Kreye and Wei (1994).

4. RELATIONSHIP BETWEEN AQUIFER CLASS AND RANKING VALUE

Aquifer class and ranking values are related in that, together, they provide both descriptive and numerical ranking information about the priority of an aquifer for management and protection. According to Kreye and Wei (1994), classification of over 430 aquifers province-wide showed that ranking values generally increase with increasing levels of development and increasing vulnerability. This occurs because factors considered in the classification component (demand, productivity and vulnerability) also appear in the ranking component.

5. INTERPRETING AQUIFER MAPS

The main product in mapping and classifying aquifers is aquifer classification maps. These maps show locations of aquifers, their classification and ranking values. Where insufficient data exists, dashed lines appear on the mapping in order to indicate a lower level of confidence of the aquifer boundaries. Data reliability can be a concern in areas where well records have not been submitted to MELP, they are incomplete, the wells could not be located or where very few wells exist in a geologic formation. These areas may, however, be revisited when additional data are available. Hydrogeological cross sections are valuable in illustrating where an aquifer is relative to another at depth, possible direction of groundwater flow, and why one aquifer may be more vulnerable than another. It is important to note that the aquifer maps are not intended to indicate geology at a site specific level of detail. A greater level of investigation is necessary in establishing site-specific details. Therefore site-specific decisions or determinations should not be made using only aquifer mapping.

6. USES OF THE BC AQUIFER CLASSIFICATION SYSTEM

The B.C. Aquifer Classification System can serve a variety of functions. A primary benefit is the accumulation of an aquifer inventory in the Regional Districts, which is critical for comprehensive groundwater management. It is important to have knowledge of the number of aquifers to be managed and their general geographical, physical and hydrologic characteristics. The classification system can guide in planning of land use as well as monitoring activities such as establishment of a Regional District network of observation wells to monitor groundwater level and ambient water quality in the key aquifers. The system can also provide a method for identifying aquifers that require more detailed assessment, including hydrogeologic mapping, modelling and identification of recharge and discharge areas of aquifers. Operational policies for hydrologic assessment could be developed for individual aquifer classes. For instance, detailed hydrogeologic mapping and groundwater flow modelling may be initiated for heavily developed aquifers (IA, IB, IC) to assist in allocation planning. Water quality surveys, vulnerability mapping and monitoring programs could be initiated for high vulnerability aquifers that have a moderate to heavy level of development (IA, IIA). The information and aquifer maps also provide managers, planners and stakeholders with interpreted groundwater information (not raw data) that will support decision-making in regional resources inventory and planning processes in B.C. (e.g. Commission on Resource and Environment (CORE); Land Resource Management Plans (LRMPs); and Growth Strategy Planning). In addition, the B.C. Aquifer Classification System produces information, which can be a valuable educational tool to promote understanding and awareness of the groundwater resource.

7. AQUIFER CLASSIFICATION MAP, APPLICATIONS AND LIMITATIONS

Aquifer Classification Maps and Worksheets are intended to identify aquifers that may or may not provide groundwater supplies, and identify aquifers that are at risk of contamination. The aquifer classification maps provide land use planners with hydrogeological information that can support the planning process and help to better understand, protect and sustain the groundwater resource. Aquifer maps can be used at the provincial, regional and local planning and management levels. They provide a regional perspective on areas that should be given priority for protection and management of the groundwater resource and they are presently used by both government agencies and industry. The aquifer classification system is, however, subjective and care must be taken when using and interpreting the maps for specific land use planning. For example, the vast majority of wells completed in surficial deposits are completed and developed without well screens. It should be recognized that if most or all wells located within an aquifer were developed with well screens, the wells would be more efficient and likely produce higher yields than those reported thus denoting a higher productivity to the aquifer. As a result, the productivity could change from low to moderate or moderate to high depending on the situation. It should also be kept in mind that although an aquifer may be classified as more vulnerable than another, how much more vulnerable cannot be determined solely from the aquifer maps. There may also be areas within an aquifer classified as moderately vulnerable that are highly vulnerable (i.e. windows of high vulnerability). For this reason a site-specific assessment may be necessary to more accurately determine aquifer vulnerability. It has also been assumed that all wells reviewed are in use and well yields reported equal the amount of groundwater used. This assumption is likely not accurate, and to gain a clearer understanding of aquifer development a site-specific assessment would also be necessary.

APPENDIX D

AQUIFER CLASSIFICATION WORKSHEETS