Ministry of Water, Land and Air Protection

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Aquifer Classification Mapping in the Peace River Region – Final Report

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EXECUTIVE SUMMARY

This report summarizes the results of hydrogeologic work carried out from 2002 to 2004 to identify, delineate and classify developed aquifers in the Peace River Region of British Columbia for the Ministry of Water, Land and Air Protection (MWLAP), Water, Air and Climate Change Branch. 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.

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.

Forty unconsolidated and bedrock aquifers have been identified, delineated and classified within the Peace River Region, to date. Twenty three of the aquifers are unconsolidated and seventeen are consolidated (sedimentary bedrock). Aquifers range in size from 0.53 km^2 to 1635 km^2. All 1:20,000 scale map sheets in the region that can be mapped from existing well records have been mapped. The number of BCGS (1:20,000 scale) mapsheets covered is 79. Most but not all of these mapsheets contained mapable aquifers.

The majority of surficial 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 alluvial or fluvial deposits. The highest capacity wells within the project area are located at the community of Tumbler Ridge. The two main Tumbler Ridge municipal production wells can yield in excess of 300 L/s (4755 Usgpm) each, (Lowen, 1984). Well records (over 300) indicate that the highest capacity bedrock wells are from what appear to be the Dunvegan Formation, Upper Cretaceous Period with yields up to 14.3 L/s or 236 USgpm (Hydrogeological Consultants Ltd, 1991). The Puskwaskau Formation sandstones of the Upper Cretaceous Period also produce higher capacity wells up to 125 USgpm (7.9 L/s).

Results of groundwater quality analyses obtained during the period 2000 to 2003 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).

Locally, natural groundwaters in the region may contain elevated concentrations of iron, manganese, barium, boron, sodium and fluoride that exceed the 2003 Guidelines for Canadian Drinking Water Quality (GCDWQ). 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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1. Background

This report summarizes the results of hydrogeologic work carried out from 2002 to 2004 to identify, delineate and classify developed aquifers in the Peace River Region of British Columbia for the Ministry of Water, Land and Air Protection (MWLAP). 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 MWLAP and the Prairie Farm Rehabilitation Administration (PFRA) of Agriculture and Agri-Food Canada.

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 on file with MWLAP. 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 and project team members: Dennis Lowen, William Hodge, and Alan Kohut wish to acknowledge the cooperation and assistance of several individuals who provided access to reports and information namely:
Kevin Ronneseth, Water Protection Section, Ministry of Water Land and Air Protection and the PFRA Dawson Creek office.

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.

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 79 trim mapsheets (1:20,000 scale) containing sufficient well information for analysis. Mapsheets are listed as follows:

  BCGS Mapsheets with well information:

  093 O – 070

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

  094 A – 001, 007, 008, 009, 010, 011, 012, 013, 017, 018, 019, 020, 023, 025, 026, 027, 028, 029, 030, 034, 035, 036, 037, 038, 039, 040, 044, 045, 046, 047, 048, 054, 055, 056, 057, 064, 065, 066, 074, 075, 076, 084, 085, 086, 095.

4. Study Region and Geologic Setting

The Peace River Region is situated in the northeastern part of British Columbia between the Rocky Mountain Foothills and the Alberta border (Figure 1). 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 on 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° (Figure 1). The area lays within National Topographic System (NTS), 1:250 000 scale map sheets 94 A (Charlie Lake) and 93 P (Dawson Creek). A key plan showing the BCGS, 1:20,000 map sheets in the Peace River Region is shown in Figure 1.

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).

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 2). 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 shown in Figure 3 and discussed further in Section 7.

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.

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.

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
	Smoky	Pushwaskau		Dark marine shale and siltsone		South of Dawson Creek
		Badheart / Marshybank		Fine-grained sandstone Sandstone, carbonaceous shale (McMechan, 1994)	Cowen (1998)	South of Dawson Creek
		Muskiki		Dark marine shale		South of Dawson Creek
		Cardium		Fine-grained, grey sandstone	Cowen (1998)	Inferior water quality south of Dawson Creek (Cowen, 1998)
		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)
		Dunvegan		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 silstone		Unfavourable as an aquifer, poor water quality where fracture porosity exists (Cowen, 1998) Well logs indicate low to moderate yields.

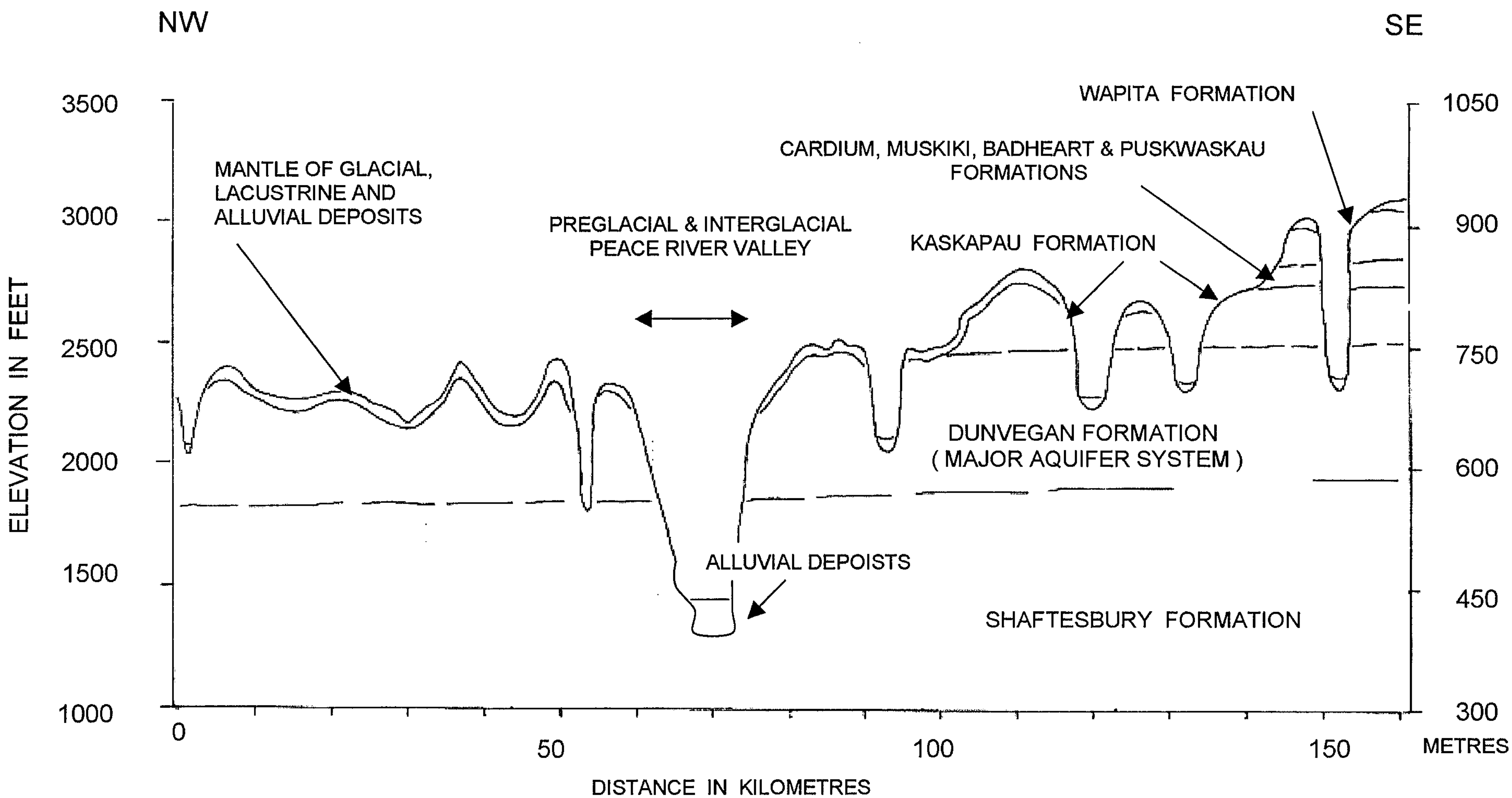

Figure 4 Schematic Cross Section NW-SE.

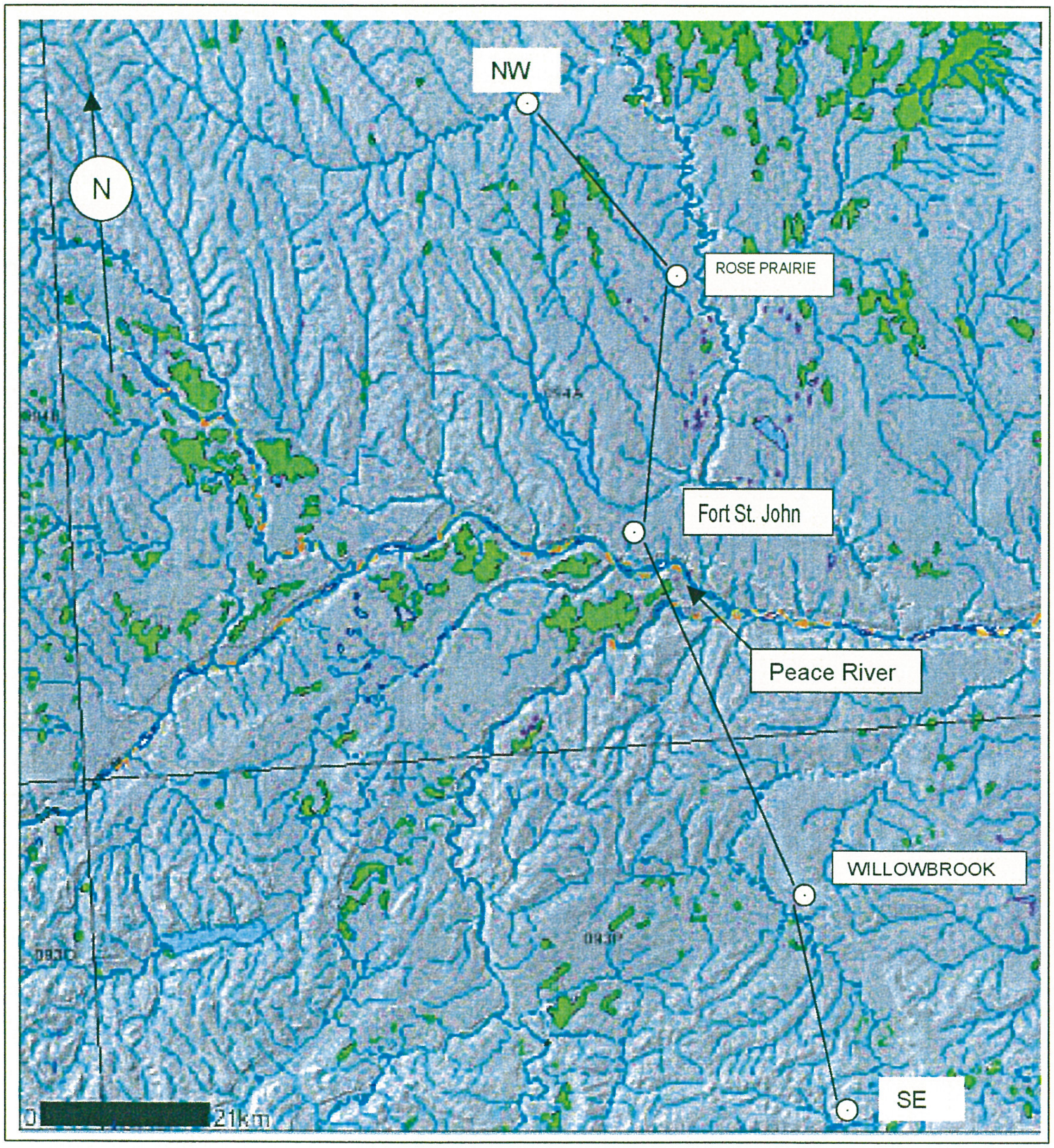

Figure 5. Location of cross section NW-SE showing bedrock formations in Peace River Region. (Base map from MWLAP, 2004)

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).

6. Unconsolidated Deposits and Potential Aquifers

Mathews (1978) and Reimchen (1980) have mapped the distribution of surficial unconsolidated deposits in the Charlie Lake (94A) and Dawson Creek (93P) 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). Ronneseth (1994) has summarized the general succession of unconsolidated deposits found in the region and major Pleistocene events.

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.

Table 2.

Unconsolidated Deposits and Potential Aquifers, Fort St. John Area

Age	Unit (Mathews, 1963)	Descriptions (Mathews, 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	Lacustrine 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		
	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		
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

Catto (1998) indicates that the pre-Late Wisconsian 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 6, 7 and 8 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 8.

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) and Ministry of Environment (1983) 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 3 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 B.

Previous aquifer classification studies in the area have been completed by EBA Engineering Consultants Ltd (2003) and Dave Thompson (2002). These studies identified 17 aquifers, some which have been revised by Lowen Hydrogeology Consulting. All of the 40 aquifers identified are listed in Table 3. Worksheets and maps outlining these aquifers are provided in Appendices C and D respectively (Ministry use only).

Table 3

Aquifer Number	Aquifer Class. and Ranking	Aquifer Type	Aquifer Size (km^2)	Aquifer Location and Description	Level of Confidence (*Aquifer Delineation*)
0440	III C - 8	Unconsolidated	9.0	Hudson Hope	High
0441	III B - 10	Bedrock	10.2	7 km NE of Hudson Hope	Medium
0442	II A - 12	Unconsolidated	1.9	3.5 km. West of Taylor	High
0443	III B - 6	Unconsolidated	11.0	Taylor	Medium
0444	III B - 8	Unconsolidated	1.5	2 Km.West of Fort St. John	Medium
0448	III B -12	Bedrock	90.1	Clayhurst	Medium
0451	III C -12	Bedrock	1635.0	North of Fort St. John	Medium
0589	III B - 8	Bedrock	19.0	Pine and Murray Rivers	Medium
0590	III C -11	Unconsolidated	49.5	Groundbirch	Medium
0591	III B -13	Bedrock	520.0	Groundbirch - Progress	Medium
0592	III C -11	Unconsolidated	56.5	Willow Valley/Groundbirch	Medium
0593	III B -10	Bedrock	114	Dawson Creek / Arras	Medium
0594	III C -10	Unconsolidated	53.0	Groundbirch-Sunset Prairie	Medium
0595	III C -10	Bedrock	67	Willow Valley	Medium
0596	III C -14	Unconsolidated	125.6	Progress-Sunset Prairie	Medium
0597	III C -10	Unconsolidated	40.5	Arras - Dawson Creek	Medium
0598	III A - 9	Unconsolidated	2.5	Pouce Coupe	Medium
0621	III B -10	Bedrock	27.50	Kelly Lake southwest of Dawson Creek	Medium
0622	III C - 10	Bedrock	65.44	South of Pouce Coupe – North of Tate Creek	Low
0623	III C - 13	Bedrock	34.69	South of Pouce Coupe – N. and W. Swan Lake	Low
0624	II C - 8	Unconsolidated	0.86	Chetwynd area	Medium

Table 3 - Continued

Aquifer Number	Aquifer Class. and Ranking	Aquifer Type	Aquifer Size (km^2)	Aquifer Location and Description	Level of Confidence (*Aquifer Delineation*)
0625	II B - 9	Unconsolidated	0.84	Chetwynd area	Medium
0626	II C - 8	Unconsolidated	2.88	Chetwynd area – north of Pine River	Medium
0627	III B - 10	Bedrock	6.45	Chetwynd area – west of Dokie Siding	Medium
0628	II B - 8	Unconsolidated	1.55	Chetwynd area – north of Pine River	Medium
0629	II B - 8	Unconsolidated	0.53	Chetwynd area – north of townsite	Medium
0630	III C - 8	Unconsolidated	7.02	Jackfish Lake area – northeast of Chetwynd	High
0631	III C - 10	Bedrock	43.72	South of the Peace River	Low
0633	III C - 9	Bedrock	47.99	South of the Peace River	Low
0634	III C - 9	Bedrock	51.30	South of the Peace River	Medium
0635	II A - 15	Unconsolidated	1.71	SW. of Tumbler Ridge	High
0636	III C - 8	Unconsolidated	3.90	East of Fort St. John	Low
0637	III B - 11	Unconsolidated	48.54	North of Fort St. John	Low
0638	III C - 8	Unconsolidated	20.35	North of Fort St. John	Low
0639	II C - 10	Bedrock	196.5	South of Prespatou	Low
0640	III A - 11	Unconsolidated	2.55	East of Tumbler Ridge	High
0687	II B - 10	Unconsolidated	1.0	Taylor Flats, S.of the Peace River and SE.of F.St. John	Medium
0688	II C - 9	Bedrock	15.1	East of Chetwynd and N. of the Pine River	Low
0689	II C - 7	Bedrock	1.8	SE.of Chetwynd, S.of Pine River and N.of LonePrairie	Low
0690	III B - 9	Unconsolidated	23.8	Clayhurst Area-extending East to the Alberta Border	Medium

Twenty three of the aquifers are unconsolidated (surficial) aquifers and seventeen are consolidated (sedimentary bedrock). Four aquifers have been identified as highly vulnerable (A) to surface contamination, fifteen aquifers have been identified as moderately vulnerable (B) and twenty-one aquifers have been identified as low with respect to vulnerability (C). Aquifers range in size from 0.53 km^2 to approximately 1635 km^2.

The majority of surficial aquifers within the project area are located along the main river valleys. The highest capacity wells are completed in glaciofluvial deposits underlying lacustrine deposits and alluvial or fluvial deposition. The highest capacity wells within the project area are located at Tumbler Ridge. 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 becomes available. Characteristics of the unconsolidated and bedrock aquifers are summarized in Tables 4 and 5, respectively.

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.

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.

Table 4 - Summary of Aquifer Characteristics, Unconsolidated Aquifers.

Aquifer Number	Aquifer Type	Deposit	Materials	Confining Deposits	Well Depths m. below ground	Well Yields L/s	Water Levels m. below ground	Comments
0440	Surficial	Glaciofluvial	Sand and gravel	Silt and clay	24.4 – 138.7	0.31 – 6.3	21.3 – 39.9	
0442	Surficial	Alluvial Fan	Sand and gravel	Clay	12.2 – 23.5	15.1 (one only)	4.7 – 23.5	
0443	Surficial	Fluvial gravel	gravel	Clay and silty sand	Testholes only	No data	No data	
0444	Surficial	Buried Valley - glaciofluvial	Gravel, sand, silt	Clay and till	12.2 – 38.7	0.13 – 0.57	9.1 – 17.4	
0590	Surficial	Glaciofluvial	Sand, gravel, silt	Clay	22 – 66.7	0.25 – 3.8	2.4 – 30.5	
0592	Surficial	Glaciofluvial	Sand, gravel, silt	Clay	8.5 – 53.3	0.31 – 12.2	0 – 16.8	
0594	Surficial	Buried Channel	Sand and gravel	Clay	68.6 - 207	0.25 – 1.3	12.2 – 72.8	
0596	Surficial	Glaciofluvial	Sand, gravel, silt	Clay	7.3 – 65.5	0.35 – 1.3	0.30 - 36	
0597	Surficial	Buried Channel	Coarse sand and gravel	Clay	98.7 - 140	1.13 – 5.5	4.6 – 22.9	
0598	Surficial	Fluvial	Sand gravel and silt	Silt	3.6 – 45.1	0.63 (one only)	0.61 – 3.0	
0624	Surficial	Alluvial fan and glaciofluvial intermixed	Gravel and some sand	Clay, silty and sandy clay, till	12.1- 115.8	0.23 - 2.3	3.6 – 30.5	May be in hydraulic continuity with Wildmore Creek
0625	Surficial	Alluvial fan and glaciofluvial intermixed	Gravel	Clay and till	7.3 – 18.3	0.45 – 3.0	3.0 – 12.2	May be in hydraulic continuity with Bissett Creek

Table 4 - Continued - Summary of Aquifer Characteristics, Unconsolidated Aquifers.

Aquifer Number	Aquifer Type	Deposit	Materials	Confining Deposits	Well Depths m. below ground	Well Yields L/s	Water Levels m. below ground	Comments
0626	Surficial	Glaciofluvial	Sand and gravel?	Sandy silt, clay and till	9.4 – 78.6	0.07 – 4.5	Flowing – 13.1	May be in hydraulic continuity with Windrom Creek, gas reported on one well
0628	Surficial	Alluvial fan	Sand and gravel	Clay and sandy clay	3.7 – 50.3	2.3	1.5 –6.1	May be in hydraulic continuity with Windrom Creek
0629	Surficial Type 1	Alluvial fan	Gravel, sand	Clay	4.3 – 9.1	No data	0.6 – 7.9	May be in hydraulic continuity with Widmark Creek
0630	Surficial Type 3	Glaciofluvial	Sand and gravel	Silt and clay	71.9 – 149.4	0.04 – 2.65	18.3 – 62.5	Buried valley, water quality reported good
0635	Surficial Type 3	Alluvial fan	Gravel	Sand and gravel and till	9.1 – 64.3	3.3 – 313.0	2.7 – 23.7	Transmissivities range from 8.7 x 10^{-3} to 8.3 x 10^{-2} m^2/s, likely recharged from Flatbed Creek
0636	Surficial Type 2	Glaciolacustrine	Sand and gravel	Clay and silt	3.4 – 64.0	0.37 – 3.2	Flowing – 12.1	High soda reported
0637	Surficial	Glacial	Till with sand and gravel	Stony silty clay and silt	6.4 – 65.2	0.12 – 1.9	5.5 – 45.7	High soda reported
0638	Surficial	Glacial	Till with sand and gravel	Stony silty clay and silt	2.1 – 61.0	0.23 – 0.76	0.3 – 44.8	High soda reported
0640	Surficial	Glaciofluvial	Sand and gravel	Sand, gravel, silt, clay	9.1 – 67.1	1.6 – 11.9	6.7 - 24	Perched aquifer
0687	Surficial	Alluvial Fan	Sand and gravel	Clay and till	8.5 – 26.5	0.31 – 1.8	4.6 - 10	
0690	Surficial	Fluvial	Sand and gravel	Clay, silt and till	12.2 - 124	0.38 – 1.3	6.1 – 33.5	

Table 5.

Summary of Aquifer Characteristics. Bedrock Aquifers.

Aquifer Number	Aquifer Type	Formation	Rock Types	Well Depths m. below ground	Well Yields L/s	Water Levels m. below ground	Comments
0441	Bedrock	Gates Sandstone	Layered sandstone and shale	7.9 – 91.4	0.05 – 1.3	4.6 – 45.1	
0448	Bedrock	Wapiti	Sandstone, shale and conglomerate	32.6 - 124	0.25 – 0.95	18.3 – 42.7	
0451	Bedrock	Dunvegan	Shale and sandstone	3.9 - 262	0.01 – 6.3	0.61 - 116	Large Bedrock Aquifer *System*
0589	Bedrock	Dunvegan	Shale and sandstone	33.5 – 103.6	0.03 – 0.50	9.1 (one only)	
0591	Bedrock	Kaskapau	Shale and sandstone	12.2 - 183	0.02 – 3.15	0 - 46	
0593	Bedrock	Kaskapau	Shale and sandstone	12.2 -106.7	0.09 – 0.57	6.1 – 30.5	
0595	Bedrock	Dunvegan	Shale and sandstone	24.3 - 122	0.06 – 1.45	8.2 - 26	
0621	Bedrock	Wapiti	Layered sandstone, shale	17.1- 48.8	0.76 - 2.2	1.8 – 8.8	Recharge from direct precip. and Kelly Lake, good water quality
0622	Bedrock	Dowling, Thistle and Hanson Members of Puskwaskau Formation	Layered sandstone, shale	41.1 – 140.3	0.23 – 2.65	11.9 – 85.3	

Table 5. - Continued

Summary of Aquifer Characteristics, Bedrock Aquifers.

Aquifer Number	Aquifer Type	Formation	Rock Types	Well Depths m. below ground	Well Yields L/s	Water Levels m. below ground	Comments
0622	Bedrock	Dowling, Thistle and Hanson Members of Puskwaskau Formation	Layered sandstone, shale	41.1 – 140.3	0.23 – 2.65	11.9 – 85.3	
0623	Bedrock	Dowling, Thistle and Hanson Members of Puskwaskau Formation	Sandstone, sandstone and shale	31.7 – 118.9	0.07 – 7.6	Flowing – 12.2	TDS 3684 mg/L, hardness 2000+ mg/L, alkalinity up to 1020 mg/L
0627	Bedrock	Cruiser	Black shale and sandstone	9.1 – 121.9	0.15 – 5.3	Flowing – 18.3	
0631	Bedrock	Dunvegan	Sandstone and shale	27.4 – 106.7	0.22 – 1.9	One level only (Flowing)	
0633	Bedrock	Dunvegan	Shale and sandstone	18.9 – 121.9	0.03 – 2.27	13.1 – 79.2	
0634	Bedrock	Dunvegan	Shale with sandstone layering	16.9 – 66.4	0.38 – 1.5	6.7 - 30.5	
0639	Bedrock	Dunvegan	Sandstone and shale	30.5 – 152.4	0.26 – 11.4	1.8 – 61.9	
0688	Bedrock	Dunvegan	Shale and sandstone	29 – 91.4	3.6 – 30.5	0.06 – 1.26	
0689	Bedrock	Dunvegan	Shale and sandstone	19.2 – 85.3	6.1 – 30.5	0.25 – 0.63	

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.

"Recharge" has generally been described on the worksheets as:
Direct infiltration of precipitation (rain or snow) at ground surface.

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 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 is 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 54 groundwater quality analyses provided by the Northern Health Authority and covering approximately 30 water supply systems in the region.

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.

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 Ft. St. John	Bedrock	2000 - 6600	Very hard to extremely hard 1000 - 2500	Calcium-magnesium bicarbonate Calcium-magnesium sulphate Sodium bicarbate	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 17-20North 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)

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 sulfate 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.

Quality Concerns

Locally, natural groundwaters in the region may contain elevated concentrations of a number of constituents that exceed the 2003 Guidelines for Canadian Drinking Water Quality (GCDWQ) prepared by the Federal-Provincial-Territorial Committee on Drinking Water. In addition to concentrations of iron and manganese, data reported below by Cui and Wei (2000) for several hundred samples from the provincial Water Quality Check Program (WQCP), which operated between 1983 and 1997, indicates that the following parameters may be elevated locally, in the region.

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	-	no guideline
Sodium	> 200	10 to 100%	< or = 200 mg/L Aesthetic objective only
Fluoride	> 1.5	1 to 20%	1.5

Table 7 summarizes results of some representative groundwater quality analyses obtained during the period 2000 to 2003 by the Northern Health Authority for a number of water supply systems in the region. These illustrate the variable nature of groundwater quality found in the region ranging 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). From a cursory examination of the data, elevated concentrations of barium and fluoride appear associated with soft, sodium bicarbonate type groundwaters. 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 7 - Summary of Representative Groundwater Quality Analyses from Water Systems, 2000 to 2003.

Site	Date	TDS mg/L	Hardness mg/L	Ca mg/L*	Mg mg/L	Na mg/L	HCO mg/L+	SO4 mg/L	Type	F mg/L	Iron mg/L	Mn mg/L	Ba mg/L
Encana	16/09/02	467	2.26	0.82	0.10	191.00	403.00	70.00	Na-HCO3	0.07	0.120	-	-
Aspen	10/01/02	-	56.90	11.90	5.90	216.00	594.14	0.25	Na-HCO3	0.79	0.241	0.0040	2.866
Shrum	11/07/01	110	99.00	29.10	6.30	0.50	98.40	13.60	Ca-Mg-HCO3	0.05	<0.030	<0.0050	<0.030
Beryl Prairie Spring	07/09/02	393	418.00	102.00	40.10	4.00	475.00	11.30	Ca-Mg-HCO3	0.20	0.180	0.1850	0.172
Dokia	07/08/02	-	246.80	70.80	17.00	4.34	294.02	6.30	Ca-Mg-HCO3	0.05	0.017	0.1860	0.262
Duke BH	17/07/02	261	224.00	65.60	14.50	5.00	213.50	56.00	Ca-Mg-HCO3-SO4	0.70	0.160	0.0340	0.130
Kobes	16/07/02	258	215.00	60.80	15.30	7.00	200.08	57.00	Ca-Mg-HCO3-SO4	0.70	1.570	0.2050	0.110
Duke	03/12/02	330	209.00	62.40	13.00	50.00	307.44	11.00	Ca-Na-HCO3	0.09	<0.030	<0.0020	0.270
Duke Willow	16/10/00	383	79.40	14.90	10.30	-	-	-	-	-	0.240	-	1.770
Forest Lawn	22/01/02	2020	933.00	184.00	115.00	311.00	747.86	892.00	Na-Mg-Ca-SO4-HCO3	1.30	0.006	0.1390	-
H. Camp	11/10/00	208	204.00	56.80	15.20	1.10	213.50	29.70	Ca-Mg-HCO3	0.10	0.010	0.0007	-
J. Camp	14/03/01	-	48.30	11.00	4.70	185.00	589.26	0.25	Na-HCO3	0.83	0.249	0.0110	1.140
Kelly Lake	14/01/02	330	298.00	82.80	22.40	11.00	351.36	15.40	Ca-Mg-HCO3	0.10	0.022	0.0030	-
K. Valley	29/06/00	1060	67.40	10.60	9.00	388.00	1129.72	2.50	Na-HCO3	0.80	1.180	0.0200	1.120
Klahanie	16/07/01	960	585.00	168.00	40.20	55.80	342.82	326.00	Ca-Mg-SO4-HCO3	0.18	0.005	<0.0010	0.078
Lynx	05/02/01	319	317.00	103.00	14.40	1.90	359.90	21.50	Ca-HCO3	0.11	0.614	0.8080	-
Mile 292	05/03/02	817	585.00	27.90	11.10	203.00	666.12	0.05	Na-HCO3	1.30	0.780	0.0150	0.550
Peace View	25/02/03	1180	698.00	156.00	74.90	115.00	502.64	420.00	Ca-Mg-Na-SO4-HCO3	0.12	0.215	1.4600	0.009
Tumbler Ridge	08/10/02	-	205.00	59.40	13.80	-	224.48	25.60	Ca-Mg-HCO3	0.07	-	0.0541	0.015
Wabi	09/01/02	526	168.30	42.90	14.50	201.20	614.76	5.00	Na-HCO3	0.50	0.034	0.0110	0.947

* all concentrations reported as total   + HCO3 calculated from Total Alkalinity x 1.22

10. Conclusions

(a) Based on the available information for review, forty surficial and bedrock aquifers have been identified, delineated and classified within the 79, 1:20,000 scale map sheets investigated in this study. Five surficial aquifers have been identified as highly vulnerable to any potential surface sources of contamination.

(b) Of the forty aquifers mapped, 23 are unconsolidated (surficial) aquifers and 17 are consolidated (sedimentary bedrock). The aquifers range in size from 0.53 km^2 to 1635 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.

(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 2003 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 2003 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.

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. Recent Provincial Legislation mandates that all well records be submitted to the Province.

(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 3 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.

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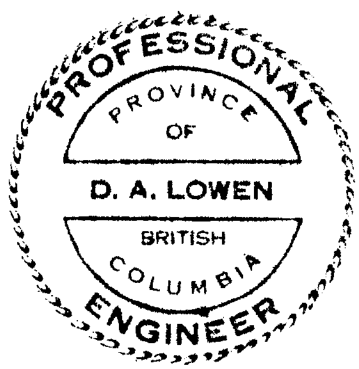
Respectfully Submitted,

LOWEN HYDROGEOLOGY CONSULTING



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DAL/sg/hmr

FIGURES

Aquifer Classification Mapping Study Area

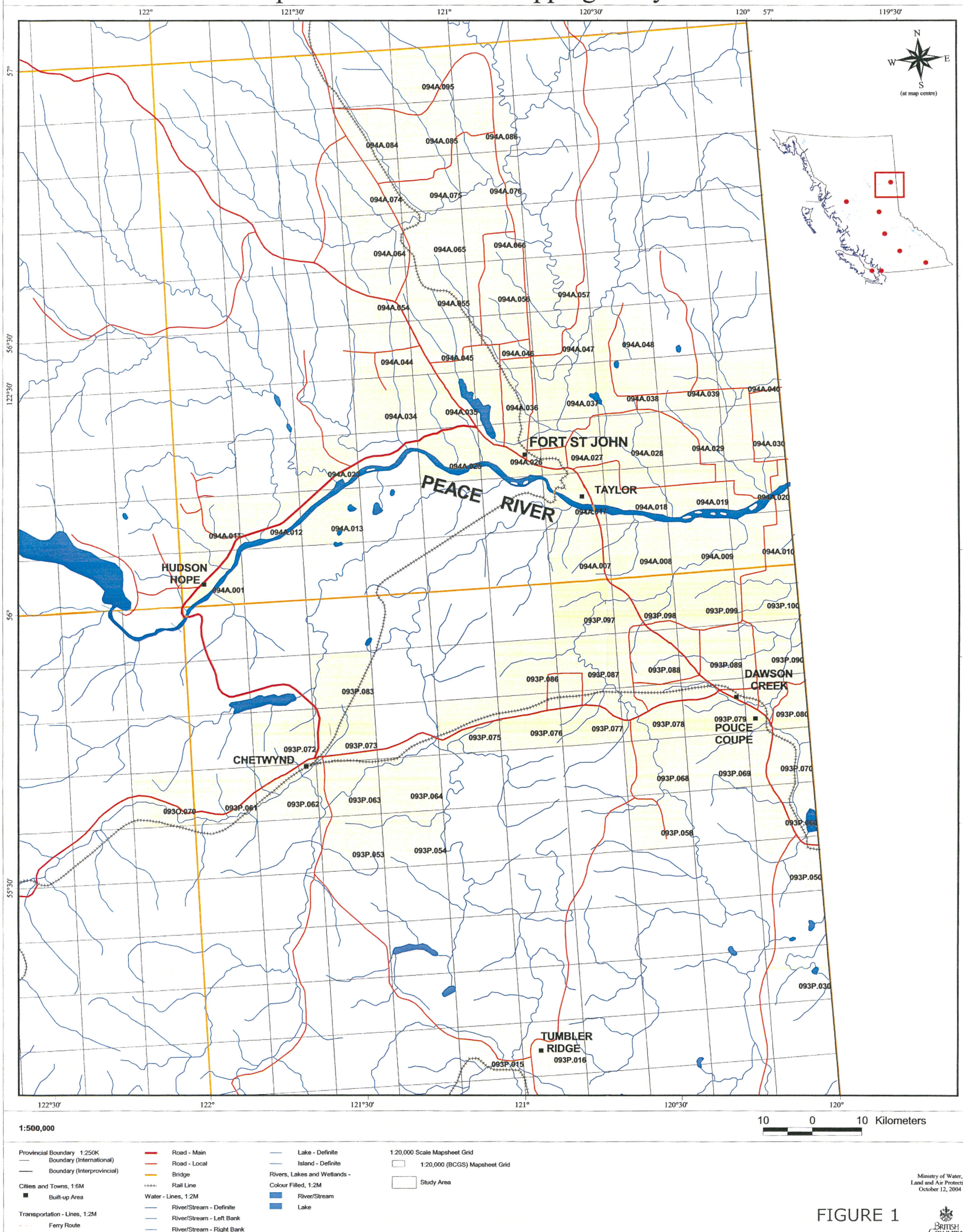
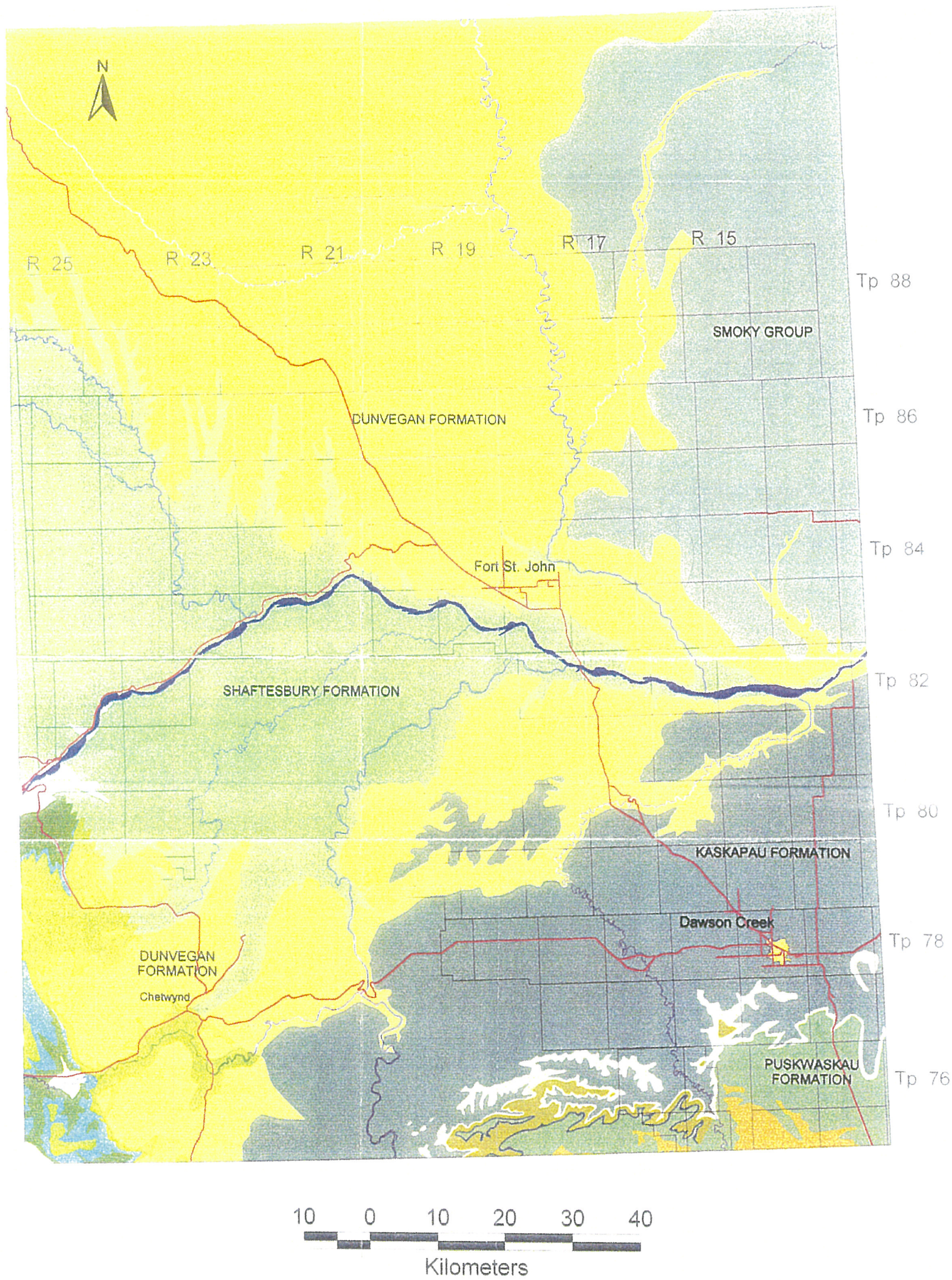


FIGURE 1

B.C. PEACE REGION GROUNDWATER INITIATIVE
BEDROCK GEOLOGY



LEGEND

WAPITI FORMATION *	DUNVEGAN FORMATION *
SMOKY GROUP	SHAFTESBURY FORMATION
PUSKWASKAU FORMATION	CRUISER FORMATION
BADHEART FORMATION *	GOODRICH FORMATION
MUSKIKI FORMATION	HASLER FORMATION
CARDIUM FORMATION *	DISTURBED BELT
KASKAPAU FORMATION *	* Potential Aquifer

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

Lowen Hydrogeology Consulting - File:04-016

Figure 2

B.C. Peace River Region
Buried Valleys

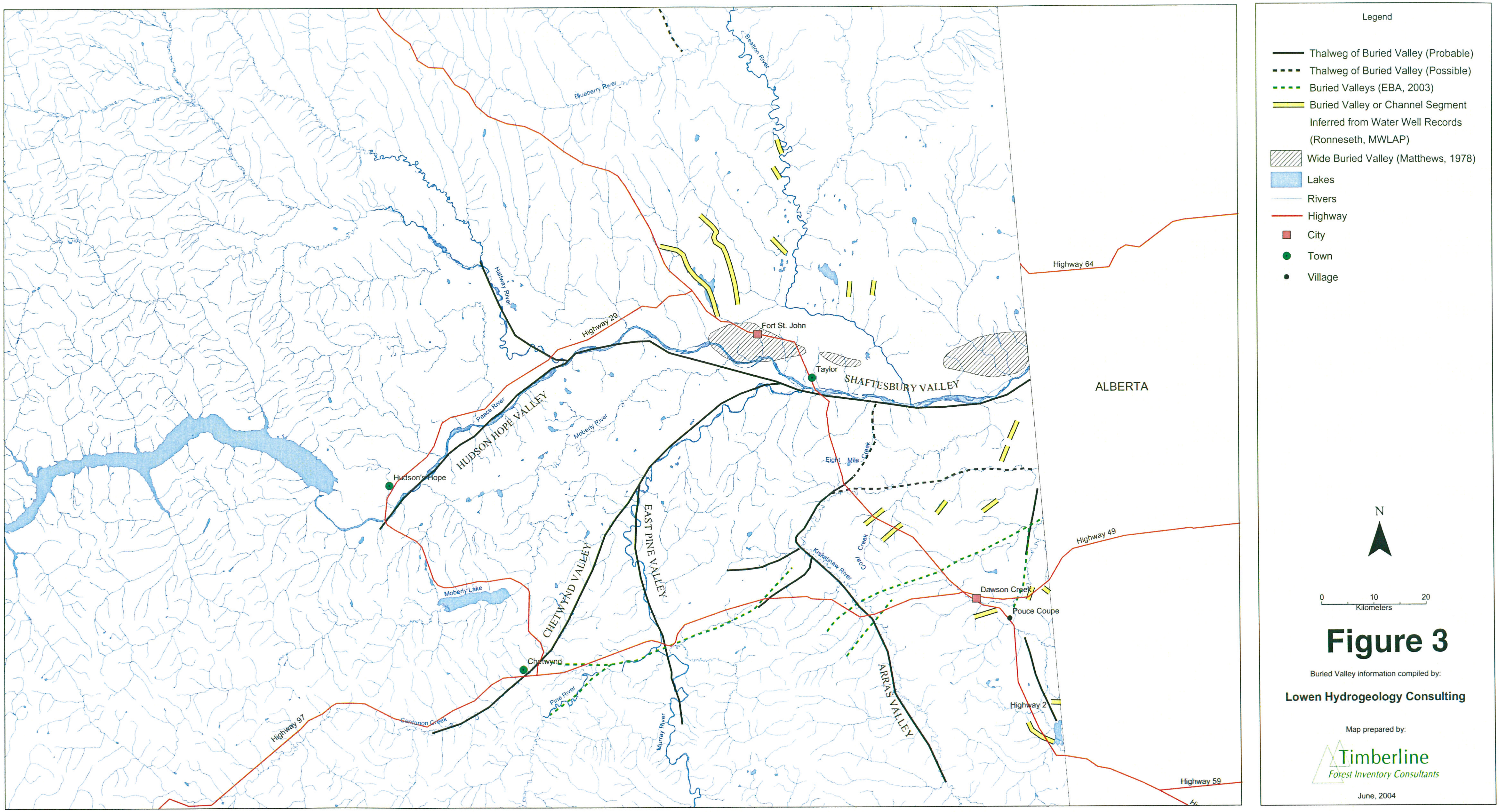


Figure 3

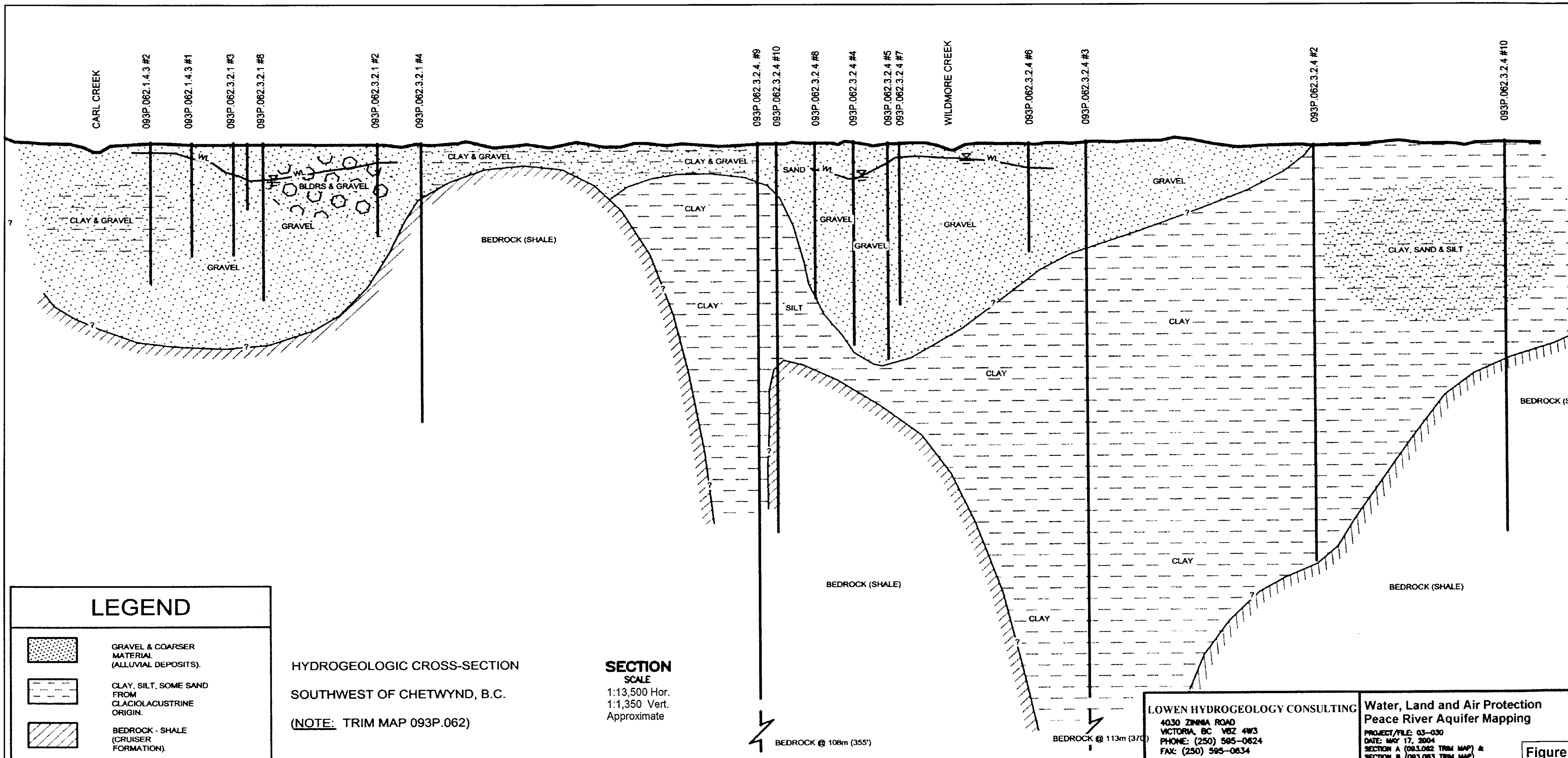
Buried Valley information compiled by:

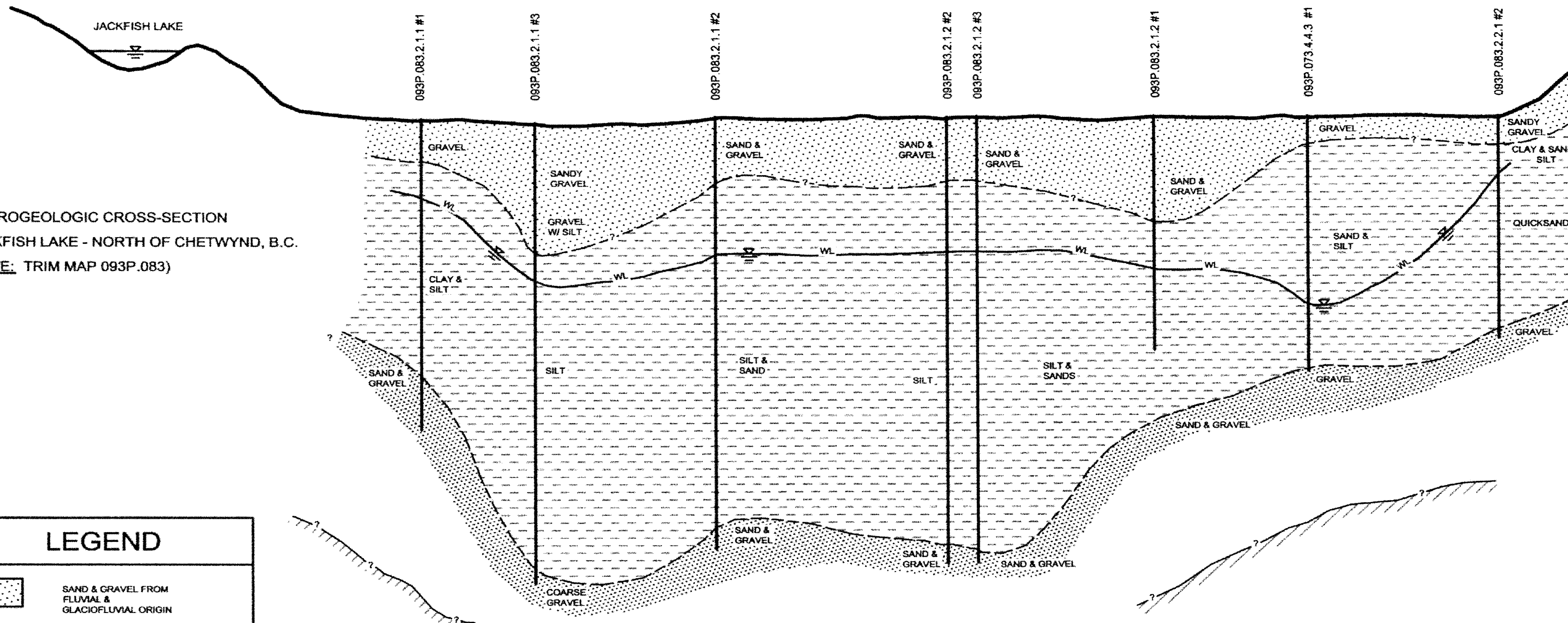
Lowen Hydrogeology Consulting

Map prepared by:

Timberline
Forest Inventory Consultants

June, 2004


CARL CREEK
093P.062.1.4.3 #2
093P.062.1.4.3 #1
093P.062.3.2.1 #3
093P.062.3.2.1 #8
093P.062.3.2.1 #2
093P.062.3.2.1 #4
093P.062.3.2.4. #9
093P.062.3.2.4 #10
093P.062.3.2.4 #8
093P.062.3.2.4 #4
093P.062.3.2.4 #5
093P.062.3.2.4 #7
WILDMORE CREEK
093P.062.3.2.4 #6
093P.062.3.2.4 #3
093P.062.3.2.4 #2
093P.062.3.2.4 #10
WL
CLAY & GRAVEL
BLDRS & GRAVEL
GRAVEL
BEDROCK (SHALE)
CLAY
SAND
SILT
CLAY, SAND & SILT
BEDROCK @ 108m (355')
BEDROCK @ 113m (370')
LEGEND
GRAVEL & COARSER MATERIAL (ALLUVIAL DEPOSITS).
CLAY, SILT, SOME SAND FROM GLACIOLACUSTRINE ORIGIN.
BEDROCK - SHALE (CRUISER FORMATION).
HYDROGEOLOGIC CROSS-SECTION
SOUTHWEST OF CHETWYND, B.C.
(NOTE: TRIM MAP 093P.062)
SECTION
SCALE
1:13,500 Hor.
1:1,350 Vert.
Approximate
LOWEN HYDROGEOLOGY CONSULTING
4030 ZINNIA ROAD
VICTORIA, BC V8Z 4W3
PHONE: (250) 595-0624
FAX: (250) 595-0634
Water, Land and Air Protection
Peace River Aquifer Mapping
PROJECT/FILE: 03-030
DATE: MAY 17, 2004
SECTION A (093.062 TRIM MAP) &
SECTION B (093.083 TRIM MAP)
Figure 6



HYDROGEOLOGIC CROSS-SECTION
JACKFISH LAKE - NORTH OF CHETWYND, B.C.
(NOTE: TRIM MAP 093P.083)

LEGEND

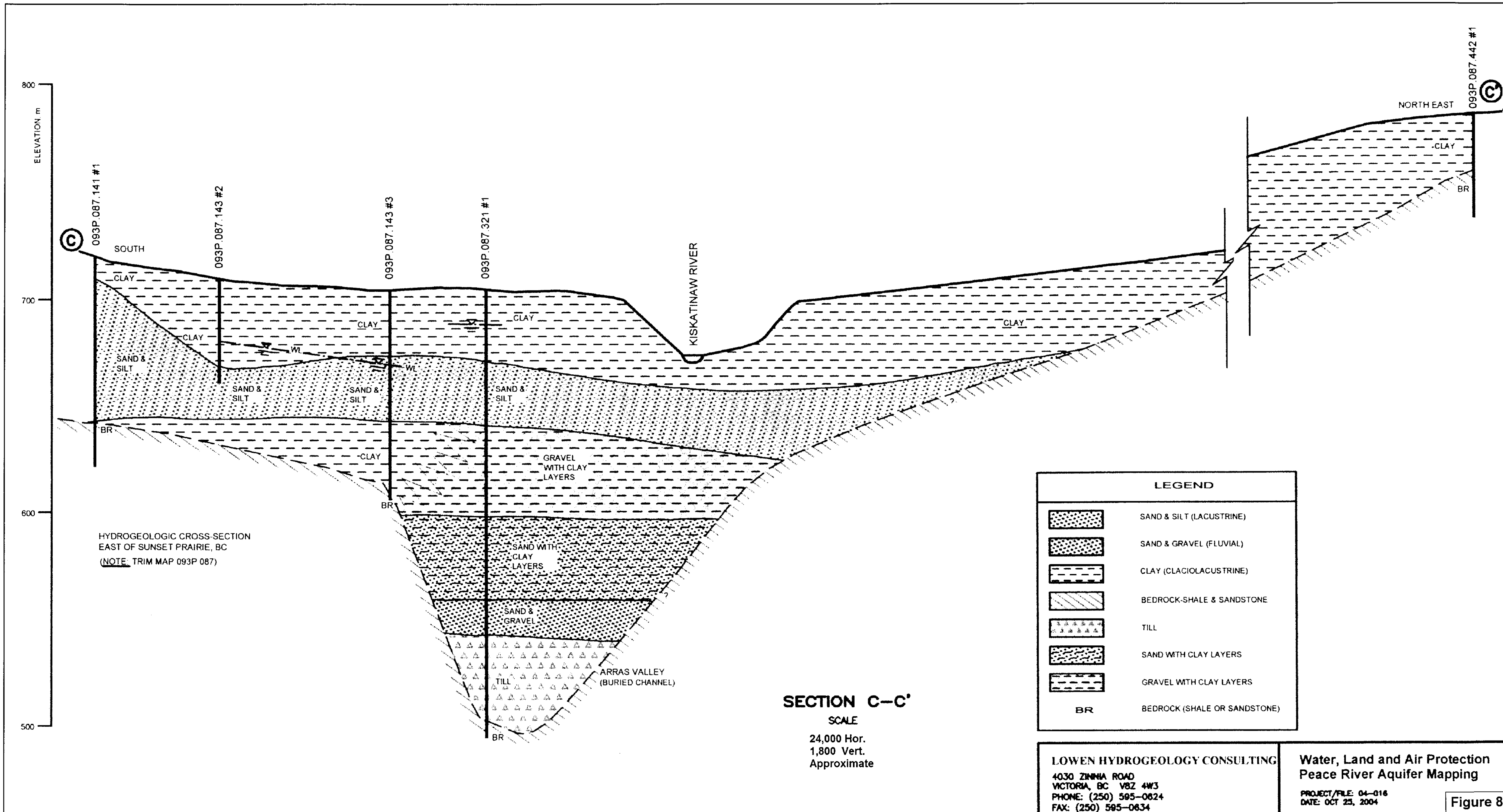
- SAND & GRAVEL FROM FLUVIAL & GLACIOFLUVIAL ORIGIN
- CLAY, SILT, SOME SAND FROM GLACIOLACUSTRINE ORIGIN.
- SAND & GRAVEL FROM GLACIOFLUVIAL ORIGIN
- BEDROCK - (DEPTH UNKNOWN).

SECTION
SCALE
1:12,500 Hor.
1:1,250 Vert.

LOWEN HYDROGEOLOGY CONSULTING
4030 ZINNIA ROAD
VICTORIA, BC V8Z 4W3
PHONE: (250) 595-0624
FAX: (250) 595-0634

Water, Land and Air Protection
Peace River Aquifer Mapping
PROJECT/FILE: 03-030
DATE: MAY 17, 2004
SECTION A (093.062 TRIM MAP) & SECTION B (093.083 TRIM MAP)

Figure 7



800
700
600
500
ELEVATION m
093P.087.141 #1
093P.087.143 #2
093P.087.143 #3
093P.087.321 #1
093P.087.442 #1
C
C'
SOUTH
NORTH EAST
KISKATINAW RIVER
CLAY
SAND & SILT
WL
BR
GRAVEL WITH CLAY LAYERS
SAND WITH CLAY LAYERS
SAND & GRAVEL
TILL
ARRAS VALLEY (BURIED CHANNEL)
HYDROGEOLOGIC CROSS-SECTION
EAST OF SUNSET PRAIRIE, BC
(NOTE: TRIM MAP 093P 087)
SECTION C–C'
SCALE
24,000 Hor.
1,800 Vert.
Approximate
LEGEND
SAND & SILT (LACUSTRINE)
SAND & GRAVEL (FLUVIAL)
CLAY (CLACIOLACUSTRINE)
BEDROCK-SHALE & SANDSTONE
TILL
SAND WITH CLAY LAYERS
GRAVEL WITH CLAY LAYERS
BR BEDROCK (SHALE OR SANDSTONE)
LOWEN HYDROGEOLOGY CONSULTING
4030 ZINNIA ROAD
VICTORIA, BC V8Z 4W3
PHONE: (250) 595-0624
FAX: (250) 595-0634
Water, Land and Air Protection
Peace River Aquifer Mapping
PROJECT/FILE: 04-016
DATE: OCT 25, 2004
Figure 8

APPENDIX A

Glossary of Terms

Appendix A

Glossary of Terms:

Alluvial deposits - Any sediment, including clay, silt, sand, gravel or similar unconsolidated material deposited in a sorted or semi-sorted condition by a watercourse.

Alluvial fans - A fan-shaped accumulation of alluvium deposited at the mouth of a ravine or at the juncture of a tributary stream with the main stream.

Aquifer - An aquifer is a geologic 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 aquifer and unconfined aquifer.)

Aquifer Classification System - The system classifies aquifers on the basis of their level of development and vulnerability to contamination. It is map-based and provides a ranking value for aquifers using hydrogeologic and water use criteria.

Aquifer vulnerability - A measure of how vulnerable an aquifer is to contamination.

Artesian well - A well obtaining its water from an artesian or confined aquifer in which the water level in the well rises above the top of the aquifer. The water level in a flowing artesian well rises above the land surface.

Bedrock - Rock underlying soil and other unconsolidated material.

Colluvial deposits - Weathered, unconsolidated materials transported and deposited by gravity.

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.

Contamination - Impairment of natural water quality by chemical or bacterial pollution as a result of human activities. The degree of contamination allowed before an actual hazard to public health is created will depend upon the intended end use, or uses of the water.

Drawdown - The variation in the water level in a well prior to commencement of pumping compared to the water level in the well while pumping. In flowing wells drawdown can be expressed as the lowering of the pressure level due to the discharge of well water.

Drift (glacial) - Glacial drift includes all rock material in transport by glacier ice, the deposits made by glacier ice and all materials mainly of glacial origin deposited in the sea or in glacial melt water bodies including materials rafted in by ice bergs or transported indirectly in the water itself. Glacial drift therefore includes till, rock fragments and stratified drift.

Drilled well - A well that is constructed with a drilling rig, such as an air rotary or cabletool drilling rig.

Dug well - A well that is dug by hand or excavated by backhoe. Dug wells are usually shallow.

Floodplain - The flat land adjacent to a river, formed by deposition of fluvial materials.

Flowing artesian well - A well where the water level is above the ground surface.

Fluvial deposits - Deposits related to a river or stream.

Fracture or fractured - A break or crack in the bedrock.

Geometric mean – A mathematical measure of central tendency. It is the *n*th root, usually the positive *n*th root, of a product of *n* factors.

Glacial drift - See Drift (Glacial)

Glaciofluvial deposits - Deposits related to the joint action of glaciers and meltwater streams.

Glaciolacustrine deposits – glacial ice contact lacustrine sediments. Often mixed with ice-contact glaciofluvial sediments (gravels and tills).

Groundwater - Water in the zone of saturation, 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 gradient - The slope of the groundwater level or water table.

Hydrogeology - Study of groundwater in its geological context.

Impermeable - Impervious to flow of fluids.

Kettle - A closed depression made in drift by a mass of underlying ice melting.

Lacustrine deposits - Sediments laid down in a lake. Includes gravelly deposits at the margin and clay in deeper water. Sediments commonly show seasonal banding or varve clays.

Lithology - All the physical properties, the visible characteristics of mineral composition, structure, grain size etc., which give individuality to a rock.

Median - Being in the middle or in an intermediate position.

Meltwater Channel - Results from erosion by streams draining from and alongside glaciers. Typically steep-sided, flat floored and mostly underlain by outwash gravels.

Moraine - An accumulation of unsorted-unstratified glacial drift mainly till, deposited by glacial ice. Drift deposited in the flanks of a valley glacier form a lateral moraine. Glacial deposits that have accumulated at the front of a glacier form a terminal moraine. Deposits of drift that have been dragged along beneath the ice form ground moraine.

Observation well - A well constructed for the objective of undertaking observations such as water levels, pressure readings and groundwater quality.

Outwash deposits - Stratified drift deposited by meltwater streams flowing away from melting ice.

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.

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.

Pleistocene - The period following the Pliocene during which an ice sheet covered the greater part of North America. Named by Lyell in 1839.

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 interference - The condition occurring when a pumping well lowers the water level in a neighbouring well.

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.

Recharge area (groundwater) - An area where water infiltrates into the ground and joins the zone of saturation. In the recharge area, there is a downward component of hydraulic head.

Specific capacity - The rate of discharge of a water well per unit of drawdown. Specific capacity can be expressed as L/s/m of drawdown.

Specific conductance (groundwater)- The ability of a water sample to conduct an electric current. Specific conductance is related to the concentration of dissolved solids in a water sample. A rapid determination of TDS of a water sample can be made by measuring the electrical conductance.

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.

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/s).

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 table - See groundwater table.

Well interference - When the area of influence, or the cone of depression around a water well comes into contact with or overlaps that of a neighbouring well pumping from the same aquifer and thereby causes additional drawdown or drawdown interference in the wells.

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

The British Columbia Aquifer Classification System (BCACS)

Appendix B

1. 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.

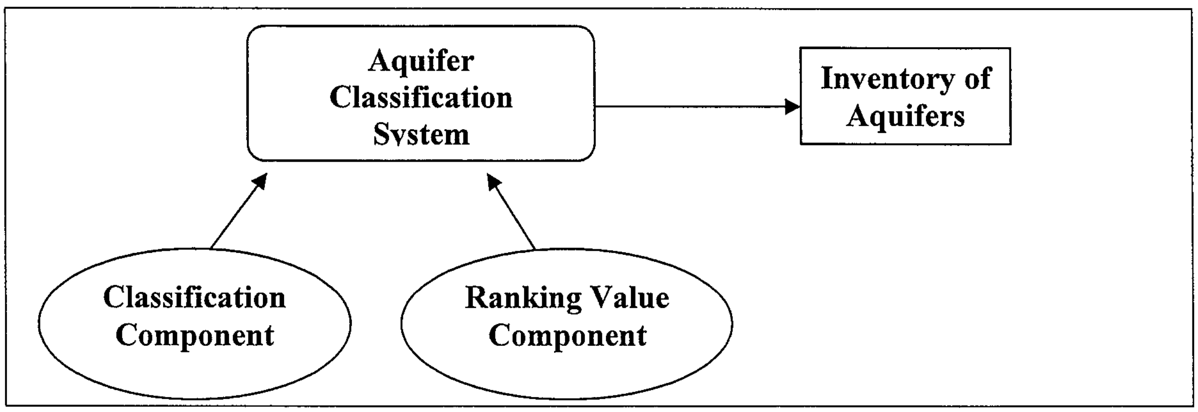


Figure 1. Structure of the British Columbia Aquifer Classification System.

1.1 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

1.2 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 up-dated information.

1.3 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).

1 .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.

1.5 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.

1.6 Uses of the B.C. 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.

1.7 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 C & D

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