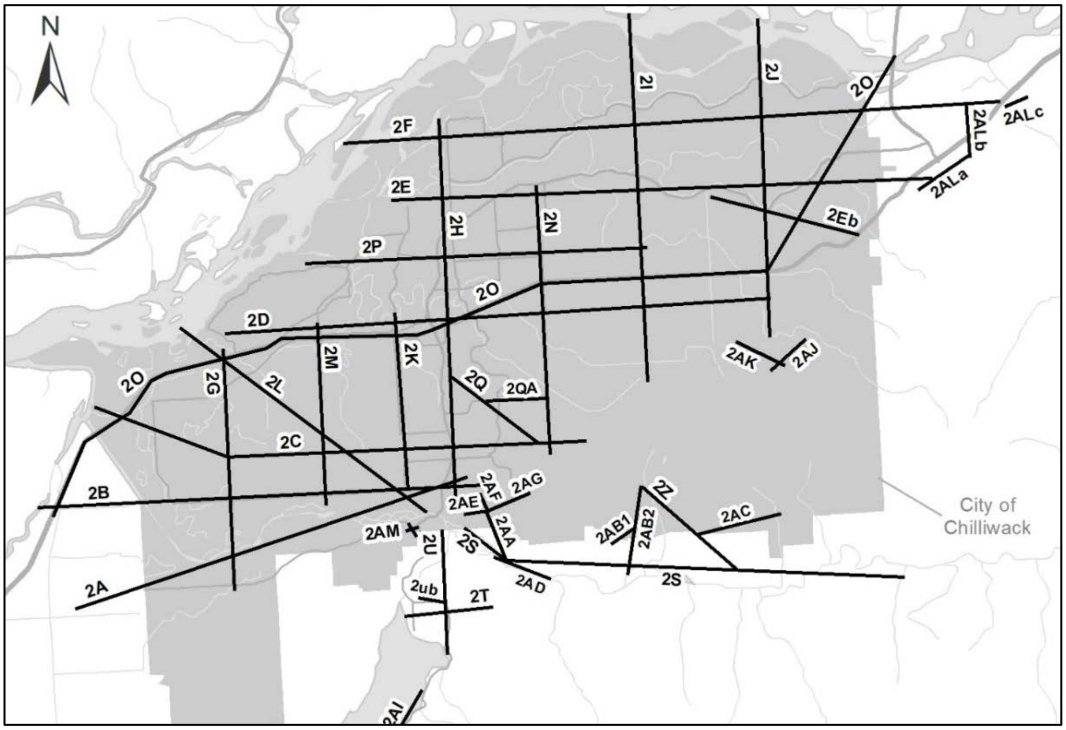
WATER SCIENCE SERIES

Chilliwack Hydrostratigraphic Interpretation and Aquifer Mapping

Patrick A. Monahan, Emilia Young, Christine Bieber, Theodore Back, Mike Simpson and Michele Lepitre



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Author's Affiliation:
Patrick Monahan, Ph.D., P.Geo.
Monahan Petroleum Consulting

Emilia Young, B.Sc.
Water Protection and Sustainability Branch, B.C. Ministry of Environment and Climate Change Strategy

Christine Bieber, M.Sc., P.Geo.
Water Protection and Sustainability Branch, B.C. Ministry of Environment and Climate Change Strategy (Corresponding Author)

Theodore Back, B.Sc.
Water Protection and Sustainability Branch, B.C. Ministry of Environment and Climate Change Strategy

Mike Simpson, M.Sc, P.Geo.
Groundwater Section, South Coast, B.C. Ministry of Forests, Lands, Natural Resource Operations and Rural Development

Michele Lepitre, M.Sc, P.Geo.
Groundwater Section, South Coast, Ministry of Forests, Lands, Natural Resource Operations and Rural Development

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EXECUTIVE SUMMARY

One of the cornerstones of British Columbia's *Water Sustainability Act* (WSA), which came into force in 2016, is the integrated management of groundwater and surface water. Fundamental to this goal is the characterization and understanding of B.C.'s groundwater resources. Building on the knowledge that the Province currently holds through the B.C. Groundwater Wells and Aquifers Application (GWELLS), the Chilliwack Hydrostratigraphic Interpretation and Aquifer Mapping Project provides a three-dimensional understanding of the hydrostratigraphy of the area within the context of its geologic history.

An extensive database of water well and geotechnical borehole logs has been compiled from provincial, municipal and private sources. This database together with surficial geological mapping and published Quaternary studies have been used to produce a refined understanding of these aquifers which will enable the Province to improve the scientific basis for decision making both for water sustainability and protection.

Study Area Description

The study area comprises the City of Chilliwack, with a population of 88,287 (BC Stats, 2018), and unincorporated areas south of the City extending to the United States border (Figure 1). Geologically, this area encompasses the eastern part of the Fraser Lowland which is underlain by Quaternary sediments; and in the south the Skagit Ranges of the Cascade Mountains where topography is controlled primarily by bedrock (Figure 2; Holland, 1976; Armstrong, 1980a, b; Levson et al., 1996a, b, c). The northwest part of the Fraser Lowland in the study area is interrupted by a northeast-oriented discontinuous range of low bedrock mountains in which the maximum elevation is 400 m, and which continues southwest to include the much higher Sumas Mountain (900 m) in Abbotsford.

The principal physiographic elements within the Fraser Lowland part of the study area are the Vedder Alluvial fan, the Fraser River Floodplain, Sumas Prairie, a former lacustrine basin, and the Cheam Plateau, which is underlain by landslide debris (Armstrong, 1980a, b; Cameron, 1989; Levson et al., 1996a, b, c; Monahan and Levson, 2003). The Skagit Ranges of the Cascade Mountains comprise rugged terrain with peaks up to 1600 m. Two prominent valleys cross this area: the valley of the west-flowing Chilliwack River, and a northeast-southwest oriented valley that extends from the Chilliwack River, through Cultus Lake and the Columbia Valley, to the United States border.

Unconsolidated Aquifers in the Fraser Lowland

Groundwater resources are being extensively exploited in the Chilliwack area, and constitute a major source of local water supply. In particular, the City of Chilliwack relies on the Sardis Vedder Aquifer (Aquifer 0008; Figures 14 and 15), which underlies the Vedder Alluvial Fan, as its primary drinking water source. The Sardis Vedder Aquifer is located on the southern margin of the Fraser Lowland and is recharged by the Chilliwack River where it flows out of the Cascade Mountains. It thins from a maximum known thickness of 75 m at the head of the fan to zero at its distal margin.

The other major aquifer within the City is the Chilliwack Rosedale Aquifer (Aquifer 0006; Figures 12, 13, 14, 15 and 16), which underlies the Fraser Floodplain and most of the Cheam Plateau. The Chilliwack Rosedale Aquifer consists of a near surface package of alluvial sands and gravels deposited by the Fraser River (CRA unit) which is generally 10 to 25 m thick; and an underlying late glacial possibly deltaic sand package (CRB unit) which is generally 15 to 40 m thick. The Chilliwack Rosedale Aquifer has not been extensively exploited for municipal use due to undesirable concentrations of iron, manganese and localized arsenic (Livingston, 1973; Dakin, 1994; Emerson, 2005; Graham 2006).

The Greendale Deep Aquifer (Aquifer 1197; Figures 13 and 16) occurs below the Chilliwack Rosedale Aquifer B unit in most of the Fraser Lowland, at an elevation of approximately 50 m below sea level. The

Greendale Deep Aquifer consists of 5 to 20 m of sand, interpreted to be a late glacial outwash deposit. Flowing artesian conditions have been reported in the Greendale Deep Aquifer. Other aquifers in the Fraser Lowland include the Elk Creek Fan Aquifer (Aquifer 1196), which underlies a small alluvial fan on the southeast side of the lowland; the Cheam Slide Aquifer (Aquifer 1198), a heterogeneous aquifer perched in landslide debris above the Chilliwack Rosedale Aquifer; and the Sumas Prairie North Aquifer (Aquifer 1199), which consists of fine sands interbedded with lacustrine silts in the southwest part of the Fraser Lowland and northeast part of the Sumas Prairie (Figures 12, 13 and 14).

Unconsolidated Aquifers in the Skagit Ranges

The principal unconsolidated aquifers in the Skagit Ranges occur in the major valleys. The Chilliwack River Shallow Aquifer (Aquifer 0009; Figures 17, 19 and 20) is restricted to the floor of the Chilliwack River Valley, where it consists of Holocene fluvial sands and gravels, and to the valley between Cultus Lake and Chilliwack River, where it includes some late glacial (Sumas Stade) outwash deposits. The underlying Chilliwack River Subtill Aquifer (Aquifer 1206; Figures 17, 19 and 20) occurs beneath late Wisconsin till in these valleys but is locally connected to the Chilliwack River Shallow Aquifer, where the Holocene fluvial gravels are incised into it or where the till is absent. The Chilliwack River Subtill Aquifer extends to the north beneath the southern parts of the adjacent Ryder Upland, where it is directly overlain by Late Wisconsin glaciolacustrine sediments. This aquifer is deep in this setting and usually dry in its upper parts. Perched above the Chilliwack River Subtill Aquifer in the southern Ryder Upland are small low productivity aquifers in sand beds interbedded with glaciolacustrine silts, the Ryder Upland Glaciolacustrine Sand A, B and C Aquifers (RUSA, RUSB, and RUSC, Aquifers 1207, 1208, and 1209, respectively; Figures 17 and 20), which each underlie a separate erosional promontory on the north wall of the valley.

The Columbia Valley has a thick fill of late glacial (Sumas Stade) recessional outwash deposits that constitute the Columbia Valley Aquifer (Aquifer 0020; Zubel, 2000). The Columbia Valley Aquifer is a heterogeneous mixture of sands, gravels, slide debris and shale gravels derived from the underlying shale bedrock. The Cultus Lake Fan Delta A, B, C and D Aquifers (CLFDA, CLFDB, CLFDC, CLFDD and CLFDE; Aquifers 1200, 1201, 1202, 1203 and 1204, respectively; Figure 17) are a series of small aquifers underlying alluvial fan deltas along the shore of Cultus Lake.

Other permeable units that form minor aquifers in the upland area north of the Chilliwack River occur in shallow sands and gravels that are commonly perched above bedrock aquifers (Figure 17). Those extensive enough to have been mapped include the Mount Tom Unconsolidated Aquifer (Aquifer 1210), the Lookout Ridge Unconsolidated Aquifer (Aquifer 1211), the Elkview Road Shallow Aquifer (Aquifer 1212) and the Marble Hill Road Unconsolidated Aquifer (Aquifer 1213). However, these are heterogeneous, poorly defined, and may be discontinuous, and others are likely to occur. At the north end of Vedder Mountain, the Vedder Crossing Aquifer (Aquifer 1205) has been mapped in near surface sands and gravels above bedrock.

Bedrock Aquifers

Bedrock aquifers have been identified in most upland areas (Figure 22). The Chilliwack Mountain Bedrock Aquifer (Aquifer 1214) and the Cannor Road North Bedrock Aquifer (Aquifer 1215) are in the low range of mountains and hills that occurs within the Fraser Lowland. The bedrock in these consists of middle Jurassic Harrison Lake Formation volcanics (Roddick, 1965; Roddick and Armstrong, 1965; Monger, 1970a, b. 1989; Journeay and Monger, 1994; Mahoney et al., 1995). The median reported well yields are 4 and 1 gallons per minute (gpm), respectively, lower than in most bedrock aquifers in the Skagit Ranges.

Several bedrock aquifers have been identified in the Skagit Ranges (Figure 22). The Mount Tom Bedrock Aquifer (Aquifer 890) underlies Mount Tom and the Ryder Upland, and extends as far east as the thrust fault that emplaces Upper Paleozoic Chilliwack Group volcanic and sedimentary rocks on Triassic to Jurassic Cultus Formation mudstones and fine sandstones. The latter form bedrock in most of this aquifer, although to the west coarser sedimentary rocks assigned to the Kent Formation, metamorphic rocks of the Vedder Complex and some Tertiary clastics occur (Monger, 1970b; Armstrong, 1980b; Monger, 1989; Journeay and Monger, 1994). The median flow rate is 2 gpm, and local water quality issues have been reported, both being likely due to the ductility and chemistry of the Cultus mudstones (Green and Bianchin, 2016; C. Naiduwa, personal communication, November 18, 2016). The Elk Mountain Bedrock Aquifer (Aquifer 0899; Figure 21) occupies the mountainous areas east of the Mount Tom Bedrock Aquifer, where bedrock consists primarily of Chilliwack Group volcanic and sedimentary rocks. Median flow rate is 10 gpm but rates up to 500 gpm have been reported at the Marble Hill Road well field, where the City of Chilliwack is developing additional groundwater supplies. The high rates are likely related to increased fracture intensity in the brittle Chilliwack Group greenstones (altered volcanics) immediately above the thrust fault that form the western boundary of this aquifer. Other areas with high productivity wells in this aquifer are also likely in proximity to major fault systems.

Two aquifers have been defined on Vedder Mountain in the southwest part of the study area, and the boundary between them is drawn along the ridgeline on the crest of the mountain (Figures 22 and 23). To the northwest, in the Vedder Mountain Northwest Bedrock Aquifer (Aquifer 1216), bedrock consists primarily of gabbro and metamorphic rocks of the Permian to Triassic Vedder Complex (McMillan, 1966; Armstrong et al., 1983), and the median flow rate is 11 gpm. To the southwest, the Vedder Mountain Southeast Bedrock Aquifer (Aquifer 1217) is in Jurassic to Cretaceous sedimentary and volcanic rocks assigned to the Kent Formation (McMillan, 1966; Roddick, 1965; Roddick and Armstrong, 1965; Armstrong et al., 1983; Monger 1989; Journeay and Monger, 1994). Median flow rate is 11 gpm.

East of Cultus Lake and Columbia Valley, the East Cultus Columbia Bedrock Aquifer (Aquifer 1218; Figure 22) is primarily in Triassic to Jurassic Cultus Formation sedimentary rock, and the median flow rate for this aquifer is 10 gpm.

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ACRONYMS

B.C.	British Columbia
BCGS	British Columbia Geographical System
CLFDA	Cultus Lake Fan Delta A
CLFDB	Cultus Lake Fan Delta B
CLFDC	Cultus Lake Fan Delta C
CLFDD	Cultus Lake Fan Delta D
CLFDE	Cultus Lake Fan Delta E
CRA	Chilliwack Rosedale A
CRB	Chilliwack Rosedale B
CSL	Cheam Slide
CVA	Columbia Valley A
CVB	Columbia Valley B
CVC	Columbia Valley C
EcoCat	Ecological Reports Catalogue (B.C. ENV)
ENV	Ministry of Environment and Climate Change Strategy
GWELLS	B.C. Groundwater Wells and Aquifers Database
gpm	U.S. gallons per minute
m	metres
MHRU	Marble Hill Road Unconsolidated
RUSA	Ryder Upland Glaciolacustrine Sand A
RUSB	Ryder Upland Glaciolacustrine Sand B
RUSC	Ryder Upland Glaciolacustrine Sand C
VCA	Vedder Crossing A
VCB	Vedder Crossing B
WSA	*Water Sustainability Act*
WTN	well tag number

1. INTRODUCTION

One of the cornerstones of British Columbia's *Water Sustainability Act* (WSA), which came into force in 2016, is the integrated management of groundwater and surface water. Fundamental to this goal is the characterization and understanding of British Columbia's groundwater resources. Building on the knowledge that the Province currently holds through the B.C. Groundwater Wells and Aquifers Application (GWELLS), the Chilliwack Hydrostratigraphic Interpretation and Aquifer Mapping Project provides a three-dimensional understanding of the hydrostratigraphy of the area within the context of its geologic history. An extensive project database of water well and geotechnical logs has been compiled from provincial, municipal and private sources. This project database together with surficial geological mapping and published Quaternary studies have been used to produce a refined understanding of these aquifers which will enable the Province to improve the scientific basis for decision making both for water sustainability and protection. The main focus of this study is on the unconsolidated aquifers, which constitute the principal groundwater sources for municipal and domestic use.

The study area comprises the City of Chilliwack, with an estimated population of 88,287 (BC Stats, 2018), and unincorporated areas south of the City extending to the United States border (Figure 1). Chilliwack is located 100 km east of Vancouver. Groundwater resources are being extensively exploited in the Chilliwack area, and constitute a major source of local water supply. In particular, the City of Chilliwack relies on the Sardis Vedder Aquifer beneath the Vedder Alluvial Fan as its primary drinking water source.

Geologically, this area encompasses the eastern part of the Fraser Lowland, which is underlain by Quaternary sediments; and in the south the Skagit Ranges of the Cascade Mountains, where topography is controlled primarily by bedrock (Figure 2; Holland, 1976; Armstrong, 1980a, b; Levson et al., 1996a, b, c). The northwest part of the Fraser Lowland in the study area is interrupted by a northeast-oriented discontinuous range of low bedrock mountains (Chilliwack Mountain and Mount Shannon) in which the maximum elevation is 400 m. This range continues southwest to include the much higher Sumas Mountain (900 m) in Abbotsford.

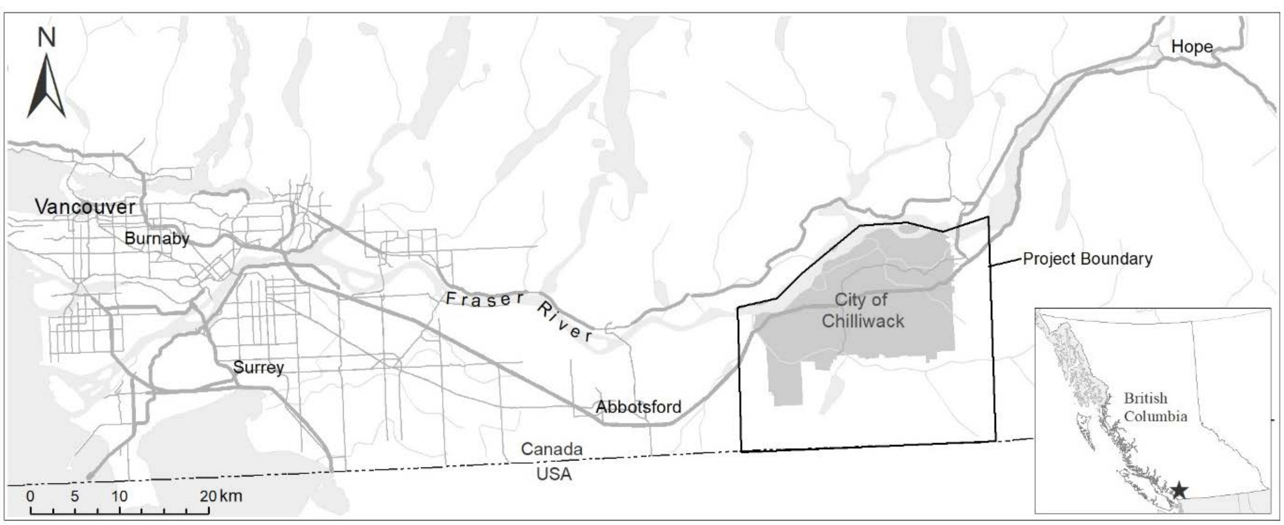

Figure 1: Map of Southwest B.C., showing the project area.

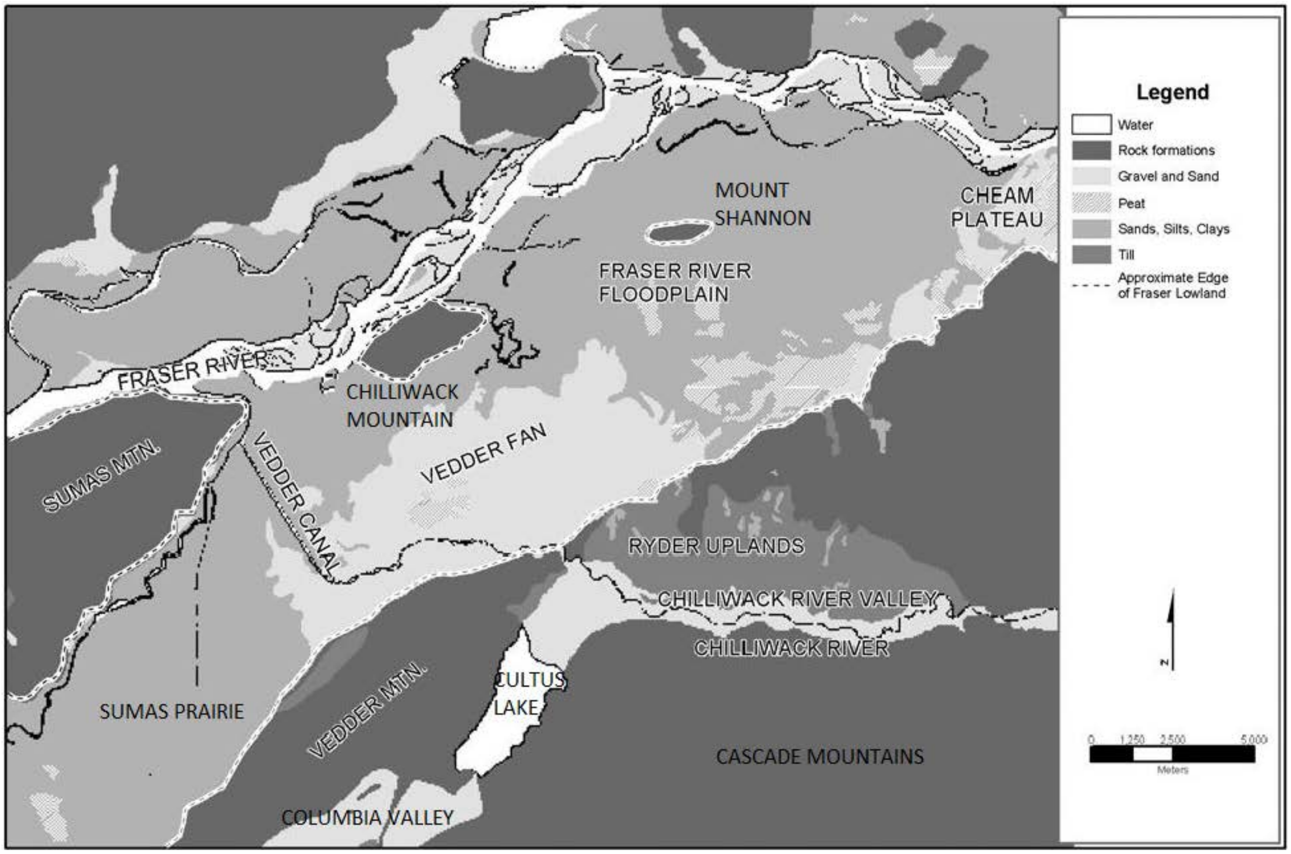

Figure 2. Chilliwack, physiographic elements (modified from Monahan and Levson, 2003)

Extensive areas of urban development and farmland are found within the Fraser Lowland portion of the study area. Accordingly, most of the population and groundwater development is in this area, as well as several critical transportation corridors, including the Trans-Canada Highway, the Canadian National Railroad, electrical transmission lines and oil pipelines.

The principal physiographic elements of the Fraser Lowland part of the study area are the Vedder Alluvial Fan, the Fraser Floodplain, Sumas Prairie, and the Cheam Plateau (Armstrong, 1980a, b; Cameron, 1989; Levson et al., 1996a, b, c; Monahan and Levson, 2003).

The Vedder Alluvial Fan has developed where the Chilliwack River exits the Cascade Mountains, and slopes down from an elevation of 36 m near the head to 12 m where it joins the Fraser Floodplain. The present-day flow of the Chilliwack River is diverted to the west along the Vedder River and Canal; however, partially abandoned channels of the river meander northward across the fan into the Fraser Floodplain.

The Fraser Floodplain, which occupies most of remaining part of the lowland within the City, surrounds Chilliwack Mountain and Mount Shannon, and includes several sloughs that represent abandoned channels of the Fraser and Chilliwack Rivers.

Sumas Prairie extends southwest from Chilliwack into Abbotsford between Sumas Mountain and the Cascade Mountains and represents a Holocene lacustrine basin that was drained in 1924 for agricultural development (Daly, 1910; Cameron, 1989; Levson et al., 1996a, b).

The Cheam Plateau in the north-easternmost part of the City forms a poorly drained undulating plateau above 40 m elevation and was formed by a catastrophic slide from the Cascade Mountains about 5,000 years ago (Naumann, 1990; Savigny and Clague, 1992; Evans and Savigny, 1994; Orwin et al., 2004; Kovanen and Slaymaker, 2015).

The Fraser River now flows along the northern margin of the Fraser Lowland in this area, having been displaced northward by growth of the Vedder Fan during the Holocene. It forms the northern boundary of the City of Chilliwack and of the study area.

The Skagit Ranges of the Cascade Mountains comprise rugged terrain with peaks up to 1600 m. Two prominent valleys cross this area: the valley of the west-flowing Chilliwack River, and a northeast-southwest oriented valley that extends from the Chilliwack River, through Cultus Lake and the Columbia Valley, to the United States border. The Columbia Valley is a terraced upland that stands 135 to 165 m above the level of Cultus Lake. Settlement and groundwater exploitation in the Skagit Ranges are restricted to these two valleys and to the lower slopes of the mountains north of Chilliwack River (Ryder Upland) and adjacent to the Fraser Lowland.

2. GEOLOGICAL SUMMARY

Structurally, the study area is dominated by a northeast oriented graben that occupies that part of the Fraser Lowland between the Cascade Mountains on the southeast (Vedder Fault) and Sumas Mountain and Chilliwack Mountain on the northwest (Sumas Fault; Monger, 1989; Journeay and Monger, 1994; Monger and Journeay, 1994). This graben extends southwest through Abbotsford and into northern Washington State.

2.1 Bedrock Geology

Bedrock in Mount Shannon, Chilliwack Mountain and a small hill to the southwest is included in the middle Jurassic Harrison Lake Formation, which consists primarily of intermediate to felsic pyroclastics and flows (Roddick, 1965; Roddick and Armstrong, 1965; Monger, 1970a, b, 1989; Journeay and Monger, 1994; Mahoney et al., 1995). To the southwest on Sumas Mountain, the Harrison Lake Formation is intruded by mid to late Jurassic intrusive rocks, which are overlain by early Tertiary terrestrial clastics of the Huntingdon Formation (Mustard and Rouse, 1994; Gilley, 2003). Approximately 1350 m of equivalent Tertiary clastics are also present in the Fraser Valley Chilliwack 14-19-26 ECM exploratory well (in D- 077-E/092-H-04) in the graben southeast of the Sumas Fault in Chilliwack (Figure 16; Cosburn, 1965).

On Vedder Mountain, which lies between the Vedder Fault to the northwest and the Columbia Valley and Cultus Lake to the southeast, two distinct outcrop belts occur (McMillan, 1966; Roddick, 1965; Roddick and Armstrong, 1965; Armstrong et al., 1983; Monger, 1989; Monger et al., 1992; Journeay and Monger, 1994). On the northwest side of the mountain, bedrock consists of gabbro, amphibolite, schist and minor ultramafics of Permian to Triassic age. In fault contact with these rocks on the southeast side of Vedder Mountain, are Jurassic to Cretaceous conglomerate, sandstone, argillite, basalt and schistose chert that have been assigned to the Kent Formation by Monger (1989). These outcrop belts extend northeast across the Chilliwack River to the southwest end of the Ryder Upland.

Elsewhere in the Cascade Mountains in the study area, bedrock consists of the Lower Pennsylvanian to Permian Chilliwack Group (which includes rocks as old as Devonian to the south in Washington) and the unconformably overlying Triassic to Jurassic Cultus Formation (Monger, 1966, 1970a, b, 1989; Monger et al., 1992; Journeay and Monger 1994). The Chilliwack Group consists of pelite, siltstone, sandstone and minor conglomerate, pyroclastics, greenstone, limestone and minor chert. The Cultus Formation is predominantly mudstone and fine sandstones. The western part of the area is underlain by the Cultus Formation, which is structurally overlain to the east by several thrust sheets of Chilliwack and Cultus strata.

2.2 Quaternary Geology

2.2.1 *Regional Stratigraphic Succession*

The stratigraphic succession identified in the Lower Mainland of Southwestern B.C. is summarized in Figure 3 (Armstrong, 1984; Ryder and Clague, 1989; Clague, 1994; Clague and Ward, 2011). The oldest defined unit is the poorly known and undated glacial Westlynn Drift, which is succeeded by the non-glacial Highbury Sediments of probable Sangamonian age. These units are overlain by the Semiahmoo Drift of the penultimate glaciation (>62,000 BP[1]), which is interpreted to be early Wisconsin (Hicock and Armstrong, 1983). The overlying Cowichan Head Formation of the non-glacial Mid-Wisconsin Olympia non-glacial interval ranges in age from 23,800 to 58,800 BP. The succeeding Fraser Glaciation is the best-known glacial interval and includes several stratigraphic units. At the base, the Quadra sand is a diachronous proglacial outwash sand that ranges in age from 29,000 BP in the north to 15,000 BP south of the United States border (Armstrong and Clague, 1977). The Cowichan Drift represents an early glacial advance between 21,700 and 18,700 BP (Hicock and Armstrong, 1981). This was followed by a glacial retreat at approximately 18,000 BP, referred to as the Port Moody Interstade (Hicock and Lian, 1995). The Vashon Drift represents the main glacial advance, which reached its maximum extent at the south end of the Puget Lowland at 14,000 to 14,500 BP (Hicock and Armstrong, 1985). The Fort Langley Formation and Capilano sediments represent a complex of glaciogenic deposits formed when the continental glacier had retreated to the central part of the Fraser lowland, and the Sumas Drift represents a late stage glacial re-advance between 11,500 and 11,100 BP (Armstrong, 1981). The Salish sediments represent deposits formed after sea level had dropped to or below its current level following the Sumas Stade and during the Holocene.

Although deposits of only three glaciations have been identified in southwestern B.C. (Armstrong, 1984; Ryder and Clague, 1989; Clague, 1994; Clague and Ward, 2011), many more likely occurred. At the southern limit of Pleistocene glaciation in Puget Sound, where glaciation was less intense, at least six glacial events have been identified, three of which are older than 700,000 years (Easterbrook, 1976; Easterbrook et al., 1981, 1988; Booth et al., 2004). These older glaciations undoubtedly affected southern B.C. as well.

[1] Dates are based on radiocarbon dating and are expressed as ^{14}C years before present (BP; i.e. before 1950), rather than calendar years. This is how the dates appear in the older literature.

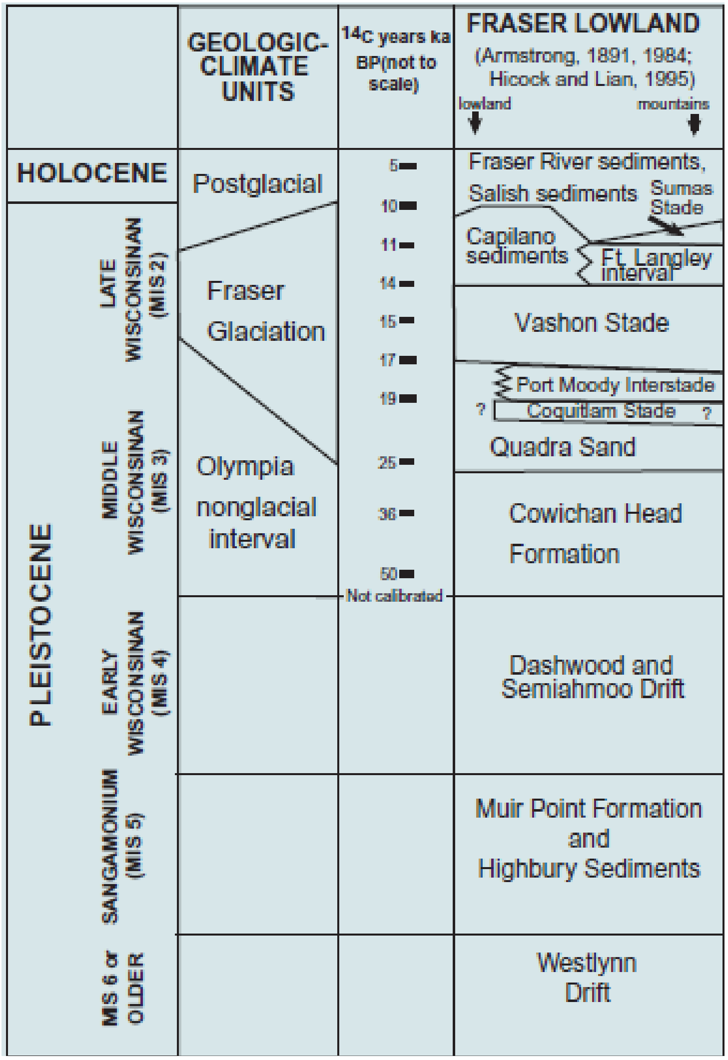

Figure 3: Pleistocene stratigraphic table for Southwestern B.C. (from Clague and Ward, 2011).

2.2.2 *Quaternary Stratigraphy of the Chilliwack Area*

In the Chilliwack area, the full thickness of Quaternary sediment fill of the Fraser Floodplain is known from only two boreholes, the Fraser Valley Chilliwack 14-19-26ECM (in D- 077-E/092-H-04) exploratory well, where it is 400 m thick (Cosburn 1965), and the Bos Trout Farm water well (WTN 1160) where it is 485 m thick (Figure 16). Most of this succession is undated, with only the upper 60 m being confidently assigned to the post Sumas recessional phases of the Fraser Glaciation and the Holocene. The deeper parts are predominantly fine grained and likely represent deep water glaciomarine and marine deposits of several periods.

The oldest dated Pleistocene sediments in the Chilliwack area are shell-bearing glaciomarine clayey silts preserved on the southern margin of the Fraser Lowland at the Bailey Landfill east of Vedder Crossing (Armstrong 1977; Hicock et al., 1982; Hicock and Armstrong, 1983; Armstrong et al., 1985). These deposits have been dated to >34,000 BP and have been correlated with the Semiahmoo Drift. They further demonstrate that marine conditions could extend far up the Fraser Valley during glacial periods.

Advance phase sand and gravel outwash of the Fraser Glaciation equivalent to the Quadra sand has been identified at the Bailey Pit overlying the Semiahmoo silts, and to the south at the Chilliwack River

Gravel Pit, at the downstream end of the Chilliwack River Valley (Armstrong 1977; Hicock et al., 1982; Clague and Luternauer 1982, 1983; Armstrong et al., 1985). Proboscidean (mammoth) tusks from these sites have been dated to 21,400 and 22,700 BP. These sediments can be traced upstream along the Chilliwack River valley and were sourced from a glacier moving down the valley from the east. In the valley floor, these sediments are overlain by till, but along the margins of the valley they are generally overlain by glaciolacustrine clayey silt and fine sand, which were deposited when the Chilliwack River became dammed by Cordilleran ice in the Fraser Lowland (Figure 20; Hicock et al., 1982; Clague and Luternauer 1982, 1983; Armstrong et al., 1985; Fletcher 2002). Glaciolacustrine deposits are over 60 m thick, and sedimentation continued until after 16,000 BP (Clague et al., 1988).

Based on correlation of water well logs for this study, the top of the Quadra Sand-equivalent advance phase outwash package appears to be highly irregular and much lower in the valley centre, where it is generally overlain by till. By this interpretation, the advance phase outwash and overlying glaciolacustrine sediments were deeply scoured by glaciers during the Vashon Stade glacial maximum at approximately 14,500 BP, by which time the Chilliwack River valley glacier and the Cordilleran ice sheet had coalesced (Clague et al., 1988). The glaciolacustrine sediments may have been deposited in part in lakes marginal to an ice mass in the valley centre.

Following the glacial maximum, glaciolacustrine sedimentation resumed in the Chilliwack River Valley as the Chilliwack River valley glacier retreated upstream. These sediments have been dated at 11,900 BP (Saunders et al., 1987), time-equivalent to the Fort Langley Formation.

The Cordilleran ice sheet re-advanced during the following Sumas Stade between 11,500 and 11,100 BP, depositing the last till in the region (Clague, 1994). A lobe of Cordilleran ice advanced up the Chilliwack River Valley as far as Tamihi Creek, where a terminal moraine developed (Saunders, 1985, Saunders et al., 1987; Clague et al., 1988). Another lobe extended from this into the valley occupied by Cultus Lake, where a prominent ice-contact face formed at the lake's southwest end (Clague and Luternauer, 1982, 1983; Saunders et al. 1987; Kovanen and Easterbrook, 2001). Southwest of this ice contact face, a thick fill of glacial outwash sands and gravels was deposited in the Columbia Valley, where it constitutes the Columbia Valley Aquifer.

Following the Sumas Stade, deglaciation proceeded rapidly, with the Cordilleran ice sheet melting back east of the Chilliwack area. In the Study Area, the deepest deposits in the Fraser Lowland to be confidently identified as having been deposited after the retreat of glacial ice are interbedded silts, clays and fine to medium sands in a 58 m deep cone penetration test in northeastern Sumas Prairie, where they can be seen to be normally consolidated, meaning that they have not experienced greater vertical loading in the past (Monahan, 1995). These sediments include an extensive fine to medium sand body that extends under much of the Fraser Lowland in Chilliwack, and is interpreted to be deep water marine glacial outwash deposit (Greendale Deep Aquifer; Figures 4, 13 and 16).

A thick sand and gravel package overlies the interbedded silts and sands in most of the Fraser Lowland and extends nearly to the surface (Figures 4 and 5; Monahan 1995; Levson et al., 1996a; Monahan and Levson, 2003). This package constitutes the Chilliwack Rosedale Aquifer. The lower part of this package (Chilliwack Rosedale B unit, CRB) consists primarily of sand and is generally between 15 and 40 m thick. It is directly overlain by the upper part (Chilliwack Rosedale A unit, CRA) in much of the eastern and central parts of Chilliwack, but in the west it is generally overlain by silt. The upper surface of this unit is at an elevation of approximately 10 m below sea level in most of the area, but in the western and southern parts of the city can be seen to dip markedly to the west and south (Figures 4 and 5; Monahan 1995; Levson et al., 1996a; Monahan and Levson, 2003). These correlations are particularly evident on cone penetration test cross-sections in the western part of the City. The unit has an interfingering contact with the underlying finer deposits.

On the basis of this morphology, CRB is interpreted as a deltaic deposit that prograded westward and southward into the recently deglaciated Fraser Lowland, when relative sea level was lower than today and the area was likely occupied by an arm of the sea – in effect an early manifestation of the Fraser delta. Progradation ceased when it reached Sumas Prairie, which was not open to the sea to the southwest, and the flow of the Fraser continued westward to the sea along its present course. At that time, Sumas Prairie is interpreted to have changed from a marine to a lacustrine basin. An alternative interpretation is that some of the westerly thinning wedge of the CRB was deposited on a block of stagnant ice in Sumas Prairie, although the apparent continuity of the Greendale Deep sands beneath the CRB argues against it.

The upper part of the package consists of sands and gravels of the CRA and forms a series of decametre-scale fining upward sequences representing active channel fill deposits of the Fraser River. These deposits become finer to the west, from gravel and sand to sand. The unit is capped by floodplain silts and clays that thin to the north reflecting the northward displacement of the Fraser River and rising base level during the Holocene. Peat deposits cap the oldest parts of the floodplain adjacent to the Cascade Mountains.

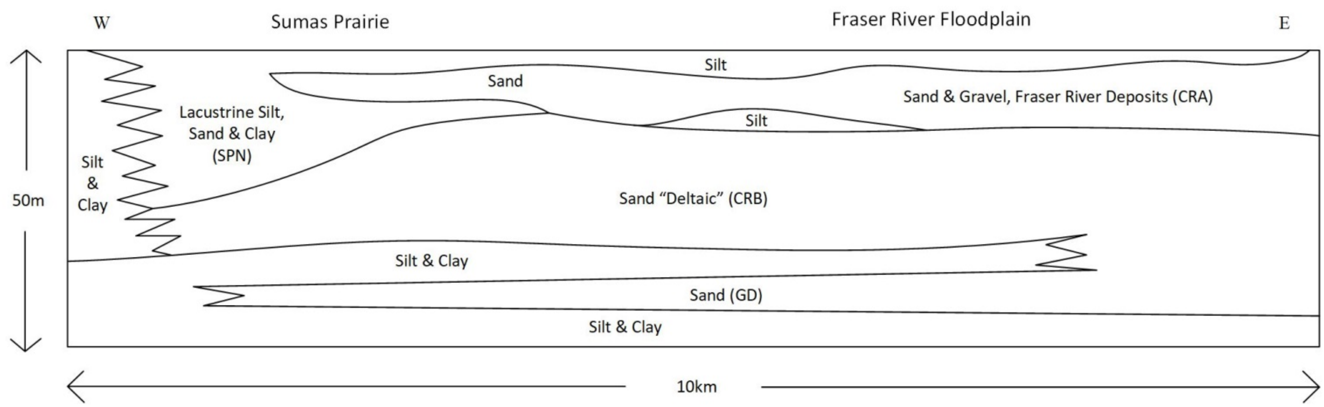

Figure 4. East-West schematic cross-section showing the Holocene stratigraphy of the Fraser Floodplain and Sumas Prairie (modified from Levson et al., 1996a, Monahan and Levson, 2003).

Contemporaneously with the early Fraser River deltaic and later fluvial deposits, the gravels and sands of the Vedder Alluvial Fan built out from where the Chilliwack River exits the Cascade Mountains (Sardis-Vedder Aquifer; Figure 5; Monahan 1995; Levson et al., 1996a; Monahan and Levson, 2003; Tunnicliffe et al., 2012). Initially, the distal deposits of the fan were likely deposited in standing water, as they are interbedded with lacustrine sediments. Later, the fan built out over the Fraser River fluvial and floodplain deposits.

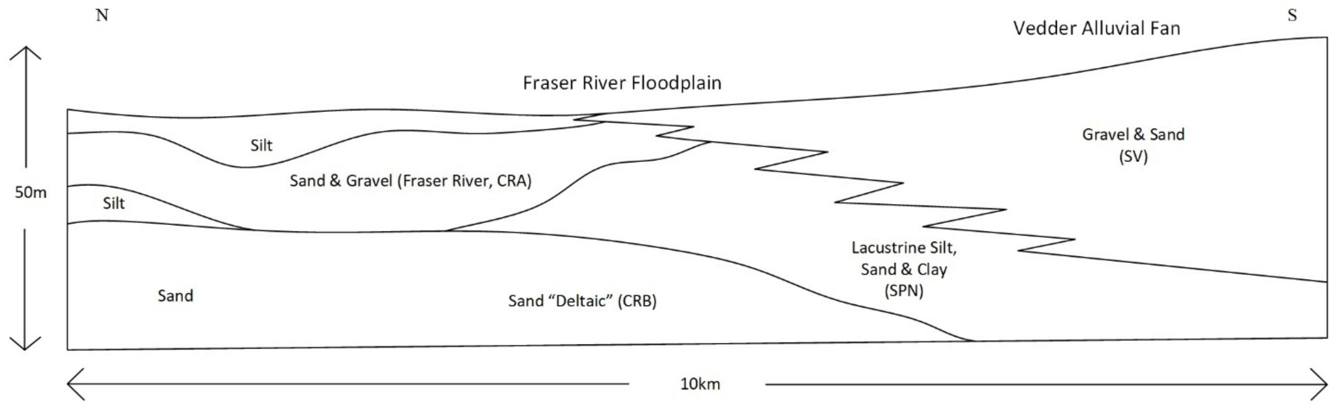

Figure 5. North-South schematic cross-section showing the Holocene stratigraphy of the Fraser Lowland from the Vedder Alluvial Fan to the Fraser River Floodplain (modified from Monahan and Levson, 2003).

Sumas Prairie was a lacustrine basin throughout the Holocene, and was gradually filled by sediment supplied from the Fraser River from the northeast, the Chilliwack-Vedder River from the east and the Sumas River from the southwest. A small lake remained in historic times until the valley was drained in 1924 (Daly, 1910; Cameron 1989; Levson, 1996a, b; Monahan and Levson, 2003).

3. <u>METHODOLOGY</u>

3.1 Data Sources: Collection and Integration

3.1.1 *GWELLS Application*

The main source of data for this study is the GWELLS Application, which contains over 113,000 records of water wells in B.C. (ENV, 2017a). From this database, a project database was generated using the following fields: well tag number (WTN), British Columbia Geographical System (BCGS) number, location in UTM coordinates, coordinate acquisition code, lithological log, finished well depth, water level depth, and reported flow rate. Elevation estimates for each well, were created based on the location coordinates and a digital elevation model. The original database for the combined Abbotsford and Chilliwack study area is included as Appendix 1.

While GWELLS includes an enormous amount of useful information, it has been generated from water well records prepared with a large variation in care and accuracy. Lithological terms are often used inconsistently. Some well logs were prepared by professional engineers or geoscientists, but most have been prepared by water well drillers. Where water well drillers' logs in GWELLS can be compared with professional engineer or geoscientist described logs for the same well, the records may show considerable differences (e.g. City of Chilliwack Marble Hill Road wells, WTN 110969-110975).

A unit referred to as "till" in one water well log may be called "gravel and clay" (or variants of these terms), "gravel with binder", "cemented gravel", "hardpan", or even just "clay" in adjacent well logs. Also, in many wells in the Vedder alluvial fan, the upper 10 m above the water table is referred to as "till" in GWELLS logs. This may refer to dry poorly sorted gravels or debris flow deposits, but in this setting is certainly not till, which by definition is a glacial deposit.

In bedrock descriptions, the term "shale", which technically refers to a fine-grained sedimentary rock has been widely used in GWELLS logs for materials that have been mapped as volcanic and metamorphic rocks.

In general, permeable saturated deposits are described more consistently and in greater detail than unsaturated or lesser permeability deposits. Lithological uncertainty can be minimized by considering data from several wells – if the descriptions in several nearby well logs are similar, then the geological interpretation is more credible. However, aquifer thicknesses interpreted for this study vary with the quality of the logs.

Well location is also a significant source of uncertainty. For many older records, locations in GWELLS have been digitized from maps of different scales, or in some cases estimated from written descriptions. Inaccuracy of up to a few tens of metres is generally not a major issue in a regional study. However, in hilly terrain such inaccuracy will have a significant effect on the estimated elevation. This can greatly impact the ability to confidently correlate one log with another.

Data entry errors were also noted during this study. In some cases, the original source documents were examined to check on anomalous wells. Some wells coded with high location accuracy were found to be mislocated by hundreds of metres (e.g. WTN 51335 in Abbotsford). In extreme cases, wells have been assigned to the incorrect BCGS mapsheet. Location accuracy descriptions can be found in Appendix 2.

In many cases, well records were identified that were duplications of one another.

3.1.2 *Other Data Sources*

Additional data sources include published geological maps, papers and reports, water well logs and groundwater reports from the City of Chilliwack and the BC Geological Survey, groundwater reports in B.C.'s EcoCat Ecological Reports Catalogue (ENV, 2017b), and other borehole logs in the senior author's files. A listing of all these reports is included as Appendix 3. These data sources provided many well and borehole logs that supplement the information available in the GWELLS database. The logs for those, as well as those for which the log in GWELLS required correction, were entered into a table of new well data for use in interpretation. Some key outcrop sections described in the literature were also incorporated into this file. The coordinates for these new wells were estimated from 1:50,000 topographic maps or using Google maps (Google). This file is included as Appendix 4.

The GWELLS database and the additional data sources provided logs for 91 wells drilled for the City of Chilliwack, including exploratory wells, production wells, and monitoring wells. A number of these wells had several different well numbers in the various reports. To assist with future use of these well data, a listing of all the wells, the various names and numbers assigned to each one and the relevant source documents is included in Appendix 5.

Additional borehole data from the senior author's files include geotechnical data, water well logs, and data from a petroleum exploration well. Data from these boreholes have been included in the new well data file in Appendix 4. These data were acquired for previous Quaternary geological investigations and were generated principally for public infrastructure or other public investigations (e.g. Levson et al., 1996a, b, c, 1998; Monahan and Levson, 2003).

Geotechnical borehole data are invaluable for subsurface geological interpretation because they are professionally and consistently described and include repeatable quantitative measurements, such as the standard penetration test blowcount and moisture content. These measurements are useful stratigraphically, in particular for discriminating between those deposits that have been glacially overridden and those that have not. Consequently, geotechnical borehole data facilitate better interpretation of the geological units recognized in the subsurface than would be provided by the water well logs alone. Cone penetration test data are particularly useful. In addition to repeatable quantitative measurements, they provide cm-scale detail, thus facilitating detailed correlation. A suite of geotechnical borehole log cross-sections, including cone penetration test data, was prepared by the senior author for the B.C. Geological Survey's Chilliwack Seismic Microzonation Project in order to outline the stratigraphic framework of the Fraser Lowland (Monahan, 1995; Levson et al., 1996a, c; 1998). These sections were scanned for the current investigation and are included in Appendix 6.

3.1.3 *Site Visit*

A full day site visit was conducted in November 2016. Sites were inspected in Chilliwack, Cultus Lake, and the Columbia Valley and included the Bailey Landfill and the Marble Hill Road well field. The visit was conducted to perform spot checks of the geomorphic expression of the hydrostratigraphy of the study area and surface water features inferred to be hydraulically connected groundwater sources. The visit provided additional contextual information for the data interpretation phase which followed.

3.2 Data Interpretation

3.2.1 *Unconsolidated Aquifers*

Geological interpretations of the unconsolidated aquifers were based on a series of cross-sections, constructed using borehole data from GWELLS and the other data sources. The distribution of wells and boreholes obtained in the project area are shown by depth range in Figure 6, and those used in the interpretations are shown in Figure 7. The wells interpreted for the cross-sections tended to be the deeper wells and those with better descriptions.

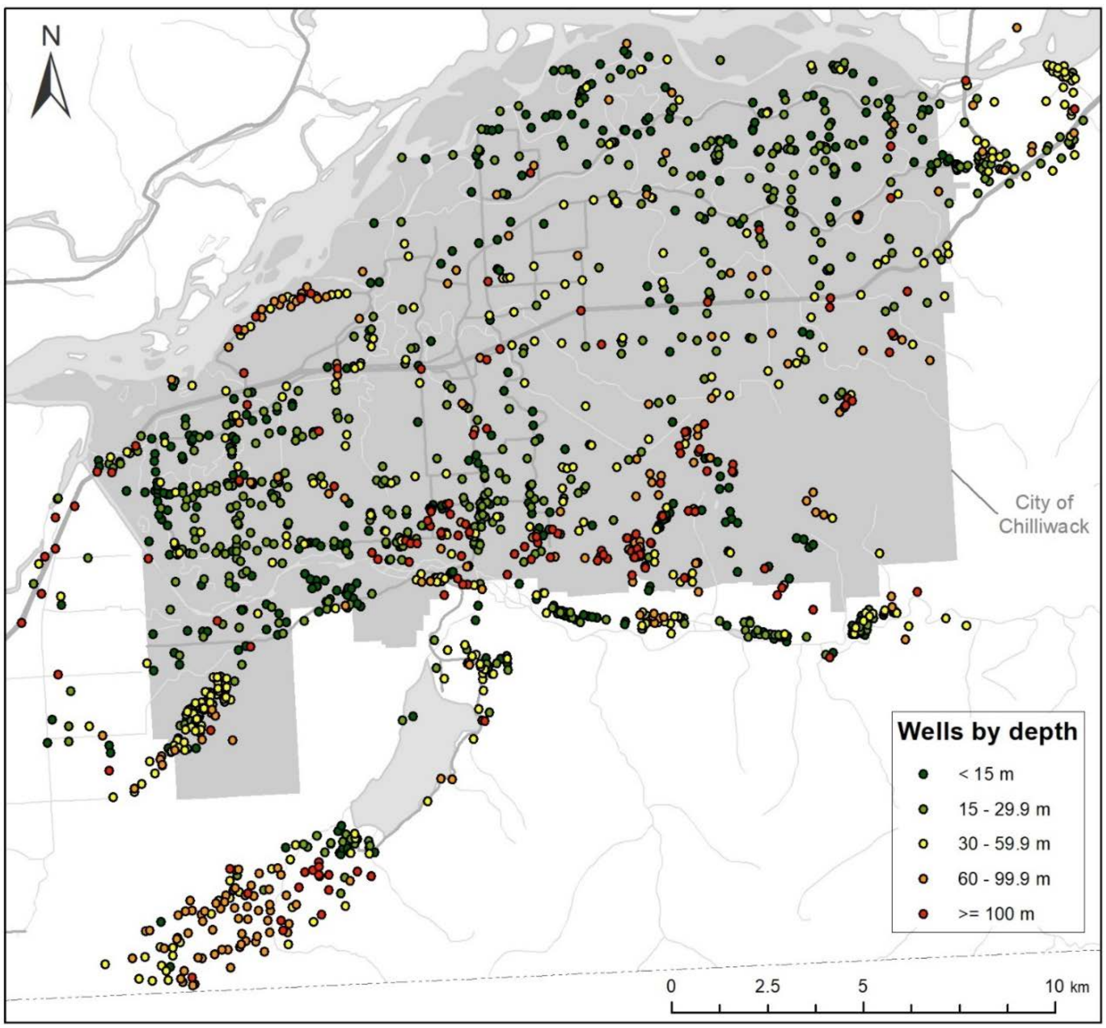

Figure 6: Depths of wells and boreholes in the project area.

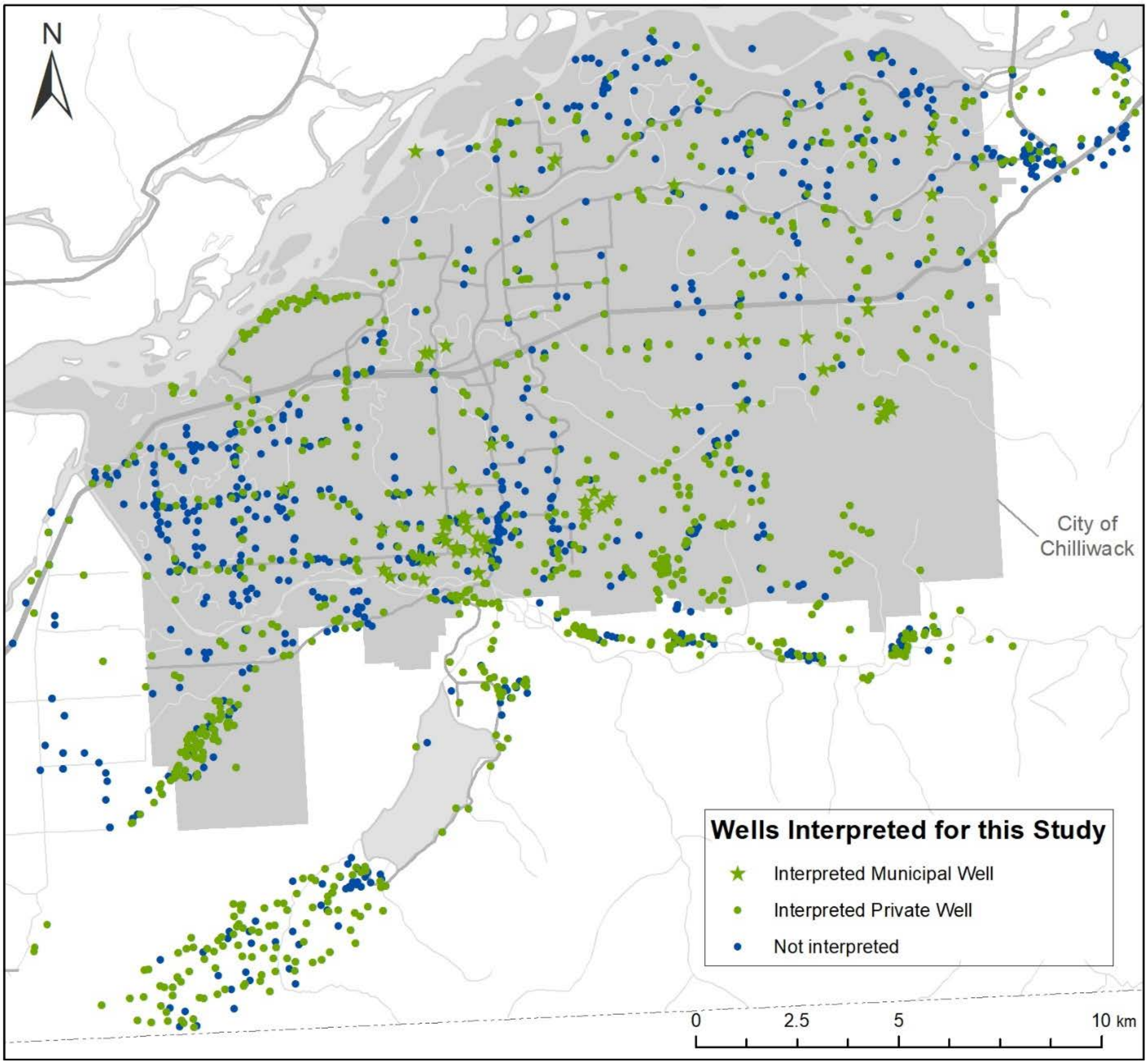

Figure 7: Boreholes and wells used for interpretation.

A web of cross-sections was constructed across the entire Chilliwack study area (Figure 8). In the Fraser Lowland part of the study area, a grid of ten primary cross-sections (labelled 2A to 2J) was created in a 1 to 2-mile N-S and E-W pattern. Inset cross-sections (labelled 2Ea, etc.) were added to better understand the correlations and an additional eight secondary cross-sections (2K to 2Q and 2AL) were plotted at the same vertical scale to provide additional detail. Similarly, in the Chilliwack River Valley, Cultus Lake area and the Columbia Valley, seven primary cross-sections were constructed:

- one oriented roughly E-W along the axis of the Chilliwack River Valley (2S);
- two north of Cultus Lake, oriented E-W (2T) and N-S (2U);
- one oriented NE-SW in the Columbia Valley (2V); and.
- three oriented E-W across Columbia Valley (2W to 2Y).

A further thirteen secondary cross-sections were plotted at the same vertical scale in the Chilliwack River Valley, Ryder Upland and the east side of Cultus Lake (2Z to 2AK, 2AM). Scanned images of the interpreted cross-sections are included in Appendix 7.

Following completion of correlations and definition of aquifers, the tops and bases of all the identified aquifers were entered into tables, which are included as Appendix 8 (Fraser Lowland and Marble Hill Road) and Appendix 9 (Columbia Valley, Cultus Lake, Chilliwack River Valley and Ryder Upland). The reported aquifer bases on these tables can be either the total depth, where the bottom of a well is still in an aquifer, or the true base, where underlying deposits were penetrated. To distinguish between these, a notation beside each base is included: "TWD" (i.e. total well depth") for cases where the well total depth is within an aquifer, and "base" for the true base of an aquifer.

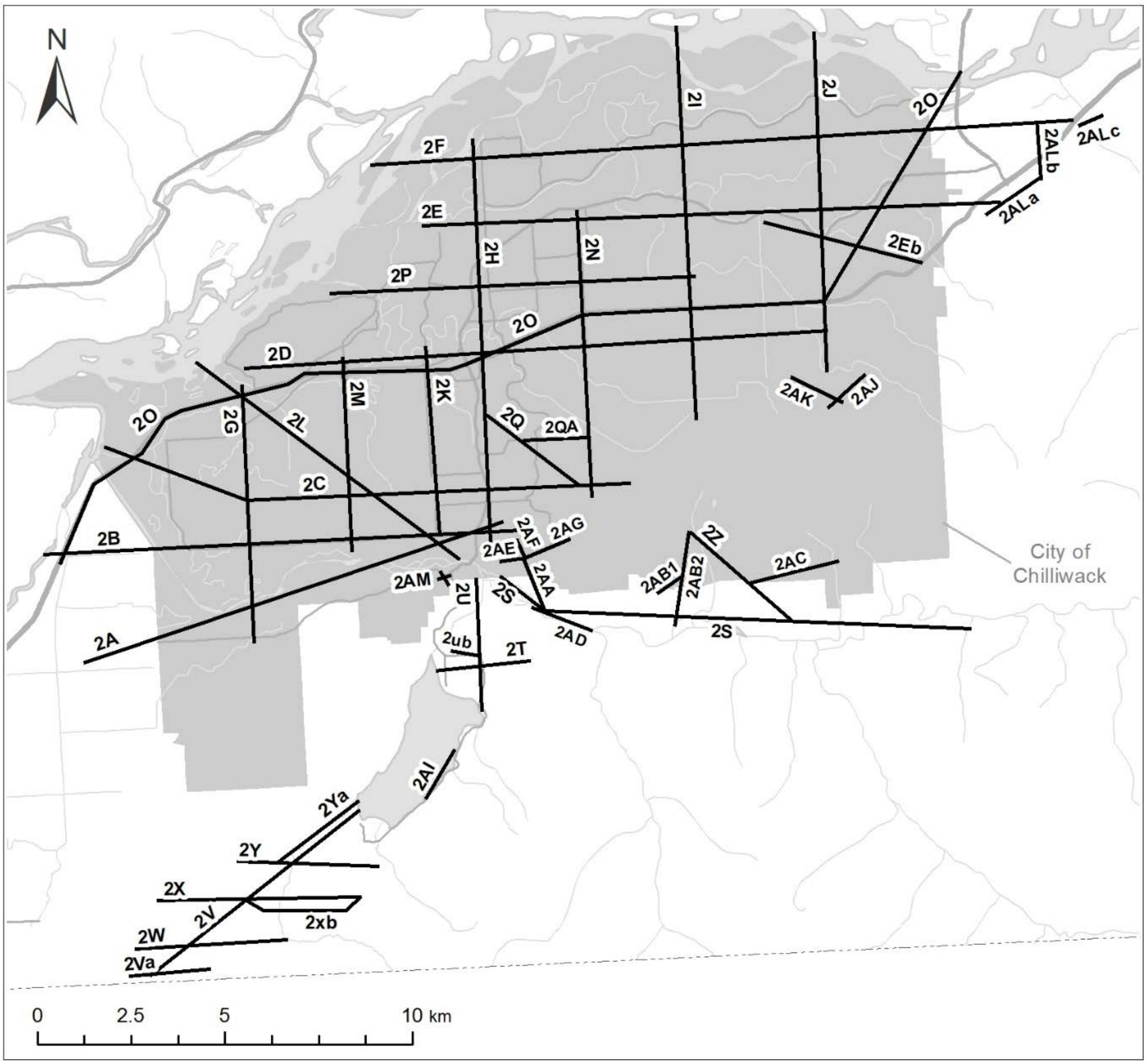

Figure 8: Approximate cross-section locations.

Subdivisions
Mappable subdivisions were recognized in several aquifers. These include stratigraphically distinct units, such as the CRA and the underlying CRB of the Chilliwack Rosedale Aquifer, as well as laterally equivalent units, such as the distal sand fringe of the Sardis Vedder Aquifer. In the case of the Columbia Valley Aquifer, the Columbia Valley Aquifer B unit (CVB) both overlies and is in part laterally equivalent to parts of the Columbia Valley Aquifer A unit (CVA). The tops and bases of these subdivisions were also included in the aquifer tables (Appendices 8 and 9).

The Chilliwack Rosedale Aquifer B unit and the Sardis Vedder Aquifer have an interfingering relationship with underlying fine-grained deposits, such that tongues of aquifer material extend laterally from the main aquifer body, are bounded above and below by non-aquifer deposits, and pinch out into the non-aquifer deposits at their distal margins (Figures 5). The upper and lower contacts of these tongues have been included in the interpretations. The tongues are labelled “tongue 1”, “tongue 2”, etc, but the number simply identifies the first, second or third tongue in that well. Tongue 1 in one well is not necessarily correlative with tongue 1 in another. For simplicity, the interval from the base of the main body of an aquifer in a well to the base of the deepest tongue was entered as a separate unit of the aquifer labelled “interbedded”, as it includes both aquifer and non-aquifer materials.

Additional borehole data were added into the aquifer tables, including some from cross-sections prepared by Monahan (1995; PM5, 6) and in Sumas Prairie prepared for the Abbotsford part of the project (SV NE-SW 1, 3, SV E-W 3). Over 400 wells and boreholes were interpreted within the Chilliwack Fraser Lowland, and nearly 300 locations for the Columbia Valley, Cultus Lake, Chilliwack River Valley and Ryder Upland.

3.2.2 *Bedrock Aquifers*
Bedrock aquifers were examined primarily to determine their lateral extent and to confirm that the water-bearing intervals are in bedrock and not in unconsolidated materials. All bedrock in the area is sufficiently dense so that water production comes from fractured intervals.

Bedrock aquifers were defined in the upland areas where water wells have been drilled. In the smaller uplands, such as Chilliwack Mountain, the entire mountain is included in a single aquifer (Chilliwack Mountain Bedrock Aquifer), with the boundary being drawn along the margin of the upland. For larger upland areas, aquifer boundaries were drawn along the ridgelines or along bedrock geological boundaries, such as the boundary between the Mount Tom Bedrock Aquifer and the Elk Mountain Bedrock Aquifer, which follows a thrust fault separating Chilliwack Group strata from underlying Cultus Formation mudstones. With the exception of the two cross-sections across the Marble Hill Road well field (labelled 2AJ and 2AK), no cross-sections were constructed specifically to illustrate bedrock aquifers.

Nearly 300 wells in bedrock aquifers are tabulated in Appendix 10. The data reported for each well are the depth, depth to bedrock, depth to water, reported flow rate, and the water-bearing intervals. The data for each aquifer are summarized in Table 4.

3.2.3 *Aquifer Boundaries and Descriptions*
Combining the data from tables, cross-sections and existing geological and topographic maps, the lateral boundaries of each aquifer were mapped, as were areas where unconsolidated aquifers were in communication with each other. The aquifer boundaries were digitized by MAF Geographix, and the shapefiles are included in Appendix 11

4. RESULTS

A summary of unconsolidated aquifers in the study area is provided in Tables 1 to 3. Detailed descriptions of these aquifers follow in section 4.1.

A summary of bedrock aquifers in the study area is provided in Table 4. Detailed descriptions of these aquifers follow in section 4.2.

The regional distribution of the aquifers by depth and age are shown in Figures 9 and 10. Aquifer mapping reports have also been prepared and are included in Appendix 12. Aquifer vulnerability ratings were designated according to criteria defined by Berardinucci and Ronneseth (2002) as summarized in Tables 1 to 4 and Figure 11.

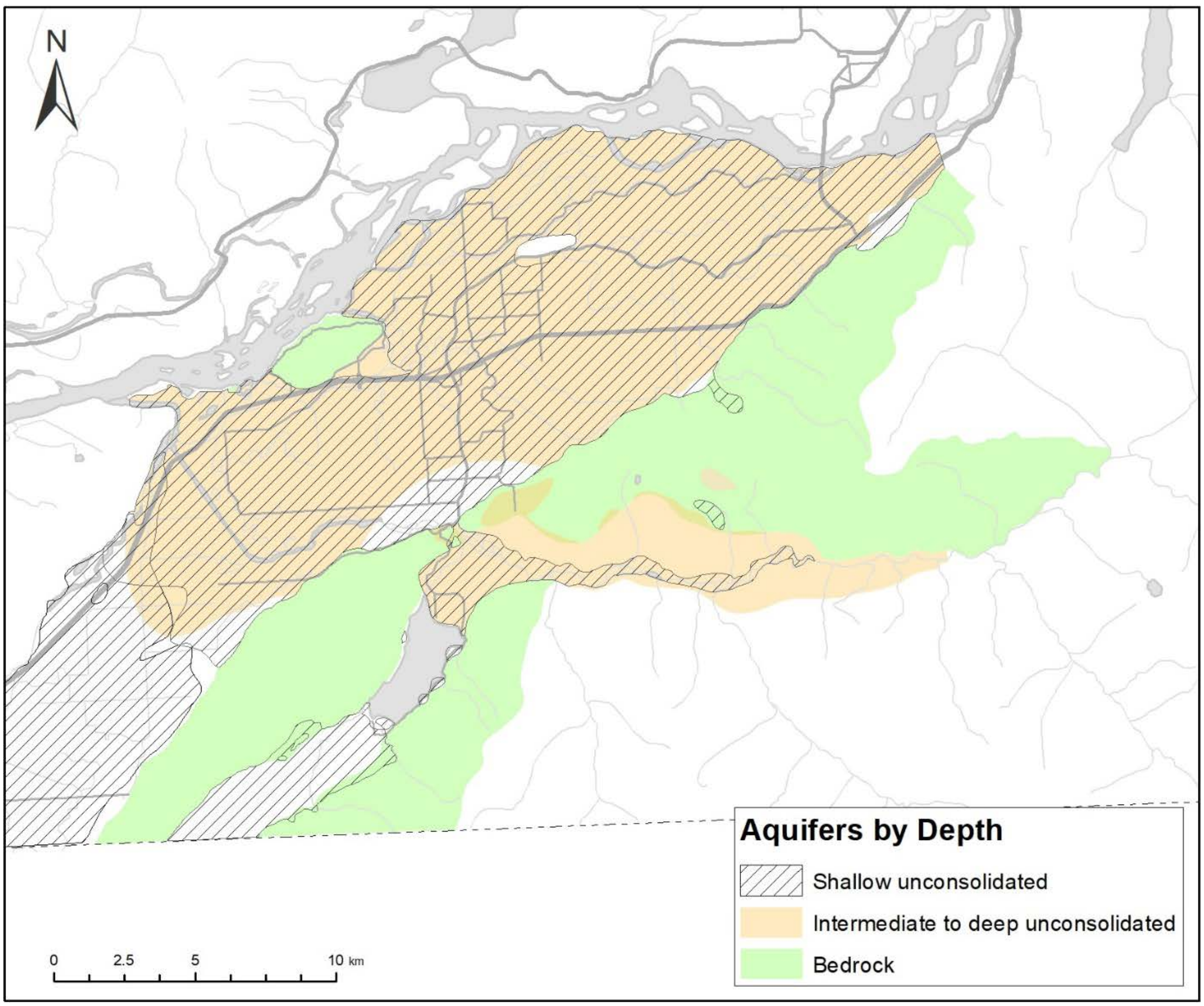

Figure 9: Aquifers by depth.

Number	Name	Lithology	Thickness	Confinement and overlying deposits	Vulnerability	Comments
0006	Chilliwack Rosedale Aquifer; CRA Unit	Holocene fluvial sand and gravel of the Fraser River; becoming finer to west; decametre-scale fining upward sequences	Generally,10-25 m, up to 35 m	Partially confined; mean depth 6 m; in Fraser Floodplain, a few m of silt and clay, locally up to 15 m in abandoned channel fill; in Vedder Fan lacustrine silt or directly overlain by Sardis Vedder Aquifer; in Cheam Plateau up to 40 m slide debris	High - partially confined; generally overlain by a few m of overbank silt and clay, but unconfined adjacent to major channels, and where overlain by Sardis Vedder Aquifer; shallow water table, and high permeability	High iron, manganese and locally arsenic reported
0008	Sardis-Vedder Aquifer	Holocene alluvial fan cobbles, gravel and sand; fines to sand downward and laterally to distal margins	Maximum known thickness 75 m; thins to zero at distal margins	Unconfined; extends to surface in most areas; overlain by up to 15 m silt, clay and peat on parts of distal margin	High - unconfined	City of Chilliwack well field at head of fan is principal domestic water supply for City
1196	Elk Creek Fan Aquifer	Holocene alluvial fan gravel and sand; includes low permeability gravels (colluvium or debris flow deposits)	Maximum known thickness 40 m, permeable intervals up to 15 m	Unconfined; generally overlain by a few m of topsoil and locally clay	High- unconfined	Laterally continuous with the CRA
1198	Cheam Slide Aquifer	Holocene slide debris and locally gravel, sand and silt within Cheam Slide mass	Slide mass 15-60 m; permeable intervals up to 20 m	Partially confined; slide extends to surface or covered beneath late Holocene colluvium and lacustrine deposits; depth to permeable intervals generally 9-24 m	High - partially confined	With Cheam Lake forms perched system above CRA
1199	Sumas Prairie North Aquifer	Fine sand beds within lacustrine silts clay and very fine sand package above CRB and below CRA and Sardis Vedder Aquifer; several minor aquifers may be present	Interval thickens south and west from 5 m to over 50 m in Sumas Prairie where Sardis Vedder Aquifer and CRA are absent	Confined; overlain by Sardis Vedder Aquifer with interfingering contact, and by CRA in western Chilliwack; by Sumas Prairie south aquifer in northern Sumas Prairie; lacustrine sediment package extends to surface where CRA and Sardis Vedder Aquifer are absent	Low - confined	
0020	Columbia Valley Aquifer	Sumas Stade outwash gravels; lower part (CVA) consists of gravel, shale gravel and boulders; upper part (CVB) broken shale, till, slide rock, dirty gravel and gravel	Maximum thickness unknown but exceeds 150 m; mean CVB thickness 58 m	Unconfined; extends to surface	Moderate - unconfined, but water table 30-100 m below surface; poorer permeability materials in upper part over most of aquifer.	
1200	Cultus Lake Fan Delta A Aquifer (CLFDA)	Shale gravel, broken shale, clay and "till" interbeds	>35 m	Unconfined; permeable materials extend to surface; impermeable units within aquifer likely to be discontinuous	High - unconfined, water table 20 m	2 wells
1201	Cultus Lake Fan Delta B Aquifer (CLFDB)	Shale gravel, gravel, sand, clay and "till" interbeds	>71 m	Unconfined; permeable materials extend to surface; impermeable units within aquifer likely to be discontinuous	High - unconfined, water table 25 m	2 wells
1202	Cultus Lake Fan Delta C Aquifer (CLFDC)	Shale and gravel	>34 m	Unconfined; permeable materials extend to surface; impermeable units within aquifer likely to be discontinuous	High - unconfined, water table 20 m	1 wells
1203	Cultus Lake Fan Delta D Aquifer (CLFDD)	Probable shale and gravel by analogy with other Cultus Lake Fan Delta aquifers		Unconfined; permeable materials likely extend to surface	High - by analogy with 1200-1202	no wells; probably similar to other Cultus Lake Fan Delta aquifers; separate from CV
1204	Cultus Lake Fan Delta E Aquifer (CLFDE)	Shale gravel	>19 m	Permeable materials extend to surface; impermeable units within aquifer likely to be discontinuous	High - by analogy with 1200-1202	1 well
1205	Vedder Crossing Aquifer	Upper part (VCA), sand and gravel with boulders and cobbles, matrix-rich and with some shale gravel; Sumas and possibly Fraser Glaciation advance outwash. Lower part (VCB), sand and gravel with some silt and clay; may be pre-Wisconsin	VCA, up to 32 m; VCB>9m	VCA unconfined; permeable materials extend to surface; VCB confined and separated from VCA by 6 to 27 m clay till, although this is locally breached.	High- unconfined -	

Table 1: Shallow unconsolidated aquifers (continues onto next page).

Number	Name	Lithology	Thickness	Confinement and overlying deposits	Vulnerability	Comments
0009	Chilliwack River Shallow Aquifer	Fluvial gravel, sand and boulders of modern Chilliwack River; in terrace at north end of Cultus Lake includes Sumas outwash	10 m mean, up to 25m	generally unconfined; locally overlain by up to 7 m of floodplain silts or colluvium in Chilliwack River Valley	High- unconfined	locally incised through till into Chilliwack River Subtill Aquifer in Chilliwack River Valley; till between Chilliwack River Shallow and Chilliwack River Subtill Aquifer pinches out in terrace adjacent to north end of Cultus Lake, forming continuous unconfined aquifer >73 m thick
1211	Lookout Ridge Unconsolidated Aquifer	Sand and gravel	>1.2 m	confined; overlain by 77 m gravel, clay and till	Low - confined	
1212	Elkview Road Shallow	Till with sand interbeds	1 m reported	probably mainly confined, overlain by 4 to 6 m of till and clay. In two wells water reported at base of well below till and clay	Low - generally confined, but confining layer thin	aquifer materials poorly defined. Four wells with poor logs in three. Perched above Mount Tom Bedrock Aquifer.
1213	Marble Hill Road Unconsolidated Aquifer	Gravel with sand, silt, colluvium and till	10 to 30 m, mean 16 m	partially confined; locally exposed at surface, locally overlain by up to 30 m of till in central part of valley	A - partially confined; high productivity, and depth to water is shallow (1 to 24 m; mean of 4 m).	Harmelling Spring flows at 960 gpm and is located where confining layer is breached at head of small creek
1206	Chilliwack River Subtill Aquifer	primarily Late Wisconsin advance phase outwash sand and gravel (Quadra equivalent); some gravel interbedded in till	> 48 m in Chilliwack Valley floor and >100 in Ryder Upland	generally confined; in valley floors overlain by 10-60 m Late Wisconsin till; separated from CRS by till up to 30 m (mean 9 m), although locally connected where fluvial gravels incised through till in Chilliwack River Valley. On south Ryder Upland overlain directly by glaciolacustrine silts and at depths up to 155 m. exposed in valley walls of Chilliwack River	Moderate - generally confined, but with some windows where 0009 incised into it; and locally exposed in outcrops and gravel pits on the valley walls of Chilliwack River and Ryder Creek	till between Chilliwack River Shallow and Chilliwack River Subtill Aquifer pinches out in terrace adjacent to north end of Cultus Lake, forming continuous unconfined aquifer >73 m thick.

Table 1: Shallow unconsolidated aquifers (continued from previous page).

Number	Name	Lithology	Thickness	Confinement and overlying deposits	Vulnerability	Comments
1210	Mount Tom Unconsolidated Aquifer	sand and gravel, interbedded with till and clays	Intervals 1-40 m thick, mean 16 m; intervals can include non-permeable intervals up to 10 m thick; mean thickness of permeable intervals 12 m, median 6 m	Confined, overlain by clay, till, and sand and gravels; depth 5 -46 m (mean 15 m)	Low - generally confined	Poorly defined low productivity aquifer. Water-bearing parts discontinuous and may represent several aquifers. Perched above Mount Tom Bedrock Aquifer.
0006	Chilliwack Rosedale Aquifer; CRB Unit	Mainly sand, some gravel to east	Mean 15 m, up to 40 m in eastern Fraser Floodplain, thins to zero beneath Vedder Fan and Sumas Prairie	Partially confined; directly overlain by CRA sand and gravel in most of Fraser Floodplain; overlain by lacustrine silt, clay and fine sand of SPN in western Floodplain and Vedder Fan; lacustrine deposits thicken south and west to over 25 m as CRB thins	High - connected with CRA over wide area	High iron, manganese and locally arsenic reported; in eastern Chilliwack merges with Greendale Deep Aquifer forming continuous aquifer 59 m thick
1206	Chilliwack River Subtill Aquifer	Primarily Late Wisconsin advance phase outwash sand and gravel (Quadra equivalent); some gravel interbedded in till	> 48 m in Chilliwack Valley floor and >100 in Ryder Upland	Generally confined; in valley floors overlain by 10-60 m Late Wisconsin till; separated from CRS by till up to 30 m (mean 9 m), although locally connected where fluvial gravels incised through till in Chilliwack River Valley. On south Ryder Upland overlain directly by glaciolacustrine silts and at depths up to 155 m. exposed in valley walls of Chilliwack River	Moderate - generally confined, but with some windows where 0009 incised into it; and locally exposed in outcrops and gravel pits on the valley walls of Chilliwack River and Ryder Creek	Till between Chilliwack River Shallow and the Chilliwack River Subtill Aquifers pinches out in terrace adjacent to north end of Cultus Lake, forming continuous unconfined aquifer >73 m thick.

Table 2: Intermediate unconsolidated aquifers.

Number	Name	Lithology	Thickness	Confinement and overlying deposits	Vulnerability	Comments
1207	Ryder Upland Glaciolacustrine Sand A Aquifer (RUSA)	Late Wisconsin pre-Vashon glaciolacustrine fine sand interbedded with glaciolacustrine silts and very fine sands	Fine sand intervals 2-40 m thick	Confined, overlain by glaciolacustrine silts and clays or till; depth 20-65 m (mean 39 m)	Low-confined	Low productivity aquifer. Sands appear to occur at different stratigraphic levels in glaciolacustrine section some wells but appear to be thick continuous intervals in others. May include more than one aquifer. Shallower sandy intervals dry close to exposure near edge of upland, where sands lose water. Perched above Chilliwack River Subtill Aquifer.
1208	Ryder Upland Glaciolacustrine Sand B Aquifer (RUSB)	Late Wisconsin pre-Vashon glaciolacustrine fine sands interbedded with glaciolacustrine silts and very fine sands	Fine sand intervals 3-39 m thick	Confined, overlain by glaciolacustrine silts and clays and later glacigenic sediments; depth of shallower interval 49 m	Low-confined	Low productivity aquifer. Two water-bearing intervals separated by 12 m hard packed sand, may be more than one aquifer. Perched above Chilliwack River Subtill Aquifer.
1209	Ryder Upland Glaciolacustrine Sand C Aquifer (RUSC)	Late Wisconsin pre-Vashon glaciolacustrine sands interbedded with glaciolacustrine silts and very fine sands	Fine sand intervals 1-43 m thick	Confined, overlain by glaciolacustrine silts and clay, till, or sand and gravels; depth 30-110 m (mean 39 m)	Low-confined	Low productivity aquifer. Correlative sandy interval in most wells. A water-bearing sandy interval 2 m thick and 43 m deeper interval in one well, may be a separate aquifer, but could be continuous by analogy with RUSA. Shallower sandy intervals dry close to exposure near edge of upland, where sands lose water. Perched above Chilliwack River Subtill Aquifer.

Table 3: Deep unconsolidated aquifers.

Number	Name	Lithology	Confinement and overlying deposits	Vulnerability	Comments
0899	Elk Mountain Bedrock Aquifer	Volcanics and sedimentary rocks of Pennsylvanian to Permian Chilliwack Group, particularly greenstones (altered volcanics) and pyroclastics of upper division; also mudstones of the overlying Triassic to Jurassic Cultus Formation	Partially confined; sediment cover thin and dioscontinuous over most of aquifer; in wells up to 68 m of glacigenic sediments overlying bedrock (median 17 m).	Moderate - partially confined; sediment cover thin and discontinuous in most of area; but in wells generally confined; moderate to high productivity, moderate depth to water (median 26 m).	City of Chilliwack Marble Hill Road well field located in this aquifer. Boundary with Mount Tom Bedrock Aquifer to west along thrust fault that emplaces Chilliwack Group on Cultus Formation; all wells reported in upper divison of Chilliwack Group; Cultus Formation generally at higher elevations
1214	Chilliwack Mountain Bedrock Aquifer	Intermediate to felsic pyroclastics and flows of middle Jurassic Harrison Lake Formation	Partially confined; sediment cover thin and discontinuous over most of aquifer; in wells 0-8 m sediment overlying bedrock (median 2 m)	Moderate - partially confined; sediment cover thin and discontinuous in most of area. Low productivity; moderate depth to water (median 24).	
1215	Cannor Road North Bedrock Aquifer	Intermediate to felsic pyroclastics and flows of middle Jurassic Harrison Lake Formation	Partially confined; sediment cover thin and discontinuous over most of aquifer; in wells 1-2 m sediment overlying bedrock.	Moderate - partially confined; sediment cover thin and discontinuous in most of area. Low productivity; moderate depth to water (median 15 m.	
1216	Vedder Mountain Northwest Bedrock Aquifer	Gabbro, amphibolite, schist and minor ultramafics of the Permian to Triassic Vedder Complex; locally Jurassic to Cretaceous conglomerate, sandstone, argillite, basalt and schistose chert	Partially confined; sediment cover thin and discontinuous over most of aquifer; in wells up to 35 m of glacigenic sediments (median 5 m)	High- partially confined; sediment cover thin and discontinuous in most of area. Moderate productivity; low to moderate depth to water (median 12 m).	
1217	Vedder Mountain Southeast Bedrock Aquifer	Jurassic to Cretaceous conglomerate, sandstone, argillite, basalt and schistose chert, Kent Formation	Partially confined; sediment cover thin and discontinuous over most of aquifer; overlain by up to 35 m of glacigenic sediments on west side of Columbia Valley.	High- partially confined; sediment cover thin and discontinuous in most of area. Moderate productivity; low to moderate depth to water (median 10 m).	
1218	East Cultus Columbia Bedrock Aquifer	Mudstones and fine sandstones of Triassic-Jurassic Cultus Formation	Partially confined; sediment cover thin and discontinuous over most of aquifer; overlain by up to 55 m of glacigenic sediments on east side of Columbia Valley.	High- partially confined; sediment cover thin and discontinuous in most of area. Moderate productivity; low to moderate depth to water water; in Columbia Valley median depth to water 39 m, but elsewhere (more representative of aquifer as a whole) 11 m.	

Table 4: Bedrock Aquifers.

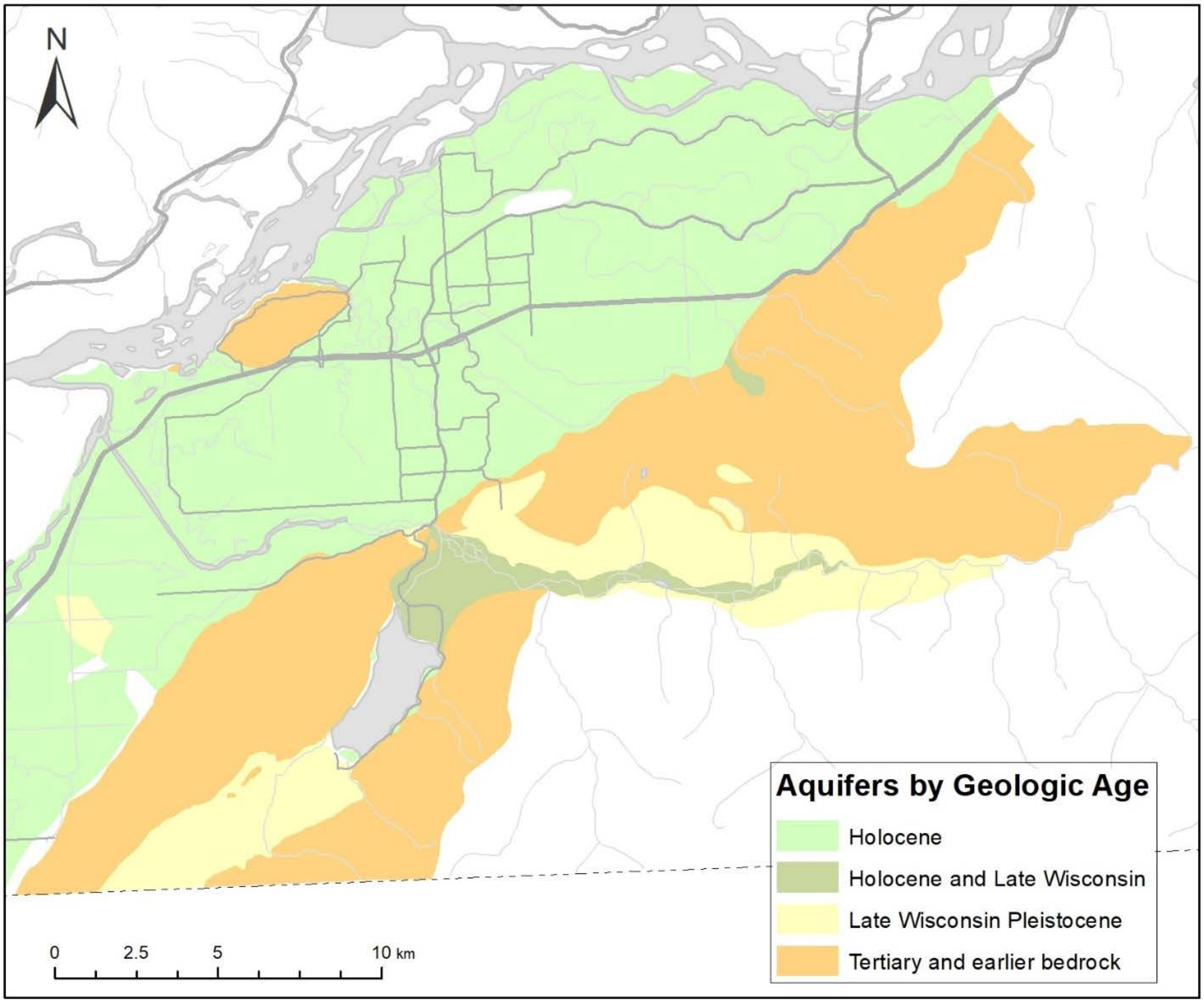

Figure 10: Aquifers by geologic age.

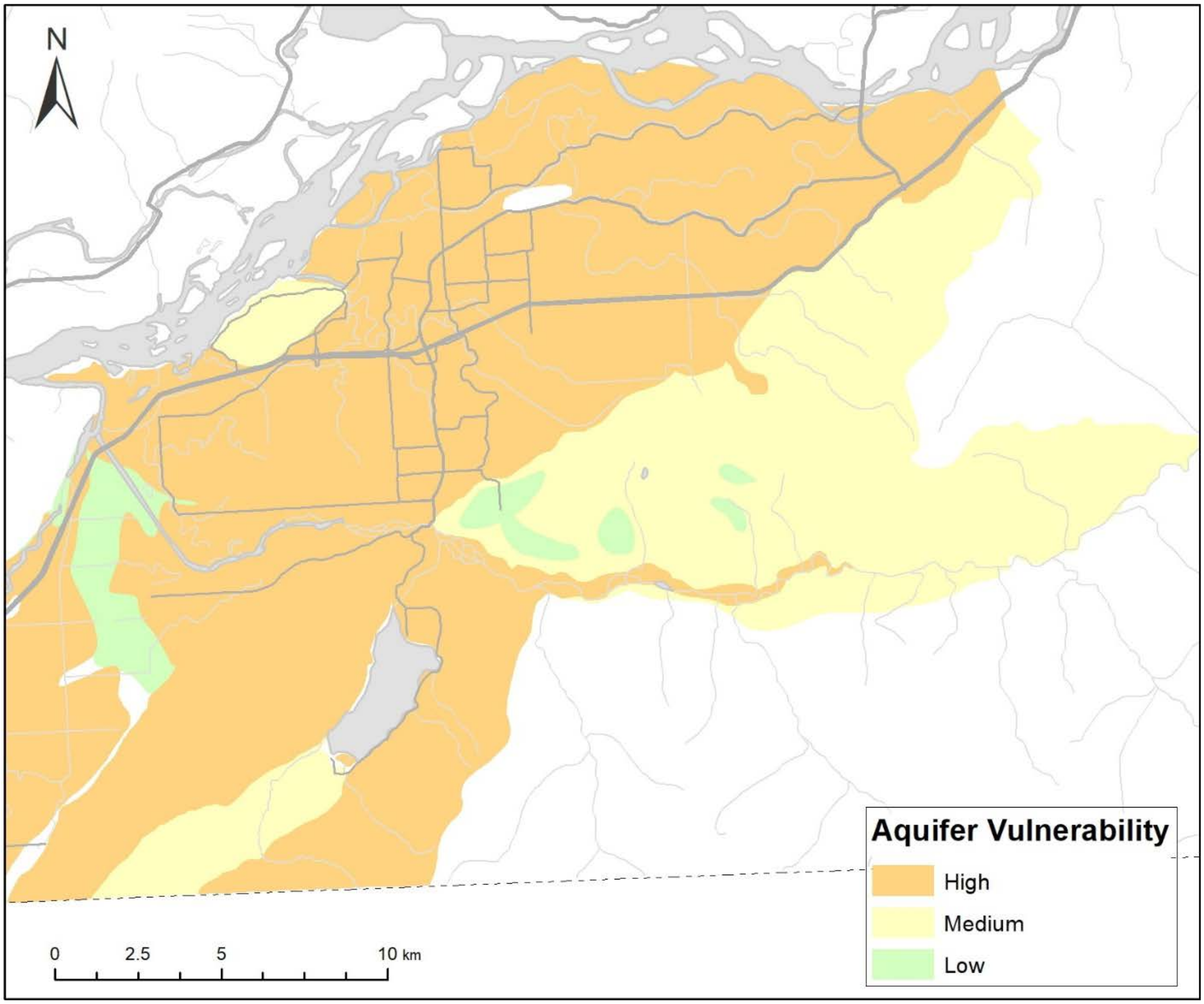

Figure 11: Aquifer Vulnerability.

4.1 Unconsolidated Aquifers

4.1.1 *Chilliwack Rosedale Aquifer - Aquifer 0006*

Figures: 4, 5, 12, 13, 14, 15 and 16
Cross-sections: 2A - 2Q, 2AL

The Chilliwack Rosedale Aquifer (Carmichael et al., 1995) comprises deposits underlying the Fraser River Floodplain in Chilliwack. Stratigraphically, it can be subdivided into two distinct units, which are hydraulically connected in much of the Floodplain area – the Chilliwack-Rosedale A unit (CRA) and the Chilliwack Rosedale B unit (CRB), which form the upper and lower parts, respectively.

Chilliwack Rosedale A Unit (CRA)

The CRA underlies most of the Fraser Lowland in Chilliwack, the Cheam Plateau, and the northern third of the Vedder Alluvial Fan (Figures 4, 5, 12, 13, 14 and 15). Its westward limits are at or immediately east of the Vedder Canal, and it is locally absent adjacent to Chilliwack Mountain and Mount Shannon. The northern boundary is the modern course of the Fraser River. The mapped limits of this aquifer differ somewhat from the previous interpretation (Carmichael et al., 1995), due in part to improved subsurface borehole control.

The CRA consists of fluvial sands and gravels representing active channel fill deposits of the Fraser River, and is commonly organized into decametre-scale fining upward sequences (Dakin, 1994; Carmichael et al., 1995; Levson et al., 1996a, b, c, 1998; Sacré et al., 1997; Monahan and Levson, 2003). Overall, grain size fines in a westward direction, and is primarily sand in the westernmost part of the City. An analogous downstream fining from gravel to sand is observed in the bed of the modern Fraser River, although this has shifted west to Mission and Abbotsford (McLean et al., 1999; Venditti et al., 2014). It is generally between 10 and 25 m thick, with a mean of 16 m, and locally exceeds 35 m in the eastern parts of the City.

The CRA is partially confined. It is generally overlain by floodplain and abandoned to partially abandoned channel fill deposits (Figure 13). The floodplain deposits consist of silts, clays, and locally peat near the Cascade Mountain front. These deposits are usually only a few metres thick but are up to 10 m locally in the southwest part of the city and near the Cascade Mountain front. Regionally, they thin and approach zero toward the banks of modern Fraser River and toward alluvial fans at the Cascade Mountains front, where the upper part of the aquifer may include some fan-derived sands and gravels. Abandoned to partially abandoned channel silts and clays with some sand interbeds occur locally, notably adjacent to sloughs that represent partially abandoned channels of the Fraser River. A particularly large body 15 m thick, 6 km long and 3 km wide is present in the vicinity of the Prest Road Interchange (Figure 13b; Monahan, 1995; Levson et al., 1996c, 1998; Monahan and Levson, 1996).

The aquifer is locally unconfined adjacent to the modern Fraser River, where partially abandoned channels of the Fraser are locally incised into it, and in two areas in western Chilliwack where it is directly overlain by and hydraulically connected with the sands and gravels of the Vedder Alluvial Fan, which constitute the Sardis Vedder Aquifer (Figures 12, 13b, 14 and 15).

In the Cheam Plateau, the CRA is overlain by debris of the Cheam Slide (Figure 12; Savigny and Clague, 1992; Evans and Savigny, 1994; Orwin et al., 2004). The thickness of slide materials overlying the aquifer is less than 10 m over much of the distal parts of the slide, but up to 47 m in the proximal parts. The top of the aquifer rises above the level of the floodplain beneath the slide deposits in this area, and the aquifer materials there may include combinations of valley edge alluvial fan deposits, Pleistocene glaciogenic deposits, and Fraser River sands remobilized by emplacement of the slide. In this area, the static water levels are the same as in the Fraser Floodplain, so that the water table is up to 30 m deep. In the most proximal parts of the slide, some wells have encountered water in Pleistocene sands and gravels beneath till and glaciomarine clay. Whether these aquifer materials are connected with the CRA is unknown, and they were not interpreted to be part of the Chilliwack Rosedale unit.

Along the Cascade Mountain front, the CRA merges laterally with alluvial deposits of the Elk Creek Fan Aquifer and with a smaller fan to the southwest (Figure 12).

In a northeast-trending swath in the central part of the floodplain and northeast of Chilliwack Mountain, the CRA is directly underlain by the sands of the early Holocene deltaic deposit formed during the early post glacial progradation of Fraser River deposits into the Chilliwack area (CRB; Figures 12, 13 and 15). The contact between the two units is marked by a downward decrease in grain size at approximately 10 m below sea level. However, in the easternmost part of the floodplain where more gravel occurs in the CRB, the contact becomes arbitrary. Elsewhere, the CRA and CRB are separated by a few metres of thinly interbedded lacustrine and floodplain silts, clays and very fine sands. In the western part of Chilliwack, this fine-grained unit thickens to over 10 m as the top of the deltaic sands descends stratigraphically to the south and west (Figures 4, 5, 13a and 15; Monahan, 1995; Levson et al., 1996a;

Monahan and Levson 2003). Where the CRA and CRB are in direct contact, they form a continuous aquifer.

The aquifer is probably recharged from precipitation, from the Vedder alluvial fan and from mountain front and mountain block recharge from the Cascade Mountains. However, with the exception of recharge from the Vedder fan, recharge is likely low, as there are naturally occurring water quality issues with this unit - iron, manganese, and in the western part, arsenic (Livingston, 1973; Dakin, 1994; Emerson, 2005; Graham 2006). Adjacent to the modern Fraser River, recharge also occurs seasonally from the river (Romano et al., 2014).

Several groundwater exploration projects have been conducted in this aquifer for the City of Chilliwack (Smith and Jardine, 1995; Jardine and Smith 1996; Klohn-Crippen, 1996; Emerson, 1995, 2005).

Chilliwack Rosedale B Unit (CRB)

The CRB unit underlies all of the Fraser River Floodplain within the City of Chilliwack, the Cheam Plateau, most of the Vedder alluvial fan, and extends southwest to the northern parts of Sumas Prairie (Figures 4, 5, 12, 13, 14 and 16). As for CRA, the mapped limits of this part of the Chilliwack Rosedale Aquifer differ from those shown by Carmichael et al. (1995) due in part to improved subsurface borehole control.

The CRB consists primarily of sands, with some gravels occurring in the eastern part of the project area. It is generally 15 to 40 m thick, but in the eastern part of Chilliwack it thickens down to merge with the Greendale Deep Aquifer, forming a continuous unit greater than 58 m thick (Figure 13c). As described above, it is overlain by Fraser River sands and gravels of the CRA in much of the area, and where this occurs, the CRA and CRB form a continuous aquifer (Figures 12, 13 and 16). Elsewhere, the units are separated by a few metres of silt, clay and very fine sand.

Like the CRA, the CRB is generally confined. However, in those areas where the CRA becomes unconfined, the CRA and CRB are in communication, making the CRB effectively unconfined there as well. These areas are adjacent to the modern Fraser River, where sloughs meander across the Floodplain, and where the CRA is directly overlain by sands and gravels of the Sardis Vedder Aquifer.

The upper surface is generally at an elevation of approximately 10 m below sea level, although in the vicinity of Mount Shannon, the surface appears more irregular, possibly due to erosion. In the western part of Chilliwack, the surface descends stratigraphically beneath the finer sediments, southward beneath the Vedder Alluvial Fan and westward beneath Sumas Prairie, ultimately pinching out into finer sediments (Figures 3, 4, 13a, 14 and 16; Monahan, 1995; Levson et al., 1996a; Monahan and Levson 2003). The CRB is underlain by fine sands, silts and clays, with an interfingering contact. Tongues of the CRB sands occur locally, and these pinch out to the west into the underlying fine deposits. As noted above, the geometry of the CRB sands suggests a deltaic origin, formed during the early post glacial progradation of Fraser River deposits into the Chilliwack area when sea level was lower. Numerous cone penetration tests confirm that it has not been glacially overridden and consequently that it is post-glacial in age (Monahan, 1995).

As in the CRA, elevated iron, manganese and arsenic levels have been reported in the CRB (Graham 2006).

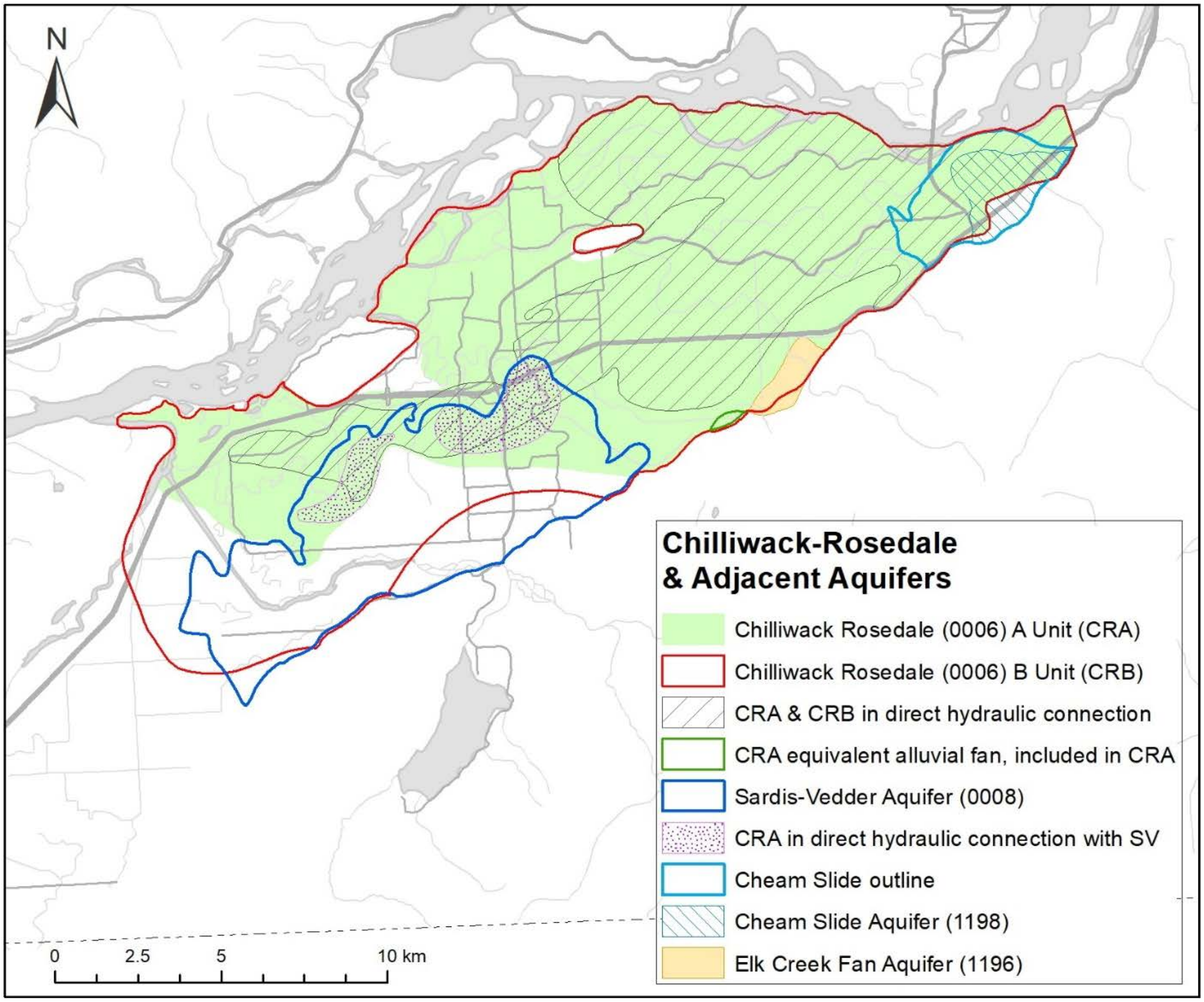

Figure 12: Chilliwack Rosedale detailed hydrostratigraphy and adjacent aquifers. Note: SV = Sardis-Vedder Aquifer.

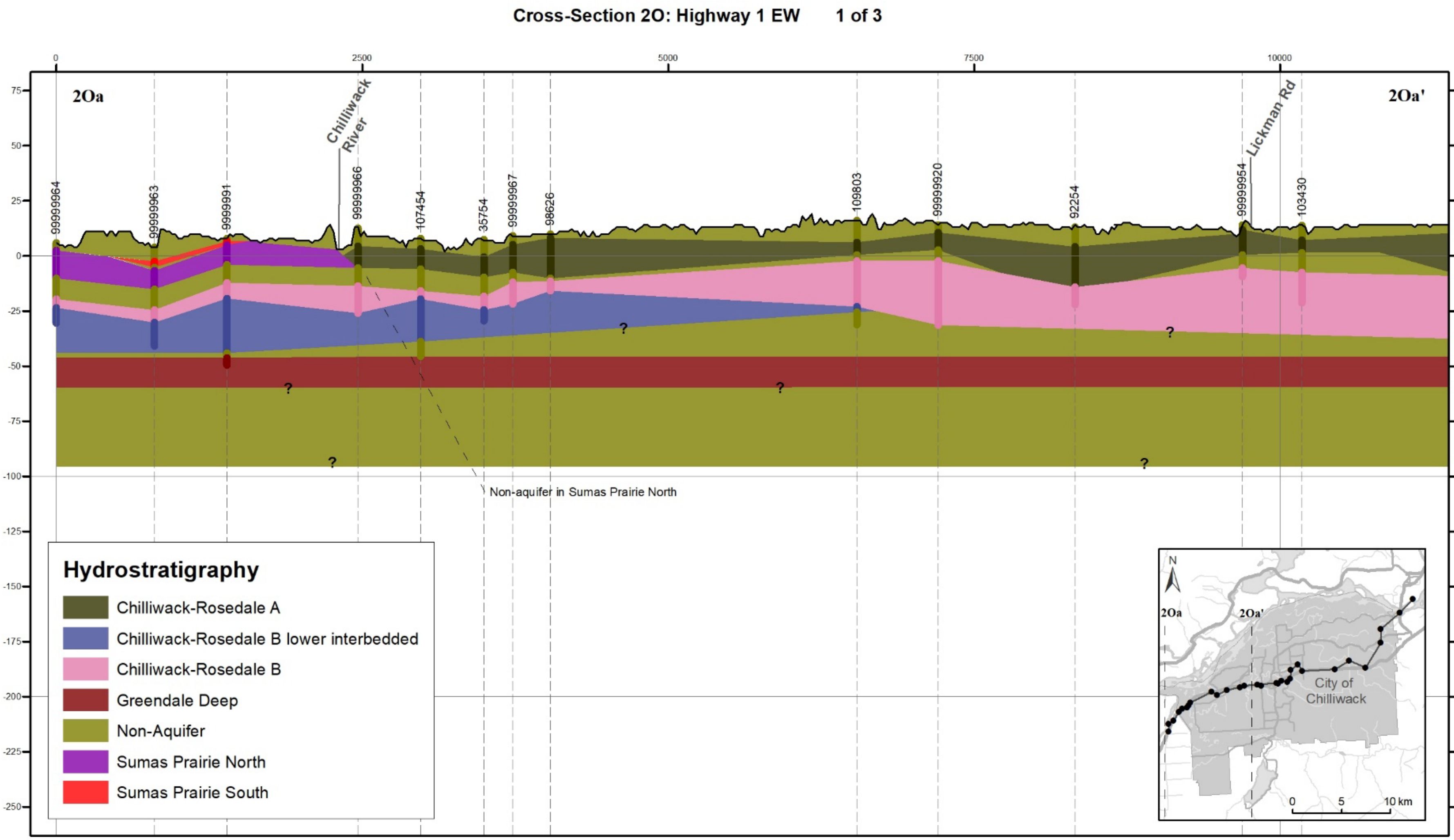

Figure 13a: Cross-section 2O, Highway 1 East-West, western third.

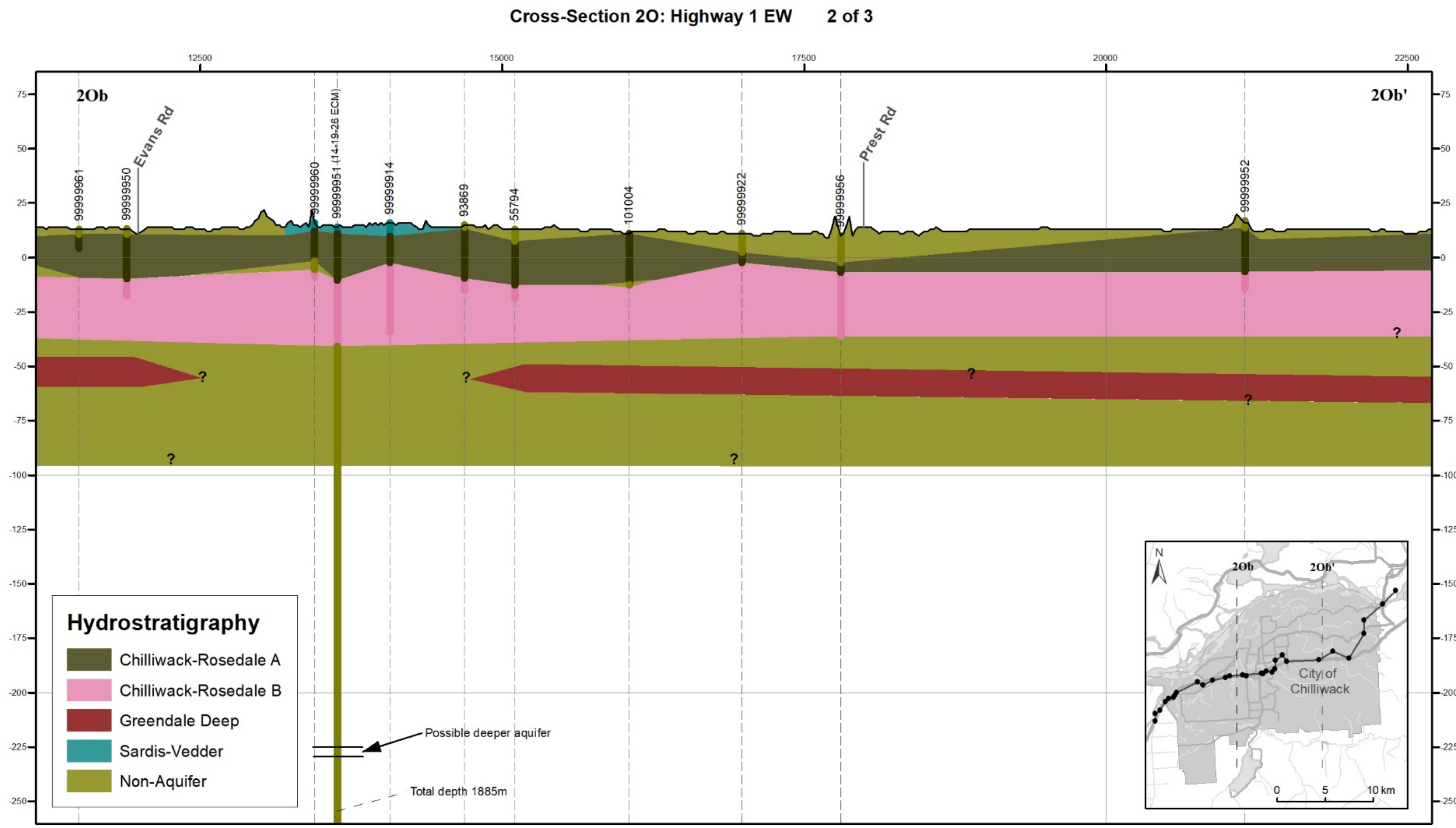

Figure 13b: Cross-section 2O, Highway 1, east-west 2 of 3, central third.

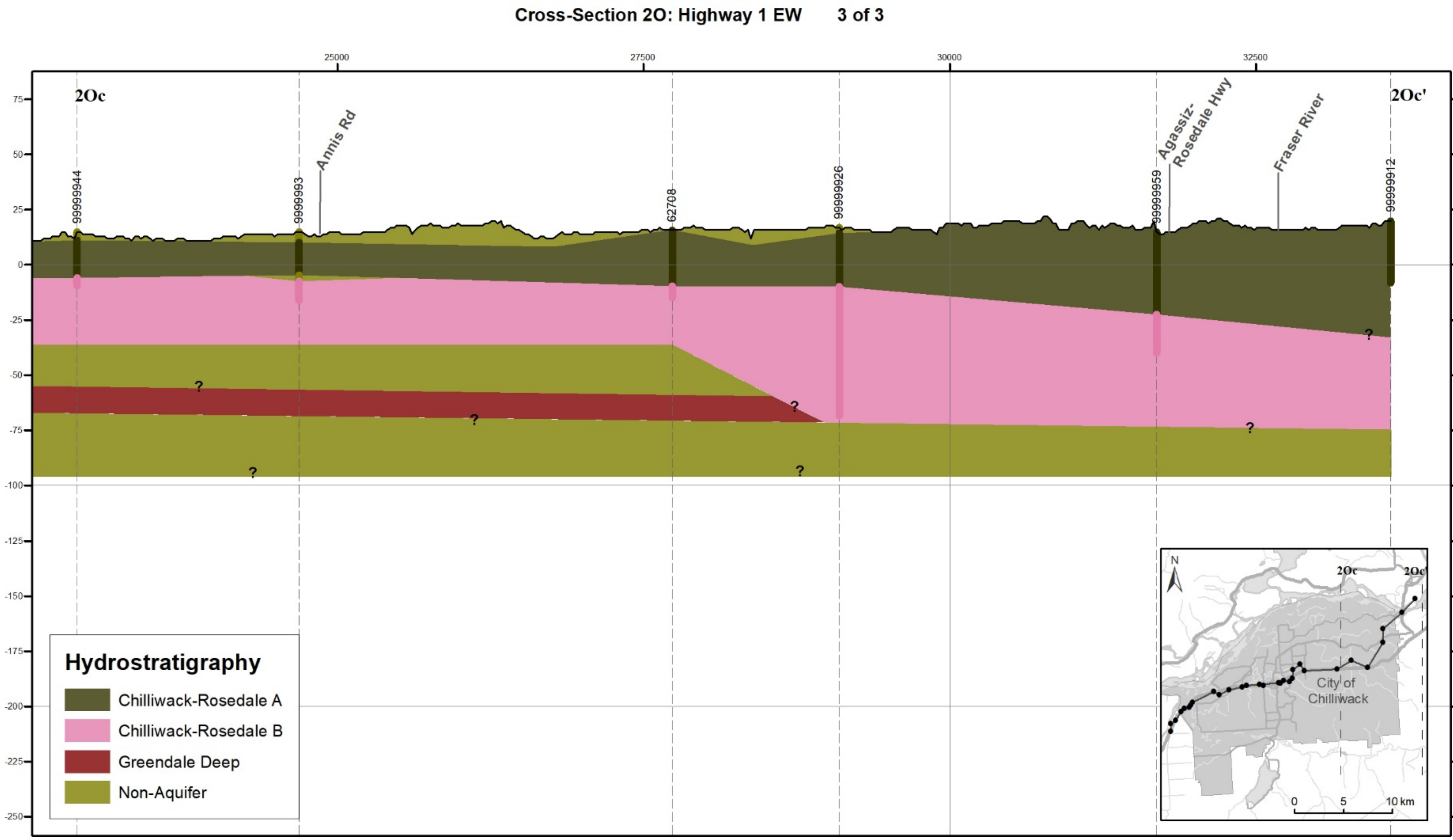

Figure 13c: Cross-section 2O, Highway 1, east-west 3 of 3, eastern third.

4.1.2 *Sardis Vedder Aquifer - Aquifer 0008*

Figures: 5, 12, 13b, 14, and 15
Cross-sections: 2A- 2D, 2G-2H, 2K-2O, 2Q

The Sardis Vedder Aquifer consists of the sands and gravels of the Vedder Alluvial fan, which has formed during the Holocene where the Chilliwack River exits the Cascade Mountains (Armstrong, 1980a, b; Dakin, 1994; Carmichael et al., 1995; Levson et al., 1996a, b, c, 1998; Emerson, 2000; Emerson Groundwater Consultants Inc, 2003; Monahan and Levson, 2003; Tunnicliffe et al., 2012). The surface of the fan is at an elevation of approximately 36 m near the apex, and it slopes down to approximately 12 m where it joins the Fraser Floodplain. In general, the mapped outline of the aquifer follows the outline of the alluvial fan on the surficial geological maps (Armstrong 1980a, b; Levson et al., 1996b), similar to what has been previously mapped (Carmichael et al., 1995).

The maximum thickness is unknown. Near the apex of the fan in well WTN 62723, cemented gravel encountered at a depth of 64 m (34 m below sea level) may represent a pre-Holocene deposit. However, the maximum known thickness is 75 m, where the depth is 44 m below sea level. Based on the interpretation that the Greendale Deep Aquifer is a post-glacial marine outwash sand, the maximum depth of the Holocene fill of the Fraser Floodplain in the area, and consequently the Vedder Alluvial Fan, is unlikely to exceed 50 - 60 m below sea level.

The aquifer materials fine from coarse sands, gravels and cobbles to sand, both downslope away from the apex and downward toward the base. Levson et al (1996b, 1998) show a lateral change on the surface from gravel and coarse sand to sand, silt and gravel approximately half way across the fan. However, the well logs used for the current study are not sufficiently detailed to recognize any more than a narrow sand fringe around the distal margin of the fan. This was recorded, mapped and digitized (Figure 14). In several wells near the apex, a sandier lower part can be identified on logs. Where observed, this contact was recorded, but it could not be recognized in most logs due to insufficient detail. It likely represents a diachronous contact within the fan.

The aquifer is generally unconfined, with a thin cap of “soil” or “topsoil”. However, in a few locations in the distal parts of the fan, it is overlain by silt, clay and peat that are generally less than 5 m thick but can collectively exceed 15 m. Adjacent to the Cascade Mountain Front at the Bailey Landfill site, the Sardis Vedder Aquifer is overlain by up to 9 m of peat and locally interbedded with it.

The Sardis Vedder Aquifer overlies lacustrine silts, clays and fine sands with an interfingering contact (Figures 5 and 14; Monahan 1995; Monahan and Levson, 2003; Emerson Groundwater Consultants Ltd., 2003). The lacustrine section includes thin water-bearing sand beds that are included in the Sumas Prairie North Aquifer. Several tongues of Sardis Vedder Aquifer material extend northward from the alluvial fan body and pinch out into the lacustrine deposits. As noted above, the top and base of each tongue in a particular well has been recorded and numbered from the top down. Where tongues are recognized in logs an interbedded facies of the Sardis Vedder Aquifer was recorded, and comprises all aquifer and non-aquifer material from the base of the main body of the aquifer to the base of the deepest tongue. At its distal margin, the Sardis Vedder Aquifer overlies and in part merges laterally with sands and gravels of the Chilliwack Rosedale Aquifer A unit (Figures 13b, 14 and 15).

The Sardis-Vedder Aquifer is recharged by the Chilliwack River, and possibly also the Chilliwack River Shallow and Chilliwack River Subtill Aquifers (Section 4.1.10 below). The depth of the water table is approximately 10 m below surface at the head of the fan, declining to within a few metres of the surface at its distal margin.

Several partially abandoned channels representing former courses of the Chilliwack River meander northward across the fan. These and some other small streams drain the fan and are sourced by precipitation and the aquifer itself. The Chilliwack River now flows west out of the mountains along the Vedder River and into the Vedder Canal.

The Sardis Vedder Aquifer is extensively exploited for groundwater. The City of Chilliwack operates a well field near the apex of the fan that includes seven production wells and seven monitoring wells and is the City's prime source of groundwater supply (Appendix 5; City of Chilliwack 2011, 2016). One of the City monitoring wells has been recently brought into the Provincial Groundwater Observation Well Network as monitoring well 459. Detailed hydrogeological assessments of this aquifer have been conducted for the City by Sacré (1997), Emerson (2000) and Emerson Groundwater Consultants Inc. (2003), and 60-day capture zone maps for six wells have been prepared by Zawadzki (2003) and AMEC Earth and Environmental (2007). Additional reports of exploratory wells were done by Smith and Jardine (1995) and Jardine and Smith (1995).

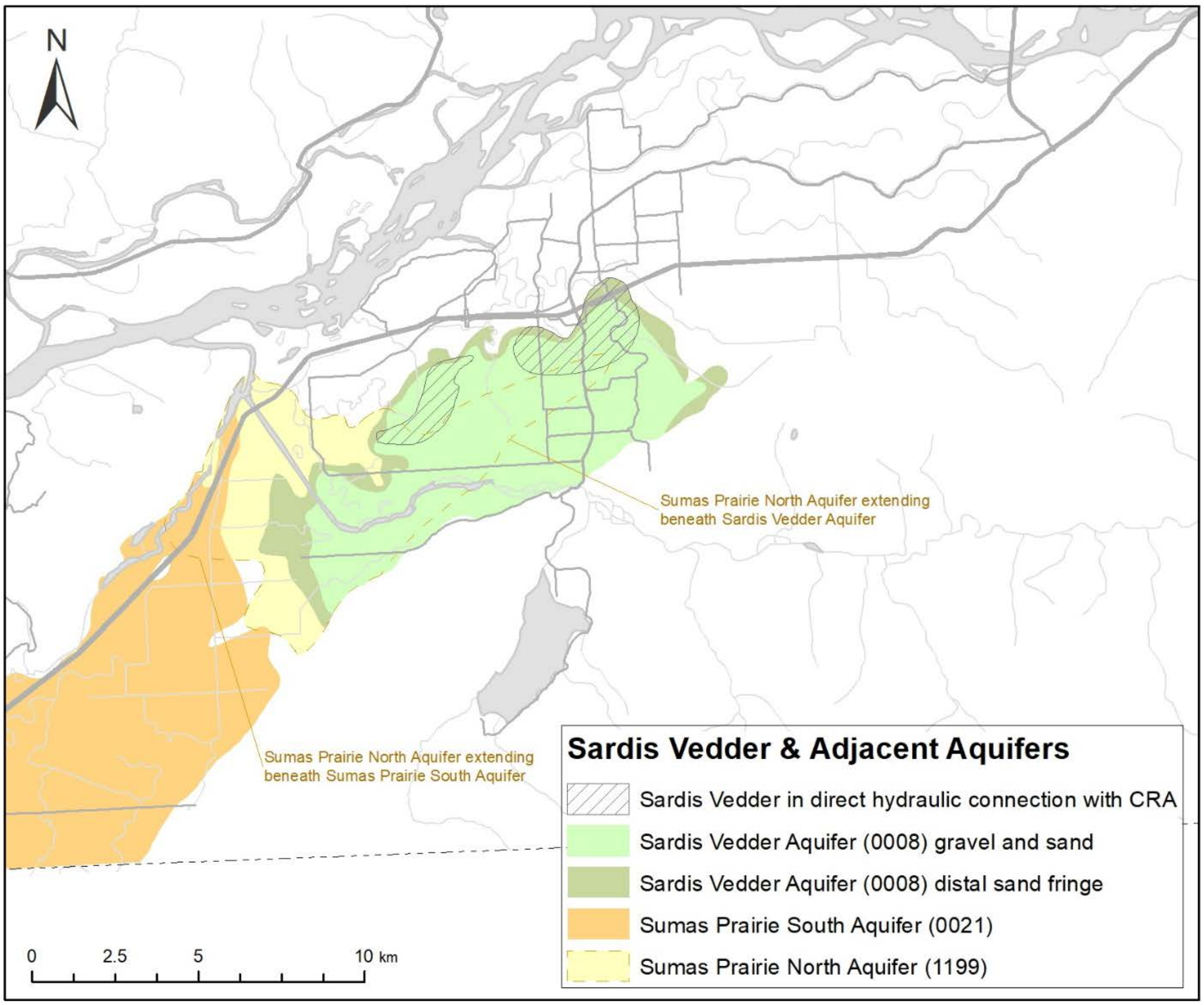

Figure 14: Sardis-Vedder detailed hydrostratigraphy and adjacent aquifers.

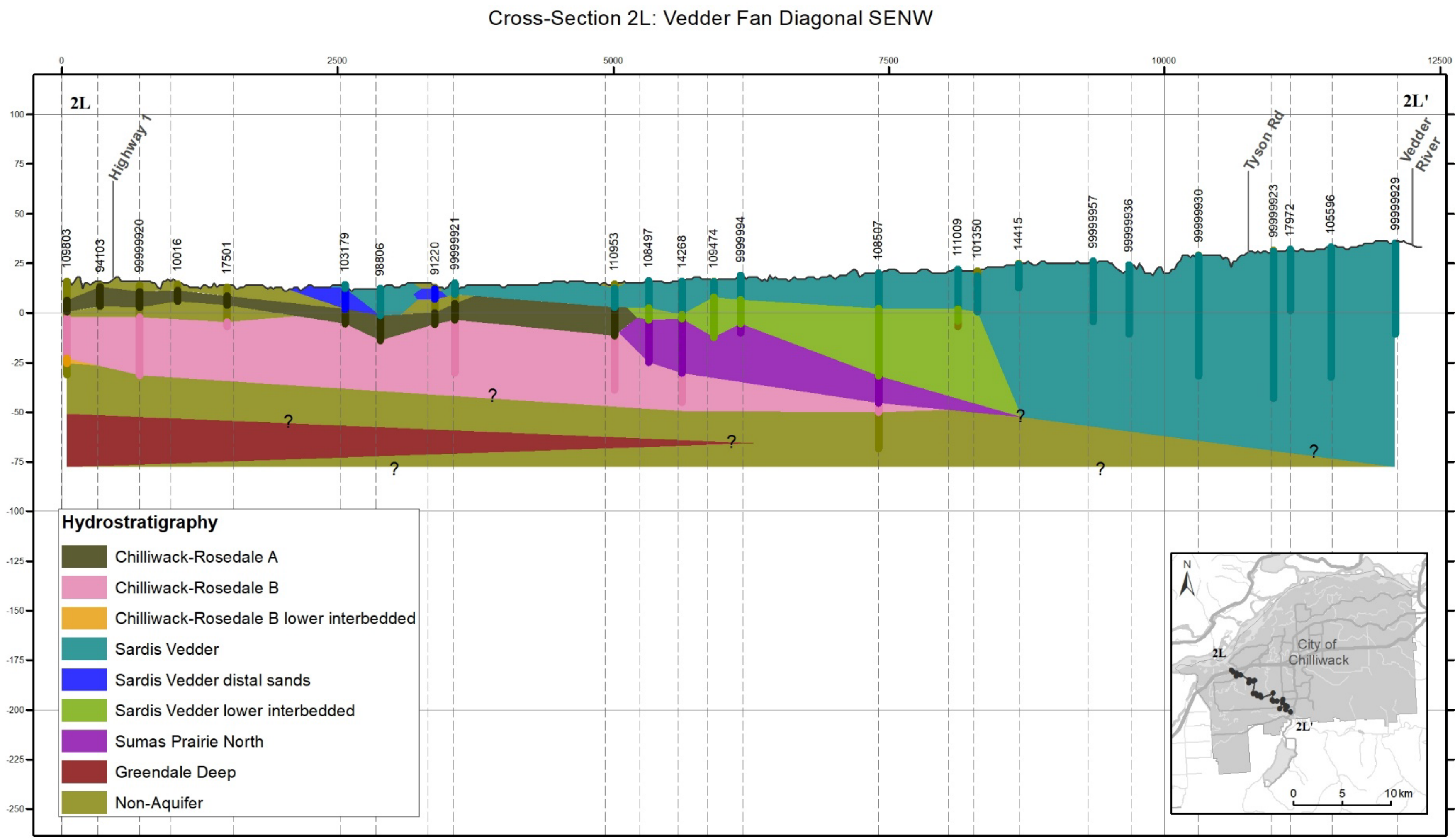

Figure 15: Cross-section 2L, Vedder Fan diagonal, southeast-northwest.

4.1.3 *Elk Creek Fan Aquifer - Aquifer 1196*

Figure: 12
Cross-sections: 2D, 2J, 2AK

The Elk Creek Fan Aquifer consists of Holocene sands, gravels and debris flow deposits in the combined alluvial fans of Elk, Marble Hill and Calkins Creeks where these streams exit the Cascade Mountains (Armstrong, 1980b; Levson et al., 1996b). The distal part of the aquifer consists up to 15 m of water-bearing sands and gravels with a thin cover of topsoil and locally a few metres of clay. In its proximal parts the aquifer is up to 40 m thick. Well logs there include sediments described as till, but these are equally likely debris flow or colluvial diamictons, as mapped by Levson et al. (1996b). The diamictons provide poorer quality aquifer material, so that wells in this setting are more likely to have been drilled deeper to an underlying aquifer. The sands and gravels of the Elk Creek Fan Aquifer grade laterally and are hydraulically connected with the sands and gravels of the Chilliwack Rosedale Aquifer A unit.

Recharge of these aquifers is expected to be from mountain front and mountain block recharge from the Cascade Mountains, with mountain front recharge principally from Elk, Marble Hill and Calkins Creeks. The Marble Hill Road Unconsolidated Aquifer may also provide some recharge to the Elk Creek Fan Aquifer. Groundwater flow would be down-fan towards the Fraser Floodplain.

4.1.4 *Greendale Deep Aquifer – Aquifer 1197*

Figures: 4, 13, 15 and 16
Cross-sections: 2A-2C, 2E-2I, 2N-2P

The Greendale Deep Aquifer underlies the central portion of the Fraser Lowland in Chilliwack. It extends from the eastern border of the City southwest into Sumas Prairie.

The Greendale Deep Aquifer consists of fine to medium sands, and near its southwestern limits, water-bearing silts. The thickness in most wells appears to be between 5 and 20 m. Thicker sections are reported in some well logs, but these are interpreted to be due to the lack of detail provided in some of the deeper well logs. It appears to be relatively flat lying, and its upper surface is at an elevation of approximately 50 m below sea level. The unit pinches out into finer grained deposits in the northeast part of Sumas Prairie. It is separated from the overlying Chilliwack Rosedale Aquifer B unit by 3 to 20 m of very fine sand, silt and clays, although the two units appear to merge in the easternmost part of Chilliwack (Figure 13c). It is underlain by finer sediments.

Based on its geometry and correlation with a cone penetration test in Sumas Prairie, the unit is interpreted as a glaciomarine outwash sand formed after the ice sheet had receded upriver from Chilliwack.

The aquifer is likely recharged from the Chilliwack Rosedale Aquifer B unit in the easternmost part of the Fraser Lowland in Chilliwack, where the Chilliwack Rosedale Aquifer B unit forms a continuous aquifer with the A unit. These are collectively recharged by mountain front and mountain block recharge from the Cascade Mountains. However, flowing artesian conditions were reported in one well in this aquifer, confirming its isolation from overlying units in the central part of the Fraser Lowland (WTN 25770; 2.4 m above ground; level; Livingston, 1973).

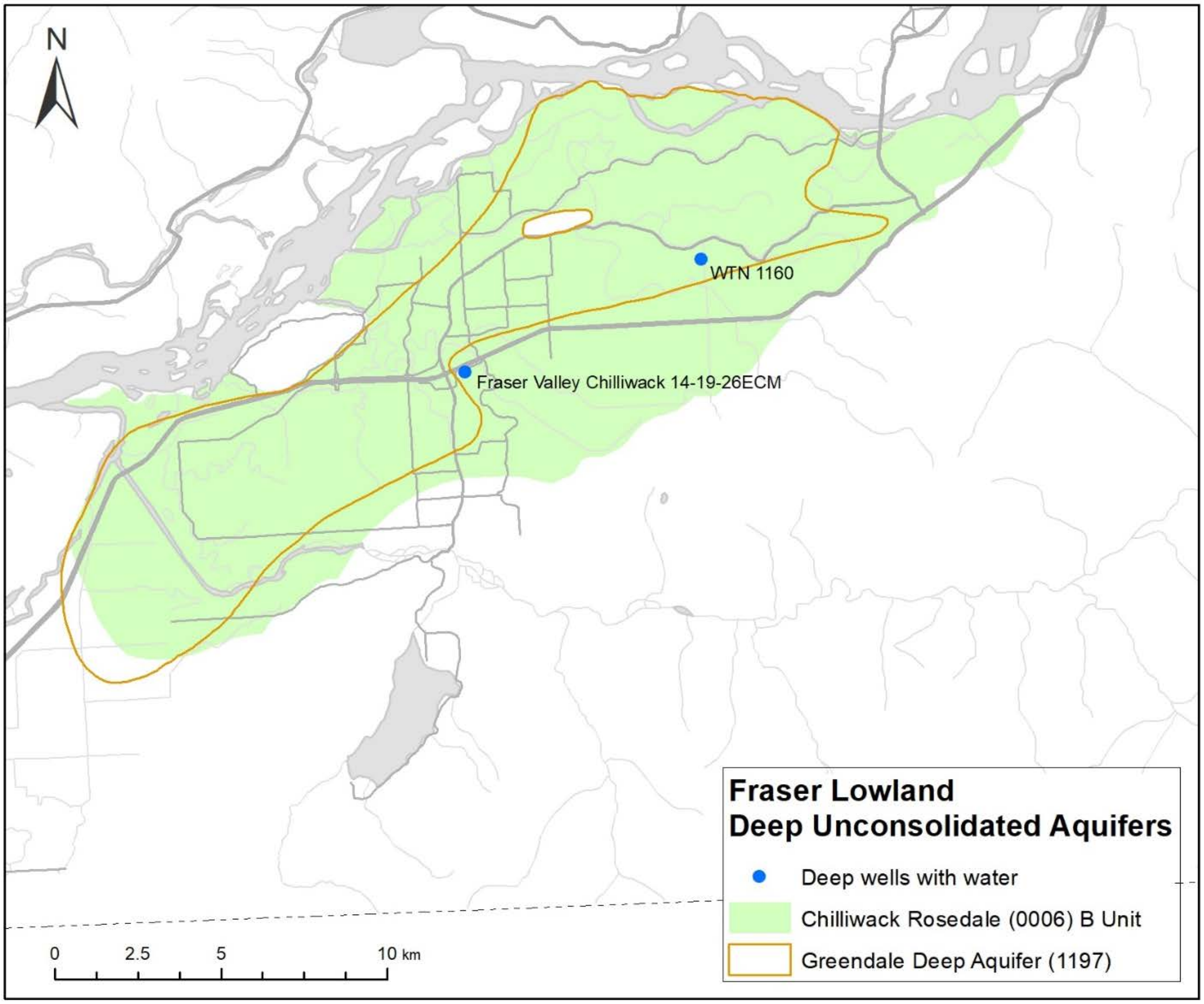

Figure 16: Deep unconsolidated aquifers in Fraser Lowland.

4.1.5 *Cheam Slide Aquifer - Aquifer 1198*

Figure: 12
Cross-sections: 2E, 2F, 2AL

The Cheam Slide Aquifer is located in the Cheam Plateau. The aquifer materials include slide debris and gravel, sand and silt within the Holocene slide mass where its thickness exceeds 15 m. The maximum thickness of slide debris exceeds 60 m and water-bearing intervals are up to 20 m thick. Water-bearing intervals were not identified in all wells in the slide mass, and are probably discontinuous, so that only those that were identified on logs were recorded. However, both the outlines of the slide mass as a whole and the area where the mass is thicker and water-bearing slide debris could potentially occur were mapped and digitized (Figure 12).

The slide debris is locally overlain by colluvium and lacustrine clays and marls, and the area includes Cheam Lake (Armstrong, 1980b; Savigny and Clague, 1992; Evans and Savigny, 1994; Monahan, 1995; Levson et al., 1996a, b, c; Orwin, 2004; Kovanen and Slaymaker, 2015). This aquifer and lacustrine system are perched – they are at a higher elevation than the water table in the underlying Chilliwack Rosedale Aquifer.

Recharge is likely by precipitation, as well as by mountain front recharge from the Cascade Mountains, particularly from Bridal Creek.

4.1.6 *Sumas Prairie North Aquifer – Aquifer 1199*

Figures: 4, 5, 13a, 14 and 15
Cross-sections: 2A-2C, 2G, 2K-2M, 2O

The Sumas Prairie North Aquifer is a low productivity aquifer located in the westernmost part of the City and the northeastern part of Sumas Prairie. It comprises a westward and southward thickening package of interbedded fine sand, silt and clay that lies stratigraphically above the westward thinning wedge of the Chilliwack Rosedale Aquifer B unit sands and below the sands and gravels of the Chilliwack Rosedale Aquifer A unit and the Sardis Vedder Aquifer. These sediments were derived from the northeast, ultimately from the Fraser River, and change facies to silts and clays to the southwest, in the northeastern part of Sumas Prairie (Figure 4). They represent the early fill of the lacustrine basin following deposition of the Chilliwack Rosedale Aquifer B unit deltaic sands.

Low water flow rates have been reported from sand beds at different levels in some wells in this sedimentary package, and several small aquifers may be present. The tops and bases of the aquifer were recorded only where water-bearing sands were identified on logs, or where the unit is thick and the logs suggest aquifer materials are likely to be present. In other wells, the equivalent stratigraphic interval is represented only by lower permeability materials. The aquifer outline was mapped where lacustrine interval appeared sufficiently thick to potentially include aquifer materials (Figure 13a).

Beyond the limits of the Chilliwack Rosedale Aquifer A unit and Sardis Vedder Aquifer, in the westernmost part of Chilliwack and the north-easternmost part of Abbotsford, the interval containing the Sumas Prairie North Aquifer locally extends to surface and is up to 50 m thick. This area has previously been included with the Sumas Prairie Aquifer (Aquifer 0021), herein renamed the Sumas Prairie South Aquifer. As a result of the current Chilliwack and Abbotsford aquifer studies, the Sumas Prairie South Aquifer is restricted to the fluvial and lacustrine sands derived from the Sumas River, which filled the Sumas Prairie lacustrine basin from the southwest during the Holocene. It is highly productive locally and is located entirely within Abbotsford. It will be discussed in further detail in the Abbotsford report. It locally overlies the interval containing the Sumas Prairie North Aquifer in the northeastern part of Sumas Prairie (Figures 13a, 14).

Water-bearing sands in the Sumas Prairie aquifer are locally connected to the Chilliwack Rosedale Aquifer B unit and Sardis Vedder Aquifer, through interfingering contacts, and possibly the Chilliwack Rosedale Aquifer A unit and Sumas Prairie South Aquifer.

4.1.7 *Columbia Valley Aquifer – Aquifer 0020*

Figures: 17 and 18
Cross-sections: 2V-2Y

The Columbia Valley Aquifer underlies the Columbia Valley and extends from Cultus Lake southwest to the international border (Carmichael et al., 1995; Zubel, 2000). Most of the Columbia Valley is a terraced upland standing between 180-210 m above sea level. Two terraces adjacent to Cultus Lake stand at 75 and 45 m above sea level, and the level of Cultus Lake is a few metres below the level of the lower terrace. The valley surface is deeply incised by Frosst Creek, which flows from the mountains on the southeast, across the valley, and into Cultus Lake.

The Columbia Valley has a thick Quaternary fill, primarily of Sumas glacial outwash gravels which constitutes the Columbia Valley Aquifer (Figures 17 and 18;Armstrong, 1980a; Clague and Luternauer, 1982, 1983; Zubel, 2000; Kovanen and Easterbrook, 2001). These deposits formed adjacent to a pronounced ice-contact face at the southwest end of Cultus Lake. Bedrock occurs at the base of many wells on the margins of the Columbia Valley, but in the valley centre the thickness of Quaternary sediments exceeds 150 m.

On the basis of till, hardpan and clay being reported in logs on the margins of the valley overlying higher permeability aquifer materials, Zubel (2000) had suggested that part of the aquifer is confined or partially confined. However, several wells have been completed in these lower permeability sediments. Water levels in these wells are comparable to those in better aquifer materials nearby, there is little evidence of shallow perched water tables[2], and creeks flowing into the valley lose water into these sediments. Therefore, the upper sediments on the valley margins are interpreted to be a less permeable part of the aquifer rather than a confining unit. They are heterogeneous, and the impermeable materials within them are interpreted to be laterally discontinuous.

Consequently, the aquifer has been subdivided into three interconnected units: the Columbia Valley A unit (CVA), which includes higher permeability deposits deeper in the section; the Columbia Valley B unit (CVB), which comprises the overlying lower permeability sediments; and the Columbia Valley C unit (CVC), which comprises Holocene stream deposits along the lower reaches of Frosst Creek. The CVA-CVB contact is diachronous.

Water levels are generally at elevations of 100 to 150 m in most of the upland part of the valley (30-100 m below surface; Figure 18). Groundwater flow is both from the valley sides toward the centre and to the northeast and the southwest from a groundwater divide in the central part of the valley. Frosst Creek and another creek both lose water into the Columbia Valley Aquifer (Zubel, 2000). Recharge is from precipitation, runoff from the adjacent mountains and losses from these creeks. The Columbia Valley Aquifer likely provides water to the lower reaches of Frosst Creek, which flows into Cultus Lake, and directly to Cultus Lake through the CVC. CVA materials do not appear to connect with Cultus Lake.

Columbia Valley A Unit (CVA)

The CVA consists of gravels, shale gravels, and boulders, comprising the better-quality aquifer materials in the Columbia Valley Aquifer. These deposits extend to the surface in a narrow northeast-southwest oriented band in the southwest part of the valley, where they are greater than 75 m thick. They also

[2] In WTN 45039, “little water” is reported in a shallow gravel-till unit above the static level for the CVA.

extend to surface where the CVB is not present in the low terrace adjacent to Cultus Lake. Elsewhere it is overlain by 40 to 140 m of CVB materials. The CVA does not extend to the valley margins, where the CVB oversteps it and overlies bedrock directly. Well yields reported in GWELLS in the CVA are generally 30 to 300 gpm, with an average of 105 gpm.

Columbia Valley B Unit (CVB)
The CVB consists of poorer aquifer materials in the upper part of Columbia Valley sedimentary fill. It includes sediments described as shale, till, slide rock, and dirty gravel. Higher permeability deposits such as sands and gravels occur locally above the water table, but these intervals are separated from the CVA by more typical CVB materials.

The CVB is up to 140 m thick and extends to the surface. On the valley margins it oversteps the CVA and overlies bedrock directly. In a few wells in this setting, intervals of water-bearing bedrock occur directly underlying unconsolidated deposits (WTN 55659, 75364, 93701, 94142; East Cultus Columbia Bedrock Aquifer, Vedder Mountain Southeast Bedrock Aquifer; Figure 18). Where reported, water levels in these wells are similar to those in other wells in the Columbia Valley Aquifer, indicating that they are connected, and these have been included in the CVB. Along the valley margins, the CVB materials are entirely above the water table.

CVB is absent in a narrow band along the southwest part of the valley, and locally in the low terrace adjacent to Cultus Lake, where the CVA extends to the surface.

Flow rates reported in GWELLS are generally lower than those in the CVA – 5 to 25 gallons per minute (gpm), with an average of 18 gpm. However, flow rates between 50 and 500 gpm are reported from CVB materials at low elevations in the terraces adjacent to Cultus Lake.

Columbia Valley C Unit (CVC)
The CVC consists of sands and gravels in Holocene stream deposits along the lower reaches of Frosst Creek, including a small fan delta where the creek enters Cultus Lake. It represents a small part of the Columbia Valley Aquifers and has been noted in only two wells.

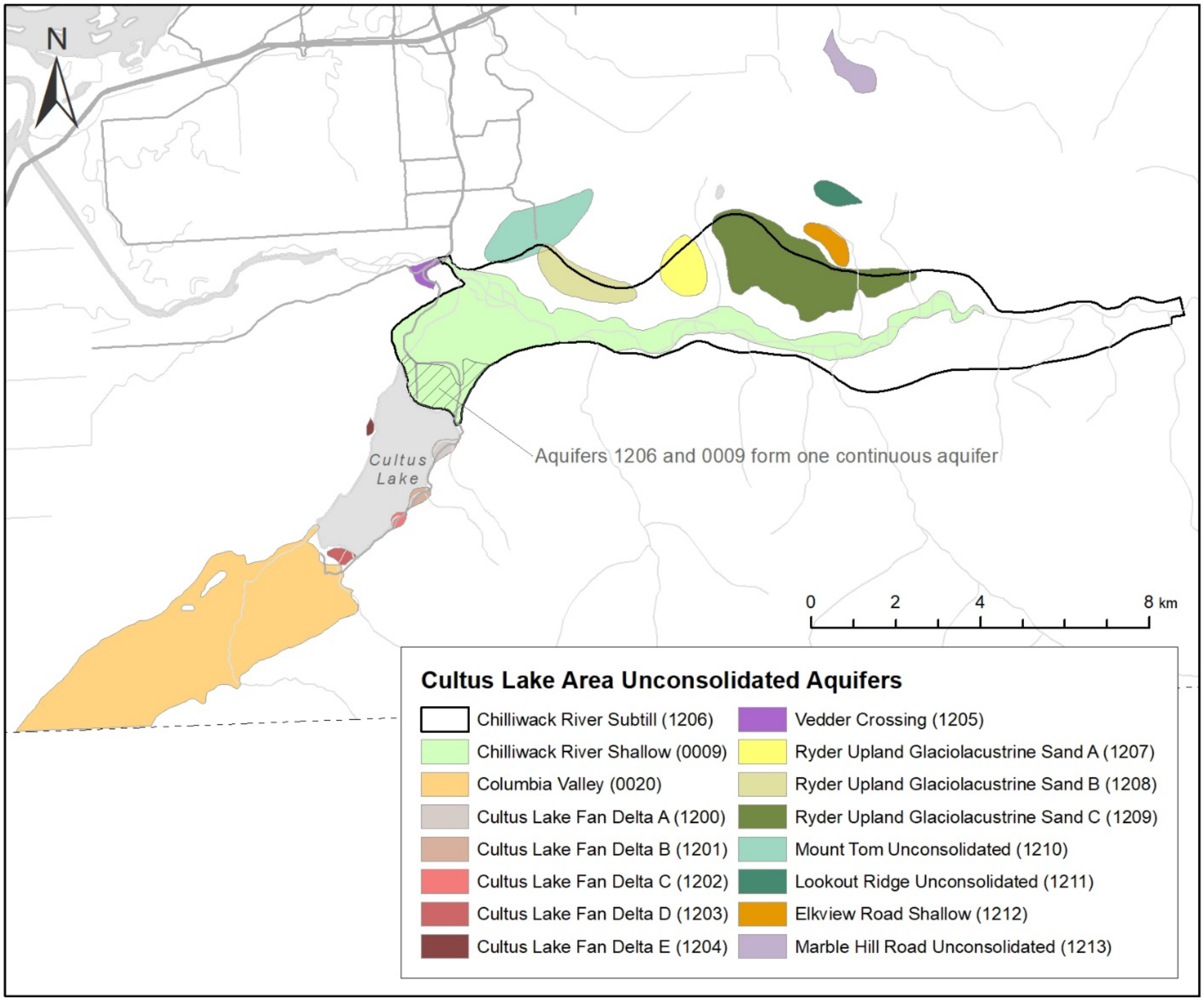

Figure 17: Cultus Lake area, Chilliwack River Valley and Ryder Upland area unconsolidated aquifers.

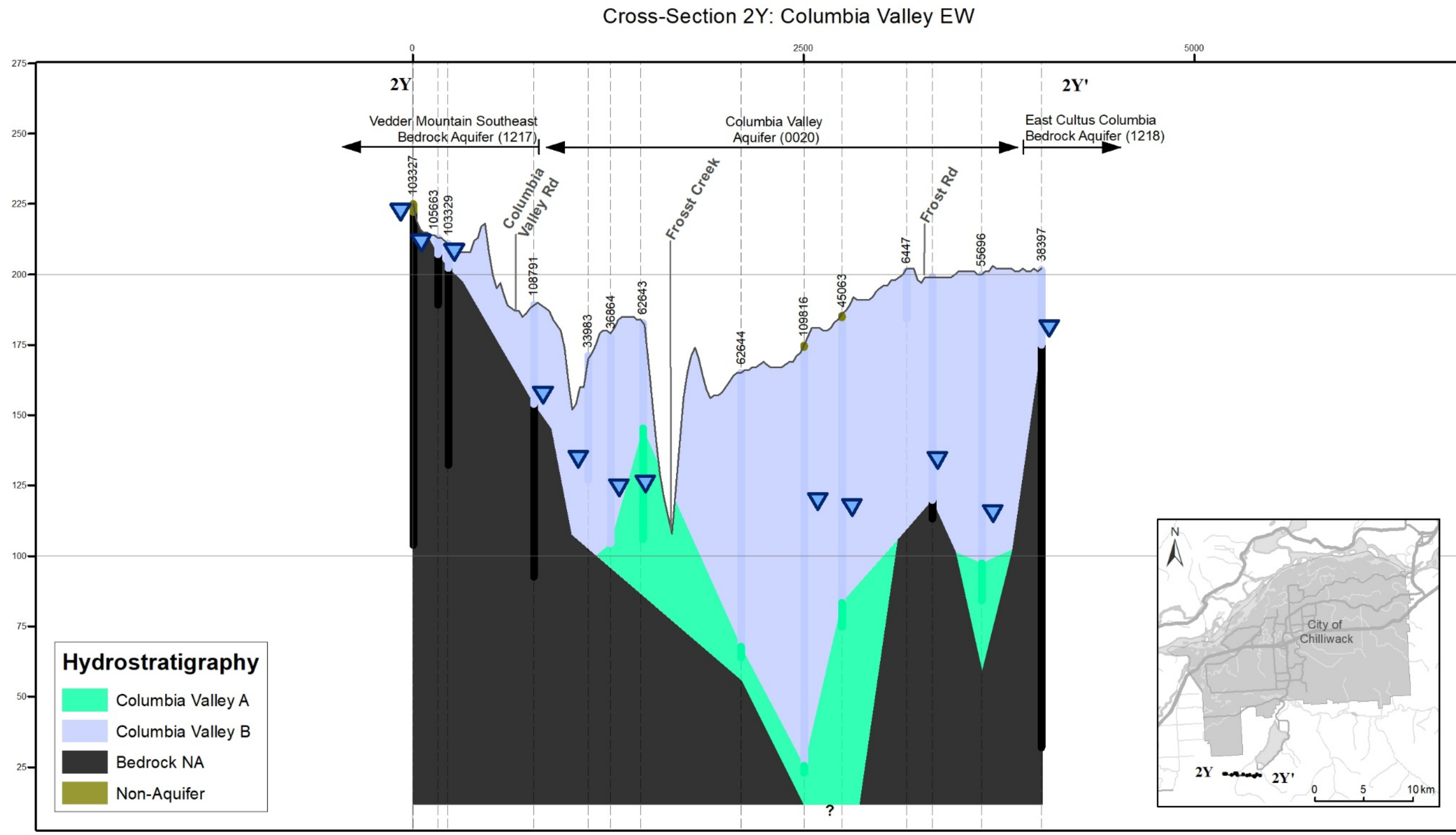

Figure 18: Cross-section 2Y, Columbia Valley east-west.

4.1.8 *Cultus Lake Fan Delta Aquifers – Aquifers 1200 to 1204*

Figure: 17
Cross-sections: 2AI

The Cultus Lake Fan Delta Aquifers are a group of small productive aquifers in fan deltas along the shores of Cultus Lake within Cultus Lake Provincial Park. These aquifers consist of gravels derived from the shale bedrock on either side of the lake. The more detailed logs indicate that permeable intervals are a minor component of these deposits suggesting that most of the fan delta materials consist of matrix-rich debris flow deposits. The intervals recorded on the aquifer tables (Appendix 9) vary according to the level of detail in the logs, but permeable intervals are likely to occur anywhere in the sequence. Wells are up to 71 m deep, and water depths are 15 to 25 m below surface. Reported yields vary from 75 to 200 gpm. All the aquifers are bounded by bedrock.

- Cultus Lake Fan Delta A Aquifer (CLFDA; 1200) is located at the northeast end of Cultus Lake beneath the Windfall Creek fan delta. Two wells have been drilled in this aquifer to depths of 24 and 35 metres without reaching bedrock.
- Cultus Lake Fan Delta B Aquifer (CLFDB; 1201) is located beneath the Clear Creek fan delta on the east side of Cultus Lake and is penetrated by two wells. The thickness of the fan delta deposits in one well is 64 m, where bedrock was encountered. The other well in this aquifer, was drilled to 71 m without reaching bedrock.
- Cultus Lake Fan Delta C Aquifer (CLFDC; 1202) is located south of CLFDB on the east side of Cultus Lake beneath the Teapot Creek fan delta and is penetrated by one well drilled to a depth of 34 m without reaching bedrock.
- Cultus Lake Fan Delta D Aquifer (CLFDD; 1203) is located at the mouth Wall Creek, east of Lindell Beach at the southeast end of Cultus Lake. No wells have been reported in CLFDD, and it is defined on the basis of surface morphology alone. It appears to be bounded to the south by bedrock but may be in communication with the Columbia Valley Aquifers to the west.
- Cultus Lake Fan Delta E Aquifer (CLFDE; 1204) is at the mouth of Ascaphus Creek on the west side of Cultus Lake and is penetrated by one well drilled to a to a depth of 19 m without reaching bedrock.

These aquifers are recharged by precipitation, runoff and mountain block recharge from the adjacent mountains, and the creeks that source the fans. Those on the east side of Cultus Lake (CLFDA to CLFDD) are likely connected to the East Cultus-Columbia Bedrock Aquifer, and the CLFDE is likely connected to the Vedder Mountain Southeast Bedrock Aquifer. All these aquifers are connected to Cultus Lake.

4.1.9 *Vedder Crossing Aquifer – Aquifer 1205*

Figure: 17
Cross-sections: 2S, 2AM

The Vedder Crossing Aquifer is a small aquifer located at the northeast end of Vedder Mountain near Vedder Crossing. It underlies a low terrace adjacent to the Fraser Lowland on the northwest side of the mountain and has been extended up small valleys crossing the northeast end of the mountain. It may also extend further east to underlie terraces on the southeast side of the mountain adjacent to the Chilliwack River-Sweltzer Creek floodplain.

The aquifer consists of Pleistocene sands and gravels and includes both unconfined and confined units (Unit A and Unit B, respectively), separated by a clay till unit up to 27 m thick (mean 16 m). The intervening clay till is at the same elevation as the Semiahmoo glaciomarine drift at the Bailey Landfill to the northeast, and may correlate with it (Hicock et al., 1982). By this correlation, the age of Vedder Crossing Aquifer A Unit (VCA) would be Late Wisconsin and could include advance phase outwash of either or both the main Fraser Glaciation (Quadra sand equivalents), and the Sumas Stade. Correspondingly, the underlying Vedder Crossing Aquifer B Unit (VCB) could be pre-Wisconsin outwash. However, these correlations are uncertain.

The VCA consists of sand and gravel with boulders and cobbles, commonly matrix-rich and with some shale gravel; it is up to 32 m thick, with a mean of 16 m. It is commonly dry near the margins of the aquifer, and where the deeper unit (VCB) is present. Where water-bearing, depth to water varies from 5 to 9 m, and well yields range from 10 to 45 gpm.

The VCB consists of sand and gravel with some silt and clay. Up to 9 m of these materials have been penetrated and the base has not been encountered. The unit occurs primarily along the axis of a valley that transects the northeast end of Vedder Mountain. It is generally entirely water-bearing, except in the southernmost and topographically highest well, in which a water table is present. Static levels range from 11 to 17 m, commonly higher than the base of the VCA where it is dry. Well yields range from 9 to 35 gpm.

In one well, the VCA is incised through the intervening clay till into the VCB, forming a continuous aquifer 31 m thick.

Recharge is inferred to be primarily by precipitation, and possibly from the Vedder Mountain Northwest Bedrock Aquifer. The VCB is likely recharged through the VCA where the intervening clay till unit is absent.

4.1.10 *Chilliwack River Shallow Aquifer and Chilliwack River Subtill Aquifer – Aquifers 0009, 1206*

Figures: 17, 19 and 20

A pair of partially connected aquifers underlies the floor and margins of the Chilliwack River Valley and the intermontane valley between Cultus Lake and the Chilliwack River. These aquifers comprise:

- the Chilliwack River Shallow Aquifer (0009), a mainly unconfined aquifer comprised of Holocene fluvial deposits of the Chilliwack River Floodplain (Salish Sediments) and locally Sumas outwash sands; and
- the Chilliwack River Subtill Aquifer (1206), a mainly confined aquifer which consists primarily of advance phase Fraser Glaciation outwash sands and gravels (Quadra sand equivalents).

The aquifers are generally separated by a till and clay unit. The intervening till pinches out to the south adjacent to Cultus Lake, where the two units effectively form a single unconfined permeable unit (mapped as the Chilliwack River Shallow Aquifer/Chilliwack River Subtill Aquifer combined (Figures 17 and 19). In the Chilliwack River Valley, intervals of water-bearing sand and gravel occurring within the till are likely in communication with the Chilliwack River Subtill Aquifer and collectively referred to as the Chilliwack River Intertill Unit of the Chilliwack River Subtill Aquifer.

Surficial deposits in the Chilliwack River Valley comprise Holocene fluvial deposits of the Chilliwack River Floodplain, and Sumas and earlier glaciogenic sediments (Armstrong, 1980b; Saunders, 1987). In the northeast part of the valley between Cultus Lake and the Chilliwack River, adjacent to the Chilliwack River, surficial deposits are Holocene fluvial deposits of the Chilliwack River Floodplain (Armstrong, 1980b; Saunders, 1987). To the southwest, adjacent to Cultus Lake, surficial deposits consist of Sumas recessional outwash sands and gravels and form a low terrace damming Cultus Lake (Figures 17 and 19).

Aquifer boundaries were mapped using surficial geological mapping, geomorphic evidence from satellite imagery and borehole data. Because of well location inaccuracy, where some wells plot may be inconsistent with the aquifer boundaries. Furthermore, the elevation uncertainties associated with location uncertainties complicate well log correlations in the Chilliwack River Valley, which has considerable relief.

Cross-Section 2U: Cultus N-S

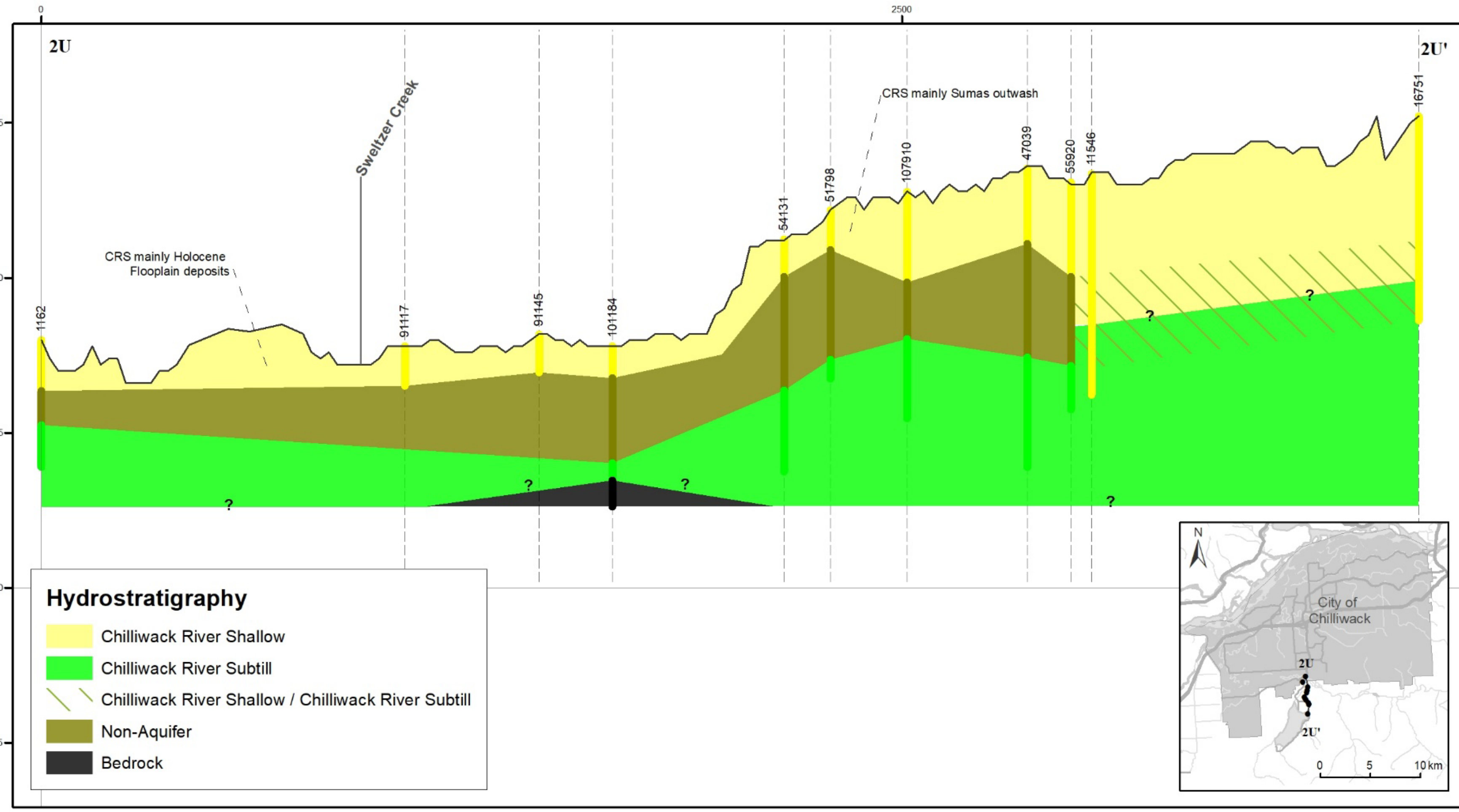

Figure 19: Cross-section 2U, Cultus north-south.

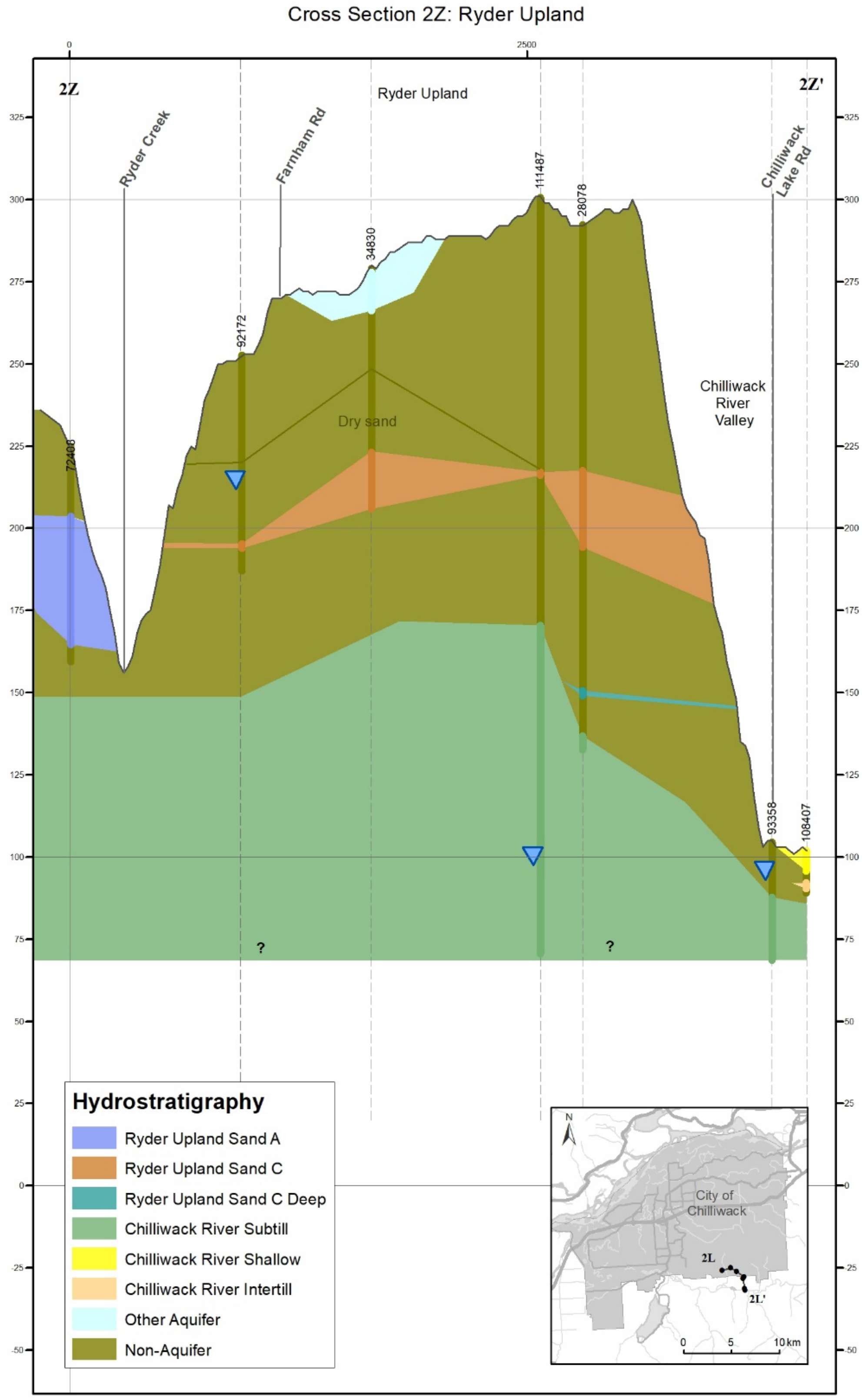

Figure 20: Cross-section 2Z, Chilliwack River Valley and Ryder Upland. Note: Chilliwack River Subtill Aquifer is overlain by till in the Chilliwack River Valley, but glaciolacustrine silts clays and very fine sands in the Ryder Upland. The latter include the Ryder Upland Sand A, B and C Aquifers.

Chilliwack River Shallow Aquifer – Aquifer 0009
Figures: 17, 19 and 20
Cross-sections: 2S-2T

The Chilliwack River Shallow Aquifer is a generally unconfined aquifer consisting primarily of Holocene fluvial sands and gravels of the Chilliwack River Floodplain, but locally includes earlier Holocene fluvial terrace deposits and in some areas, Sumas outwash sands. The mapped limits follow approximately those of Carmichael et al. (1995), and it occurs in two settings.

In the Chilliwack River Valley, the aquifer is restricted to the modern floodplain, which forms a 400 to 800 m wide strip along the valley floor. Its limits were defined on the basis of subsurface borehole control, surficial geological maps, topographic maps and satellite images that show abandoned meander loops and scroll bars. Its eastern limits are mapped near the eastern boundary of the project area, 12 km upstream from Vedder Crossing. However, similar deposits likely extend further upstream (Armstrong, 1980b).

This part of the aquifer consists of sand, gravel and boulders. Boulders occur commonly in the upper parts and were derived from the tills into which the river incised during the Holocene (Tunnicliffe et al., 2012). The upper parts of the aquifer also commonly include sediments described as till, which could be either dry fluvial sands and gravels, or colluvium and slide deposits. The aquifer is in most places unconfined, but locally it is capped by up to 7 m of overbank and abandoned channel fill silts and clays, and colluvium and slide deposits (Armstrong, 1980b; Saunders, 1985; Saunders et al., 1987; Fletcher et al., 2002). The thickness averages 10 m, and is locally up to 25 m.

In the valley between Cultus Lake and the Chilliwack River, the aquifer is unconfined. It is water-bearing mainly in the northern and topographically lower floodplain portion of the area, where it consists primarily of Holocene fluvial sands and gravels of the Chilliwack River and is 5 to 10 m thick. To the south, on the terrace adjacent to Cultus Lake, the aquifer materials are primarily Sumas recessional outwash sands and gravels. The latter are generally above the water table but are likely in communication with the floodplain part of the aquifer to the north. Southwards across this terrace, the till unit separating the Chilliwack River Shallow Aquifer from the Chilliwack River Subtill Aquifer pinches out, and the two units effectively form a single unconfined permeable unit greater than 73 m thick. In this area they are mapped as the Chilliwack River Shallow Aquifer/Chilliwack River Subtill Aquifer combined (Figures 17 and 19). However, the water-bearing parts are primarily in the lower part that is stratigraphically equivalent to the Chilliwack River Subtill Aquifer.

Recharge is from the Chilliwack River, Cultus Lake, Sweltzer Creek and runoff from the sides of the two valleys. It is also likely recharged from the Vedder Mountain Southeast Bedrock Aquifer and the East Cultus Columbia Bedrock Aquifer, and well as the Chilliwack River Subtill Aquifer, into which it is locally incised. To the west, the aquifer may be in communication with the Sardis Vedder Aquifer in the Fraser Lowland.

Chilliwack River Subtill Aquifer – Aquifer 1206
Figures: 17, 19 and 20
Cross-sections: 2S-2T

The Chilliwack River Subtill Aquifer consists of sands and gravels that underlie till and other glaciogenic deposits in the Chilliwack River Valley, the southern part of the Ryder Upland, and the valley between Cultus Lake and the Chilliwack River. This aquifer consists at least in part of advance phase glacial outwash of the Fraser Glaciation (Quadra Sand equivalents), although the deeper parts may include older units. The top of the aquifer is highly irregular.

In the Chilliwack River valley floor, the aquifer underlies till that extends to depths of 20 m or more below current river level[3]. The top of aquifer rises up the northern side of the valley to the southern part of the Ryder Upland, where it is commonly overlain by glaciolacustrine silts, clays and fine sands (Figure 20). The aquifer outcrops locally on the valley walls, including at the gravel pit where the proboscidean (mammoth) tusk-bearing gravels were dated to 21,400 and 22,700 BP (Quadra sand equivalent; Hicock et al., 1982; Clague and Luternauer, 1982, 1983; Armstrong et al., 1985; Fletcher et al., 2002). These relationships suggest that the advance phase outwash and glaciolacustrine deposits were eroded by glacial ice during the glacial maximum, when the till capping the aquifer in the valley floor was deposited.

In the valley floor, the water table is above the top of the aquifer, 5 to 10 m below ground level, and most wells have penetrated less than 30 m of this aquifer. The thickest penetration is 50 m. In the topographically higher areas, on the north margin of the valley and the southern part of the Ryder Upland, up to 100 m of aquifer materials have been penetrated (e.g. WTN 111487; Figure 20). In these areas, the top of the aquifer materials rises above the water table. Consequently, wells exploiting this aquifer in the southern Ryder Upland will need to be greater than 200 m deep. The Chilliwack River Subtill Aquifer in the Chilliwack River Valley is generally confined but is locally unconfined where the Holocene fluvial sands and gravels of the Chilliwack River Shallow Aquifer are incised into it and where it outcrops on the valley walls.

The northern limits beneath the Ryder Upland are poorly defined, as there is insufficient information to determine at what point bedrock rises above the top of the outwash sands and gravels. The southern margin has been drawn to include some Quaternary terraces on the valley margin that may include materials of this aquifer (Saunders, 1985; Saunders et al., 1987). To the east, this aquifer extends beyond the limits of the project area. It may connect with the Upper Chilliwack River Aquifer on Larson's Bench at the confluence of Chilliwack River and Slesse Creek (Aquifer 0010), and this should be investigated.

The aquifer also underlies the valley between Cultus Lake and the Chilliwack River. The aquifer in this area consists of sands and gravels, the maximum penetrations are 20 m, and it is generally confined. However, the till separating this aquifer from the Chilliwack River Shallow Aquifer changes southward to a "cemented" or compact silty gravel and disappears, either by erosion or facies change, into gravels similar to those above and below, in the southern part of the Sumas recessional outwash plain adjacent to Cultus Lake (Figures 17 and 19). Where the till is not present, the Chilliwack River Shallow Aquifer and Chilliwack River Subtill Aquifer effectively form a continuous unconfined aquifer, and they are mapped together as the Chilliwack River Shallow Aquifer/Chilliwack River Subtill Aquifer combined. The combined aquifer materials are greater than 73 m thick, and likely comprise both Sumas outwash and advance phase glacial outwash of the Fraser Glaciation. Water levels are 20 to 30 m below the surface, so that most of the water-bearing part of the combined aquifer is laterally equivalent to the Chilliwack River Subtill Aquifer.

The aquifer is likely recharged by precipitation and runoff through areas of exposure in outcrops and gravel pits on the valley walls of the Chilliwack River and Ryder Creek, and possibly from Cultus Lake. It is also likely recharged from the Mount Tom Bedrock Aquifer. As noted above the Chilliwack River Subtill Aquifer is locally hydraulically connected with the Chilliwack River Shallow Aquifer in the Chilliwack River

[3] The Chilliwack River has been downcutting throughout the Holocene (Tunnicliffe at al., 2012). Consequently, the sediments described as till that overlie the aquifer and extend to depths of 20 m or more below current river level are likely to be true tills and are not modern colluvium.

Valley and adjacent to Cultus Lake. The aquifer may also be in communication with the Sardis Vedder Aquifer to the northwest.

Metre-scale water-bearing sand and gravel interbeds in the till overlying the Chilliwack River Subtill Aquifer occur in the floor of the Chilliwack River valley and are designated the Chilliwack River Intertill unit (Figure 20). These occur at several discrete levels, but many probably grade laterally into and are likely hydraulically connected with the Chilliwack River Subtill Aquifer. As such, it is best considered a facies of the Chilliwack River Subtill Aquifer, and so has not been mapped as a separate aquifer. Nonetheless, intervals with this unit are reported on sections and tables. Wells in this unit have lower productivity than the main part of the Chilliwack River Subtill Aquifer.

4.1.11 *Ryder Upland Glaciolacustrine Sand Aquifers – Aquifers 1207, 1208 and 1209*

Figures: 17 and 20
Cross-sections: 2Z, 2AA, 2AB, 2AB

The Ryder Upland Glaciolacustrine Sand Aquifers comprise a group of perched low productivity aquifers in fine sand interbeds within Late Wisconsin glaciolacustrine silts, clays, and fine sands in the southern margin of the Ryder Upland. These glaciolacustrine sediments were deposited prior to the Late Wisconsin glacial maximum, when the Chilliwack River was dammed by Cordilleran ice in the Fraser Lowland (Hicock et al., 1982; Clague and Luternauer 1982, 1983; Armstrong et al., 1985). Three separate aquifers have been identified in erosionally separated promontories and benches.

Sand intervals are generally less than 10 m thick, but in some cases approach 40 m. However, the upper parts of the thicker intervals are usually dry, so that the thickest reported water-bearing interval is 13 m. Sand intervals occur at several levels within the glaciolacustrine section, so that several water-bearing intervals may be present in each promontory. However, it is unclear whether these are connected. For the purposes of this study, all those in a single promontory are considered as one aquifer.

These aquifers lose water in seepages along the walls of Chilliwack River Valley and its tributaries. Because of this and the potential for connection between the sand intervals at different levels in each promontory, only the deeper sand units may be water-bearing near the valley walls. The aquifers are likely recharged by precipitation and runoff from the higher parts of the Ryder Upland to the north and are perched above the Chilliwack River Subtill Aquifer.

Ryder Upland Glaciolacustrine Sand A Aquifer – Aquifer 1207

Figures: 17 and 20
Cross-sections: 2Z, 2AB

The Ryder Upland Glaciolacustrine Sand A Aquifer (RUSA) is a confined sand aquifer within the Late Wisconsin glaciolacustrine silt, clay and fine sand deposits on the promontory west of Ryder Creek, near Sherlaw and Briteside Roads. Fine sand interbeds in this section are 2 to 40 m thick but the thickest water-bearing interval is 13 m. Four wells have been completed in a correlative 5 to 17 m thick sandy interval near the top of the glaciolacustrine section at an elevation of approximately 210 m. This interval can be followed in several other wells. However, in two wells located near the margin of the promontory this sandy interval is dry, and these wells have been completed in a deeper sandy interval at an elevation of approximately 165 m. It is unclear whether one or two separate hydrostratigraphic units are present. In one of the latter wells dry sands extend up to the stratigraphic level of the shallower water-bearing interval and may provide communication between the two, but this is not the case in the other.

The depth to the top of the aquifer varies from 20 to 65 m. The overlying materials are generally glaciolacustrine silts, clays and fine sands, but in some of the wells the shallower water-bearing horizon is overlain by sand and gravel and till.

The limits of this aquifer have been mapped based on subsurface borehole control and topography. The northern limit is uncertain but would extend north of the limits of the Chilliwack River Subtill Aquifer.

Reported production rates in the RUSA are 1 to 3 gpm.

Ryder Upland Glaciolacustrine Sand B Aquifer (RUSB) - Aquifer 1208
Figure: 17
Cross-section: 2AA

The Ryder Upland Glaciolacustrine Sand B Aquifer (RUSB) is defined on the basis of a single well on a bench on the southwest margin of the Ryder Upland near Thornton Road (WTN 23374). The aquifer in this well is a 3 m thick fine sand interbed in Late Wisconsin glaciolacustrine silts, clays and fine sands at a depth of 77 m and an elevation of approximately 110 m. Productivity is reported at 1 gpm. "Some water" is reported in the lower 6 m of a shallower glaciolacustrine sand that is 17 m thick at an elevation of roughly 125 m, but connection between the two is unclear. Separation is suggested by the fact that the reported water level in the deeper sand is below the shallower zone, which is recorded separately as "RUSB shallower interval" on the aquifer table (Appendix 9). By analogy with the other Ryder Upland Aquifers, other low productivity aquifers could potentially occur at other stratigraphic levels in the glaciolacustrine section in this promontory. The limits of this aquifer have been extended 2 km southeast of this well along the bench, where glaciolacustrine sediments are inferred to be present. The southern limit of the aquifer is defined primarily based on topography. The northern limit is uncertain but would extend north of the limits of the Chilliwack River Subtill Aquifer.

Ryder Upland Glaciolacustrine Sand C Aquifer (RUSC) - Aquifer 1209
Figures: 17 and 20
Cross-sections: 2Z, 2AC

The Ryder Upland Glaciolacustrine Sand C Aquifer (RUSC) is a confined aquifer in sands within the Late Wisconsin glaciolacustrine section on a bench on the south margin of the Ryder Upland east of Ryder Creek. Water has been reported in a sandy unit 1 to 23 m thick in wells at depths of 30 to 110 m and between elevations of 190 to 250 masl, and this may be a correlative unit. The upper part of this sand in well WTN 28078 is dry. In the same well, a water-bearing sand 1.5 m thick occurs deeper in the glaciolacustrine section at an elevation of approximately 150 m, and connection with the main RUSC sand is uncertain; it is recorded separately as "RUSC deeper interval" (Appendix 9). As with the other areas with Ryder Upland Glaciolacustrine Sand Aquifers, several low productivity aquifers may be present in this bench in the glaciolacustrine section. The area of this aquifer has been extended 2 km further southeast beyond the well control along this bench toward outcrops of glaciolacustrine deposits located above the river at the Slesse Slide (Allison Pool; Saunders, 1985; Clague et al., 1988; Fletcher at al., 2002). The southern limit of the aquifer is defined primarily based on topography. The northern limit is uncertain but would extend north of the limits of the Chilliwack River Subtill Aquifer.

Productivities reported in the two wells completed in these aquifers are 1 and 13 gpm.

In well WTN 34830 in this area, some water was reported in surficial gravels and may represent a perched aquifer above the RUSC.

4.1.12 *Mount Tom Unconsolidated Aquifer – Aquifer 1210*

Figure: 17
Cross-sections: 2AE-2AG

The Mount Tom Unconsolidated Aquifer is a poorly defined group of perched aquifers in unconsolidated deposits above the Mount Tom Bedrock Aquifer at the southwest end of the Ryder Upland. The aquifer consists of sands and gravels beneath till and glaciolacustrine clay and is Late Wisconsin in age – Sumas or earlier. Depth to the top of the aquifer materials varies from 5 to 46 m (mean 15 m). Correlation of the aquifer materials is speculative, and several hydrostratigraphic units could be present. The aquifer appears to form an inclined unit that dips to the north parallel to the topographic slope. The interpreted dip may be the result of deposition on top of an ice mass, but the interpretation is uncertain due to the poor elevation control of the wells used to define it. These deposits may be either incised into or laterally equivalent to the glaciolacustrine sediments that host the RUSB Aquifer and are likely in communication with them. The aquifer materials are 1 to 40 m thick (mean 16 m), but are water bearing in fewer than half of the wells; in either the lower parts of thick developments, possibly in small depressions at the base of the aquifer; or in thin developments that may represent isolated sand and gravel stringers. The aquifer is confined, and the depth to the top varies from 5 to 35 m. Productivities are low (2 to 4 gpm). This aquifer is perched above the Mount Tom Bedrock Aquifer. Recharge is inferred to be from precipitation.

4.1.13 *Lookout Ridge Unconsolidated Aquifer – Aquifer 1211*

Figure: 17

The Lookout Ridge Unconsolidated Aquifer is located, on Lookout Road, in the southeast part of the City on a slight terrace at an elevation of approximately 600 m on the south flank of Lookout Ridge. The areal extent of the aquifer has been mapped to coincide roughly with the terrace, where a Pleistocene section thicker than 78 m is preserved.

The aquifer has been penetrated by a single well that encountered 1.2 m of water-bearing sands and gravels beneath till and clay at a depth of 75 m. These deposits are probably Late Wisconsin in age, but likely pre-date the Sumas Stade, because they are situated topographically higher than the Tamihi Sumas end moraine (Saunders at al., 1987; Tunnicliffe et al., 2012).

The reported well yield is 10 gpm. Recharge is inferred to be from precipitation. The Lookout Ridge Unconsolidated Aquifer is likely hydraulically connected with the Elk Mountain Bedrock Aquifer, which it overlies. The aquifer may also provide some water to the upper reaches of Young Creek.

4.1.14 *Elkview Road Shallow Aquifer - Aquifer 1212*

Figure: 17

The Elkview Road Shallow Aquifer is a small poorly defined aquifer in unconsolidated materials near Elkview Road in the southeast part of the City, on the south flank of Lookout Ridge at an elevation of approximately 400 masl. Four wells were defined in this aquifer. The wells are located on the west flank of the Tamihi Sumas end moraine, and the aquifer has been mapped to encompass this moraine (Saunders at al., 1987; Tunnicliffe et al., 2012). Logs lack sufficient detail to characterize the aquifer, but it appears to be confined. In one well 11484, it consists of sand, 1.2 m thick, interbedded with clayIn other wells, aquifer materials are described as gravel and hardpan. Well depths range from 4 to 9 m, and water levels are from near surface to 9 m. The deposits are interpreted to have been deposited during the Late Fraser Sumas ice advance. Recharge is inferred to be from precipitation. The aquifer is likely perched above the Mount Tom Bedrock Aquifer, which it overlies.

4.1.15 ***Marble Hill Road Unconsolidated Aquifer (MHRU) – Aquifer 1213***

Figures: 17 and 21
Cross-sections: 2AJ & 2AK

The Marble Hill Road Unconsolidated Aquifer is a small aquifer within the unconsolidated valley fill of Marble Hill Creek. The aquifer boundaries have been mapped to include all of the Quaternary valley fill, which locally reaches a thickness of 68 m. However, these sediments are water-bearing only in the thicker Quaternary sections and topographically lower wells in the valley centre.

The aquifer materials consist primarily of poorly sorted sand and gravel interbedded with Late Wisconsin till, but also include poorly sorted till-like gravels without clay, as well as laterally equivalent materials described as slide debris. The thickness of aquifer materials varies from 5 to 37 m, with a mean of 22 m. Reported water-bearing intervals are a maximum of 9 m thick. The aquifer is partially confined, being capped by up to 24 m of Late Wisconsin gravelly till with clay and Holocene colluvium (Armstrong 1980b; Levson et al. 1996b; Green and Bianchin 2015, 2016). The confining deposits are thicker in the valley centre and may be absent higher on the valley walls.

Reported well yields vary with lithology. In the sand and gravel intervals, well yields range from 20 to 100 gpm; in the till-like gravels, the yields are 10 to 20 gpm; and in the slide debris, well yield is 6 gpm.

The Harmeling Spring, which flows at an average rate of 960 gpm, originates directly from this aquifer, where a confining till layer above the aquifer is breached at the head of Wilfred Creek, which flows into Marble Hill Creek (Tixier and Tiplady 2013; Green and Bianchin 2015, 2016). The aquifer directly overlies and is hydraulically connected with the Elk Mountain Bedrock Aquifer in the Marble Hill Road well field. In these wells, reported flow rates from the Marble Hill Road Unconsolidated Aquifer are up to 100 gpm.

This aquifer is recharged by precipitation and runoff from the Cascade Mountains (mountain front) and Marble Hill Creek, as well as from groundwater flow from the Marble Hill Road portion of the Elk Mountain Bedrock Aquifer (mountain block).

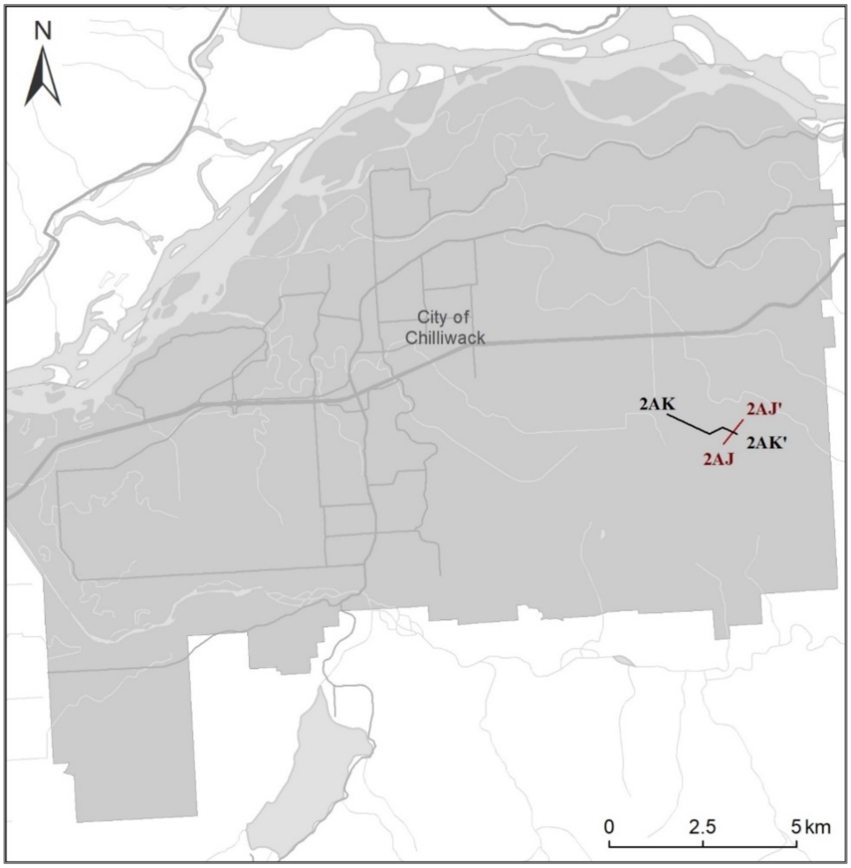

Figure 21a: Plan view location of cross-section 2AJ.

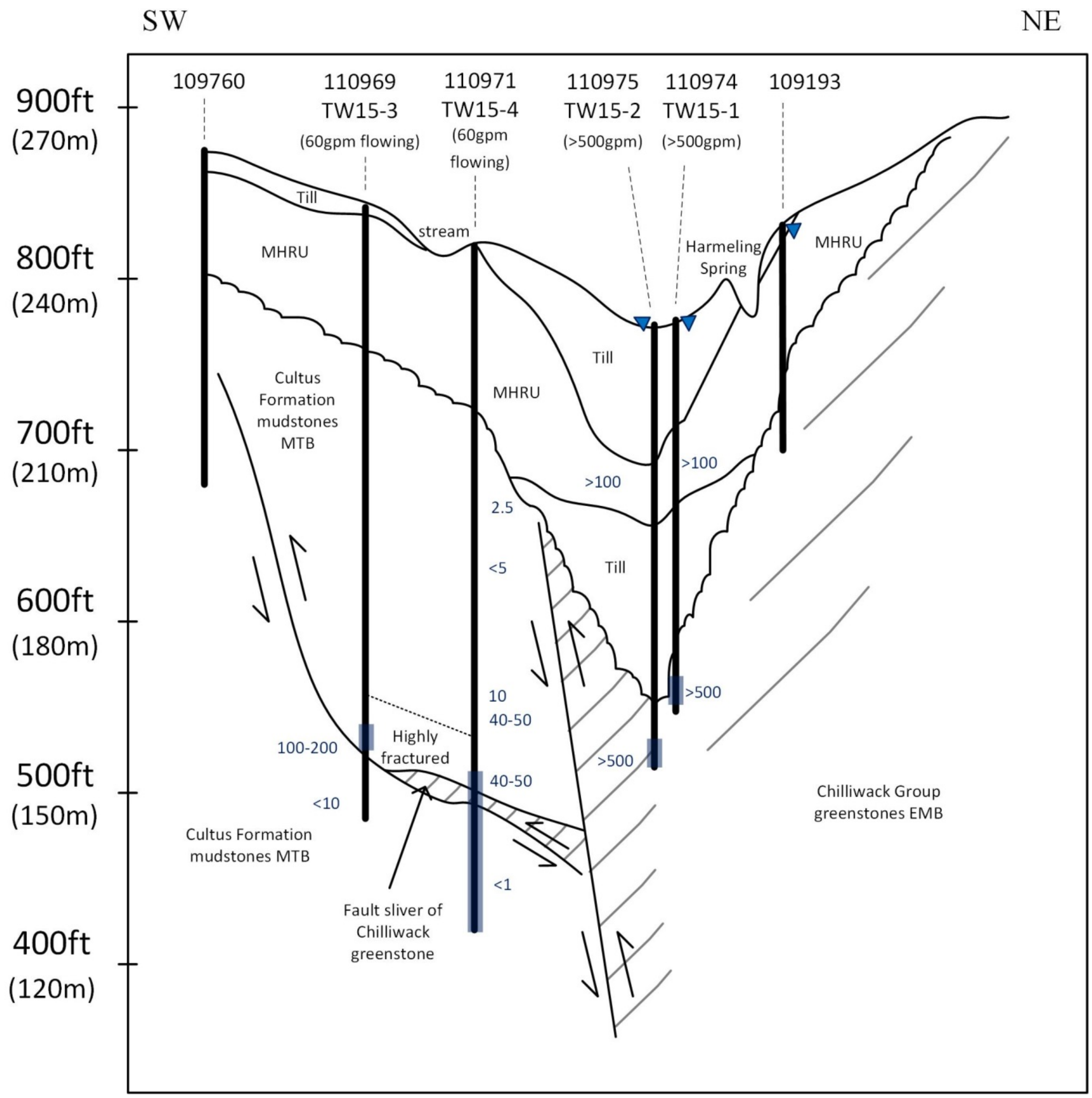

Figure 21b: SW-NE cross-section 2AJ over Marble Hill Road well field.

Notes:

1. The interpretation shown here is based on a simple planar thrust fault model for the main thrust fault. However, with this interpretation the minimum dip of the fault plane between TW15-2 and TW15-4 would be 18^{O}, compared to a regional dip of 7^{O} from the bedrock geological mapping (Monger, 1970b). Therefore, a more complex model probably occurs. Possibilities include a fold in the fault plane; a later normal fault along the axis of Marble Hill Creek valley that cuts the thrust fault, displacing the east side downward; or that the Chilliwack greenstone aquifer is a slide deposit.

2. Water levels in the three northeastern wells (inverted triangles). The numbers beside wellbores represent flow rates estimated by the drillers in gpm. Initial flows reported in TW 3 and 4 were ~60 gpm, but these declined to 5 to 20 gpm, flowing artesian (Green and Bianchin, 2016). Screened intervals in City of Chilliwack Marble Hill Road wells (blue bars). Aquifers: MHRU = Marble Hill Road Unconsolidated (1213) in Late Wisconsin gravels and Holocene colluvium; EMB = Elk Mountain Bedrock (0899) in Chilliwack Group greenstones; and the MTB = Mount Tom Bedrock (0890) in Cultus Formation mudstones.

4.1.16 *Other Unconsolidated Aquifers*

Water-bearing sands not correlated to any of the above aquifers were encountered in several other wells examined for this study.

- WTN 71335 (Cross-section 2A), located adjacent to the north end of Vedder Mountain, by the Vedder Fan, contains three metre thick intervals of sand beneath till, which represent one or more thin Pleistocene aquifers preserved along the edge of Vedder Mountain. The aquifer is likely to be small.
- WTN 1160 and Fraser Valley Chilliwack 14-19-26ECM exploratory well (in D- 077-E/092-H-04; Figures 13b and 16; Cross-sections 2D, 2E, 2H, 2O), located in the eastern and central parts of the Fraser Lowland, suggest that water-bearing sands may be present deep within the Quaternary fill of the Fraser Lowland. WTN 1160 penetrated 485 m of Quaternary sediment above bedrock. Beneath the Chilliwack Rosedale A unit and the Chilliwack Rosedale B unit, the well encountered "fine to medium grey silty sand" between depths of 201 and 281 m (660-922 ft), although no water was reported. In the Fraser Valley Chilliwack 14-19-26ECM exploratory well, this interval is mainly silt and clay, but a 3 m thick fine to medium sand interval occurs between 235 and 238 m (770-780 ft; Cosburn, 1965). The well record reports water at 231 m, presumably from the same interval. Water quality in this deep aquifer is likely to be poor.
- WTN 24848 (Cross-sections 2Ga, 2P), located north of Chilliwack Mountain, encountered a 5 m thick water-bearing sand encased in clays between depths of 56 and 61 m (185-200 ft). This appears to be an isolated sand body, although it could be a distal tongue of the Chilliwack Rosedale B unit. However, the base of the Chilliwack Rosedale B unit is 26 m higher in a nearby well.
- WTN 19353, 50237, and 53797 (Cross-sections 2ALa and 2ALb) located in the southeast part of the Cheam Plateau, have water-bearing sand and gravel intervals 0.3 to 1 m thick that occur at different horizons beneath the most proximal parts of the Cheam slide. In one well (WTN 53797) aquifer materials occur between 56 m of slide debris and bedrock. In the other two, they underlie either "blue clay", which may be glaciomarine (WTN 19353), or cemented gravel (WTN 50237). These deposits are interpreted as Pleistocene deposits preserved on the steep valley walls of the Fraser Lowland. Whether these are connected with each other or with the Chilliwack Rosedale A unit is unknown.
- Several wells in the Ryder Upland outside of the defined aquifers encountered water in isolated surficial deposits up to 10 m thick overlying bedrock (Cross-section 2H). Several minor aquifers are represented, and aquifer materials include gravels (e.g. WTN 11519 and 11634) and till (e.g. WTN 11540). Similarly, "some water" has been reported in shallow till perched above the RUSA in WTN 45394 (Cross-section 2AB), and in surficial gravels perched above the RUSC in WTN 34830 (Cross-section 2Z; Figure 20).
- WTN 56192 (Cross-section 2H) located 500 m south of Ryder Lake in the Ryder Lake upland, includes a 2 m thick gravel interval beneath 13 m of till and had an initial reported flow rate of 20 gpm. However, the aquifer was depleted and was re-drilled to bedrock. This well suggests that a small gravel aquifer may extend beneath the topographic depression that includes Ryder Lake and a wetland to the southeast, and with the lake form a perched hydrological system.

4.2 Bedrock Aquifers

Bedrock aquifers are shown in Figure 22 and summarized in Table 4.

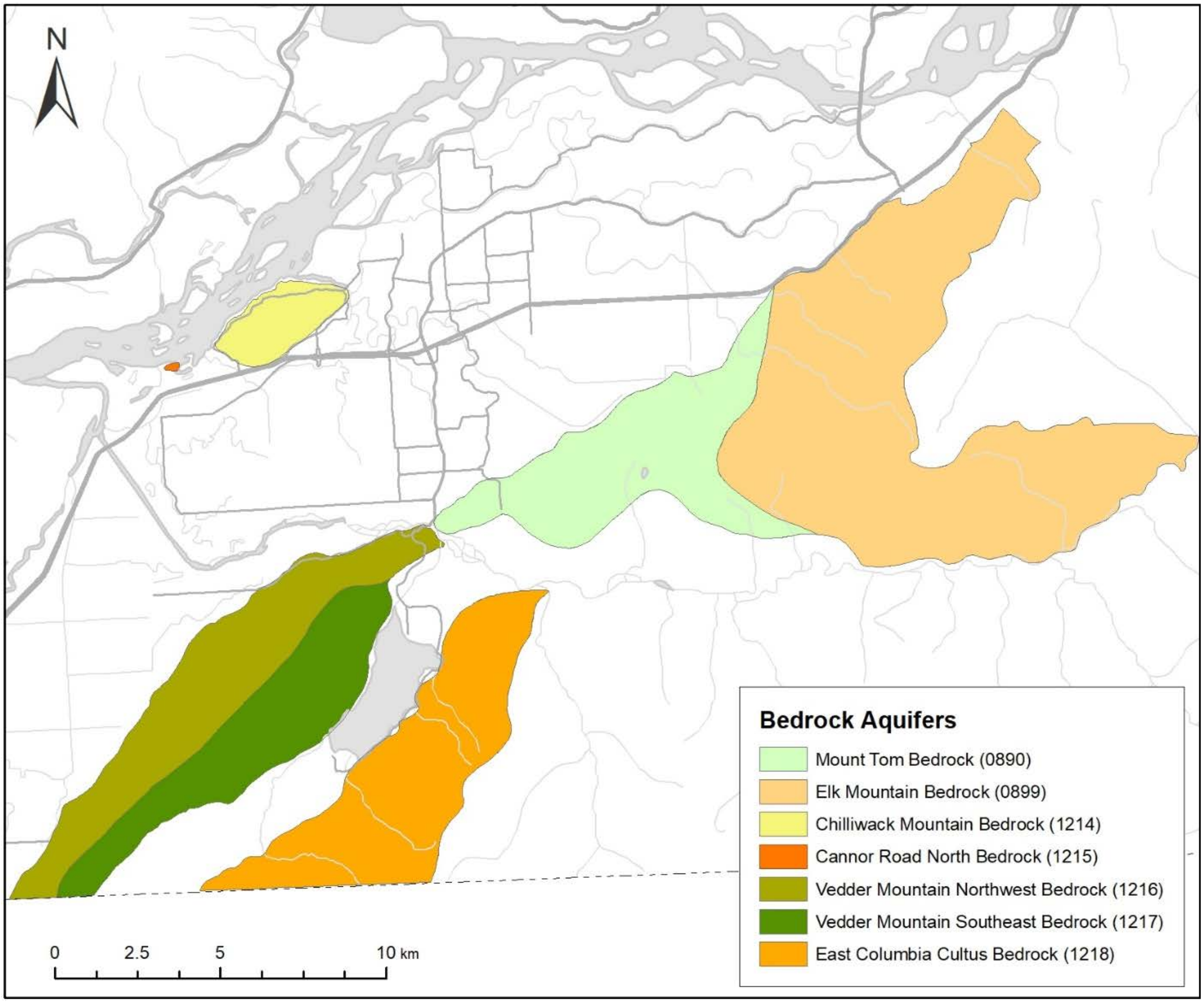

Figure 22: Bedrock aquifers.

4.2.1 *Mount Tom Bedrock Aquifer – Aquifer 0890*

Figures: 21 and 22
Cross-sections: 2AC, 2AE-2AH, 2AJ

The Mount Tom Bedrock Aquifer underlies Promontory Heights, Mount Tom and the Ryder Lake Upland. The aquifer has been mapped as far east as the approximate trace of the east-dipping thrust fault that emplaces Pennsylvanian to Permian Chilliwack Group rocks on Triassic to Jurassic Cultus Formation mudstones and fine sandstones. The latter form the bedrock of the eastern half of the aquifer. Further west, coarser sedimentary rocks, including conglomerates, assigned to the Kent Formation have been mapped, and at the southwestern end of the upland, Vedder Complex metamorphic rocks and some Tertiary clastics occur (Monger, 1970b; Armstrong, 1980b; Halstead, 1986; Monger, 1989).

Bedrock is overlain by Late Wisconsin glaciogenic sediments, mainly of Sumas age, that consist of till, clay, and sand and gravel (Armstrong, 1980b; Halstead, 1986; Levson et al., 1996b). In wells, depth to bedrock varies from less than 1 to 117 m; although the mean is 20 m and the median is 7 m. However, surficial geological maps show significant thicknesses of Quaternary sediment over bedrock in only the southern half of the aquifer. Elsewhere, bedrock is overlain by a thin discontinuous cover of sediment and colluvium.

Ninety wells have been reported in this aquifer. Well depths range from 3 to 245 m, and the median depth is 93 m. The depth to water ranges from 0 to 100 m, with a median of 21 m. The principal water-bearing intervals are fractured intervals, both at or near the bedrock top and in deeper fractured zones.

Reported well yields are generally less than 5 gpm; the maximum is 100 gpm, and the median is 2 gpm. The low flow rates are probably due in part to the relative ductility of the Cultus Formation mudstones that make up much of this aquifer.

Flow rates of 60 gpm have been reported from wells directly underlying the major thrust fault in the Marble Hill Road well field (TW 15-3 and 15-4; WTN 110969 and 110971; Figure 21, Appendix 5), at the eastern limit of this aquifer. The high productivity is likely related to increased fracture intensity in proximity to the fault. However, these rates were not sustainable, and declined to 5 to 20 gpm (Green and Bianchin, 2016). Hydrogen sulphide odour has been reported in wells in the area where the Cultus Formation mudstones form the bedrock, including at Marble Hill Road (e.g. WTN 93302, 100985, 110969, 110971; Green and Bianchin, 2016; C. Naiduwa, personal communication, November 18, 2016). The source of this odour may be due to weathering of pyrite in the Cultus Formation mudstones. Further investigation of this aquifer would be useful to determine if it can be subdivided on the basis of the bedrock type and water quality.

Isolated perched aquifers occur within the overlying Quaternary sediments, particularly where thicker Quaternary sections occur. The principal ones are the Mount Tom Unconsolidated Aquifer, the Elkview Road Shallow Aquifer, and part of the Marble Hill Road Unconsolidated Aquifer. Water has also been reported in several small unconfined sand, gravel and hardpan horizons, particularly southwest and east of Ryder Lake.

Recharge is inferred to be primarily from precipitation through areas of bedrock exposure, including Mt. Tom.

4.2.2 *Elk Mountain Bedrock Aquifer – Aquifer 899*

Figures: 21 and 22
Cross-sections: 2AJ and 2AK

The Elk Mountain Bedrock Aquifer is located in the Skagit Ranges, and underlies the slopes of Elk Mountain, Mount Archibald, Mount Thurston and Mount Mercer that drain directly into the Fraser Lowland and Chilliwack River. The western boundary follows the approximate trace of the east-dipping thrust fault that emplaces Pennsylvanian to Permian Chilliwack Group rocks on the Triassic to Jurassic Cultus Formation (Monger, 1970a, b, 1989; Monger et al., 1992; Journeay and Monger, 1994). The eastern boundary follows the drainage divide between the Chipmunk Creek and the Chilliwack River drainages on the south, and between the Chipmunk Creek and the Fraser Lowland drainages on the north, as far as Mount Archibald and Bridal Veil Falls. It may extend further northeast adjacent to the Fraser Lowland as far as Mount Cheam and Popkum, where the Chilliwack Group rocks are intruded by the Mount Barr Batholith. This aquifer has been expanded to include wells formerly included in the Upper Young Creek Aquifer (891).

The aquifer consists of a thrust faulted succession of volcanic and sedimentary rocks of the Pennsylvanian to Permian Chilliwack Group and mudstones and fine sandstones of the overlying Triassic to Jurassic Cultus Formation (Monger, 1970a, b, 1989; Monger et al., 1992; Journeay and Monger, 1994). However, Chilliwack Group rocks predominate at lower elevations, where groundwater development has occurred, and Cultus Formation mudstones occur mainly at higher elevations. All wells to date have been drilled into the upper division of the Chilliwack Group, which consists of greenstones (altered volcanic rocks) and pyroclastics. Represented in other parts of the Chilliwack Group are conglomerate, limestone, sandstone and pelite.

The aquifer is overlain by Late Wisconsin glaciogenic sediments, comprising till, clay, and sand and gravel, and Holocene colluvium and alluvial fan deposits (Armstrong, 1980b; Levson et al., 1996b). In wells, depth to bedrock varies from 0 to 68 m with a median of 20m. These sediments are thickest in valleys of major creeks, such as Marble Hill Creek, alluvial fans at the mountain front deposits, and the southern flank of Lookout Ridge (Levson et al., 1996). However, surficial geological maps show that over most of this aquifer, bedrock is overlain by a thin discontinuous cover of sediment and colluvium (Armstrong, 1980b; Levson et al., 1996b).

Thirty wells have been reported in this aquifer, and these are located in four clusters: at the City of Chilliwack Marble Hill Road well field, Nixon Road, the Dunville and Nevin Creek Alluvial Fan, and Lookout Ridge. Overall in this aquifer, well depths range from 25 to 195 m with a median of 53 m and depth to water ranges from 1 to 93 m, with a median of 26 m. The principal water-bearing intervals are fractured intervals, both at or near the bedrock top and in deeper fractured zones.

Reported well yields are variable, ranging from 0 to 500 gpm. The latter are the highest reported in bedrock in the study area, and account for the high mean of 72 gpm. However, the median is 10 gpm, higher than that of the adjoining Mount Tom Bedrock Aquifer, but comparable to the other bedrock aquifers in the Skagit Ranges. The higher flow rates compared to the Mount Tom Bedrock Aquifer are most likely due to the greater brittleness of the Chilliwack group greenstones of the Elk Mountain Bedrock Aquifer relative to the Cultus Formation mudstones of the Mount Tom Bedrock Aquifer.

Well yields of 100 to 500 gpm are reported at the City of Chilliwack Marble Hill Road well field and in the Dunville and Nevin Creek alluvial fan (Baldry, 1976; Green and Bianchin, 2015, 2016). At the Marble Hill Road well field, the high rates are related to a greater degree of fracturing in proximity to the thrust fault that forms the western boundary of the aquifer (Figure 21). At the Dunville and Nevin Creek alluvial fan, increased fracture intensity in proximity to faults is also likely the cause of the high productivity (Monger, 1970a, b, 1989; Monger et al., 1992; Journeay and Monger, 1994). However, pump tests on one well in this locale suggest the lateral extent of the highly fractured interval may be limited (Badry, 1976). Elsewhere in the aquifer, median well yield is 10 gpm.

Recharge is inferred to be primarily from precipitation through areas of bedrock exposure, particularly at higher elevation on Elk Mountain, Mount Thurston, Mount Mercer and Mount Archibald.

Aquifers in unconsolidated sediments overlying the Elk Mountain Bedrock Aquifer have been defined in the Marble Hill Road area (Marble Hill Road Unconsolidated Aquifer) and at Lookout Ridge (Lookout Ridge Unconsolidated Aquifer). Others are likely to occur. This aquifer likely recharges the Marble Hill Road Unconsolidated Aquifer, the Chilliwack Rosedale Aquifer and the Cheam Slide Aquifer in the Fraser Lowland, and the Chilliwack River Shallow and Chilliwack River Subtill Aquifers in the Chilliwack River Valley.

Marble Hill Road Well Field and Harmeling Spring (Figure 21 and 22; X-Sect. 2AJ & 2AK)
The City of Chilliwack drilled six wells at the Marble Hill Road site to develop the groundwater resource in the vicinity of Harmeling Spring. The Harmeling Spring is located in a gully 100 to 300 m northeast of the Marble Hill Road test wells and flows at an average rate of 960 gpm (Tixier and Tiplady 2013). The spring originates directly from water-bearing gravels of the Marble Hill Road Unconsolidated Aquifer (section 4.1.15), which is in communication with the Elk Mountain Bedrock Aquifer (Green and Bianchin,

2015, 2016). Development has focussed on the bedrock rather than the Quaternary aquifer because of higher flow rates.

The six City wells have been professionally surveyed and logged (Appendix 5; Green and Bianchin, 2015, 2016), allowing greater confidence in interpretations based on these logs. Of these, four (TW 15-1, 15-2, 15-5 and 15-6; WTN 110974, 110975, 110970 and 110972, respectively) encountered fractured greenstones of the Chilliwack Group, and are assigned to the Elk Mountain Bedrock Aquifer (Figure 21). Two of these, TW 15-2 and 15-6, have been completed as production wells, and TW 15-1 and 15-5 are monitoring wells. The other two wells are farther away from the spring (TW 15-3 and 15-4; WTN 110969 and 110971, respectively) and encountered primarily Cultus Formation mudstones in the bedrock; as such they are west of the main thrust fault that separates the Chilliwack Group from Cultus Formation. They are assigned to the Mount Tom Bedrock Aquifer.

Differences in static water levels and in water chemistry and quality demonstrate that separate aquifers were encountered (Green and Bianchin, 2015, 2016; C. Naiduwa, personal communication, November 18, 2016). Static levels are 232 m asl in the wells in Elk Mountain Bedrock Aquifer Chilliwack greenstones, but 259 to 264 m asl (flowing artesian conditions) in the wells in the Mount Tom Bedrock Aquifer Cultus mudstones. Furthermore, the wells in the Mount Tom Bedrock Aquifer produce water with a hydrogen sulphide odour, whereas the wells in the Elk Mountain Bedrock Aquifer do not.

The Chilliwack Group greenstone of the Elk Mountain Bedrock Aquifer is described as highly fractured, with sand and gravel infilling fractures, and fracture aperture widths as up to 100 cm (Green and Bianchin, 2015, 2016). Quartz and calcite-filled fractures are abundant. Sustained flow rates in the production wells are 340 to 500 gpm. The intensity of fracturing is related to proximity to the thrust fault that separates Chilliwack Group greenstones from Cultus Formation mudstones.

As noted above in section 4.2.1, flow rates of 60 gpm have been reported from the wells in the Mount Tom Bedrock Aquifer Cultus Formation mudstones beneath the thrust fault. However, these rates were not sustainable, and declined to 5 to 20 gpm (Green and Bianchin, 2016). Fracturing in these rocks also is most likely directly related to thrust faulting. This is further demonstrated by TW 15-4, where flow rates in the Cultus mudstones decrease upwards from a 4 m fault sliver of Chilliwack Group greenstone, which is bounded below by a secondary thrust fault. This secondary strand can be projected into the highly fractured interval in the Cultus Formation mudstones in TW 15-5 (Figure 21).

The Marble Hill Road well field does not fit a simple planar thrust fault model (Figure 21). The average easterly dip of the fault plane as mapped by Monger (1970b) is approximately 7^{o} to the east, but a local dip of at least 18^{o} is required to separate the Marble Hill Road test wells on either side of the fault. A more complex structural model is likely present. This could involve a fold in the fault plane, or a later normal fault that is oriented along the axis of Marble Hill Creek valley and cuts the thrust fault, displacing the east side downwards. By the latter model, the increased fracture intensity in the Chilliwack greenstones would be localized by the intersection of the two fault systems. Another possibility is that the aquifer represents a landslide deposit, the location of which was controlled by the fault – either with the Chilliwack Group rocks being undercut by erosion of the weaker Cultus mudstones at the head of Marble Hill Creek Valley, or with the fault plane acting as a failure plane, as suggested by Naumann (1990) at the Cheam Slide. The slide hypothesis is supported by the large fracture apertures, the fracture fill with sand and gravel, and the embayment in the slope uphill of the site.

The City of Chilliwack has commissioned further geological and geophysical work to determine the extent of the high productivity aquifer at Marble Hill Road. The results of this work were not available to ENV at the time of this study.

4.2.3 *Chilliwack Mountain Bedrock Aquifer – Aquifer 1214*

Figure 22

The Chilliwack Mountain Bedrock Aquifer underlies all of Chilliwack Mountain in the western part of Chilliwack. Bedrock in the area is mapped as the middle Jurassic Harrison Lake Formation, which consists primarily of intermediate to felsic pyroclastics and flows (Roddick, 1965; Roddick and Armstrong, 1965; Monger, 1970a, b. 1989; Journeay and Monger, 1994; Mahoney et al., 1995).

The materials overlying bedrock include till, gravel and boulders, with some clay and sand. Depth to bedrock in wells varies from 0 to 8 m; and the median is 2 m. However, surficial geological maps report a thin discontinuous sediment cover over bedrock (Armstrong, 1980a, b; Levson et al., 1996b).

Thirty-five wells have been reported in this aquifer. Most wells are located in the northern slopes of Chilliwack Mountain, in the vicinity of Old Orchard and Chilliwack Mountain Roads. Well depths range from 14 to 116 m, with a median of 70 m. The depth to water ranges from 2 to 43 m, with a median of 24 m. Reported well yields vary from 1 to 50 gpm, and the median is 4 gpm. The principal water-bearing intervals are fractured intervals well below the bedrock top.

Recharge is inferred to be primarily from precipitation through areas of bedrock exposure.

4.2.4 *Cannor Road North Bedrock Aquifer – Aquifer 1215*

Figure: 22
Cross-section: 2D

The Cannor Road North Bedrock Aquifer is restricted to a small bedrock hill along the banks of the Fraser River at the north end of Cannor Road, west of Chilliwack Mountain (Levson et al., 1996b). Bedrock likely consists of the middle Jurassic Harrison Lake Formation.

A thin and discontinuous sediment cover overlies bedrock (Levson et al., 1996b). In wells, the depth to bedrock ranges from 0 to 2 m, and the unconsolidated materials are described as clay and stones. The sediment cover likely consists of Late Wisconsin glaciogenic sediments and possibly Holocene colluvium.

Three wells have been reported in this aquifer. Well depths range from 5 to 61 m, and depth to water ranges from 6 to 24 m. Reported flow rates are low, 1 to 1.5 gpm, comparable to those in the Chilliwack Mountain Bedrock Aquifer, which also consists of the Harrison Lake Formation. The principal water-bearing intervals are fractured intervals, both at the bedrock top, and in deeper fractured zones.

Recharge is most likely from precipitation, but the aquifer is likely in contact with the Fraser River. Because the hill is low, there may be some seasonal recharge from the river.

4.2.5 *Vedder Mountain Northwest Bedrock Aquifer – Aquifer 1216*

Figures: 22 and 23
Cross-section: 2G

The Vedder Mountain Northwest Bedrock Aquifer underlies the northwest side of Vedder Mountain, in both the western part of Chilliwack and the southeastern part of Abbotsford. The southeast limit is arbitrarily drawn along the northeast-southwest-oriented ridgeline of Vedder Mountain. Where the ridgeline splits at the northeast end of Vedder Mountain, the aquifer boundary follows the divide between Hatchery Creek and Cultus Lake, which coincides with the main lithological boundary between the northwest and southeast sides of Vedder Mountain (Figure 23.) The southern boundary is arbitrarily drawn along the international boundary.

The aquifer consists primarily of gabbro, amphibolite, schist and minor ultramafics of the Vedder Complex (Figure 23; Roddick, 1965; Roddick and Armstrong, 1965; McMillan, 1966; Armstrong et al., 1983; Monger 1989; Journeay and Monger, 1994). However, the fault separating these rocks from the Jurassic and Cretaceous rocks on the southeast side of Vedder Mountain lies to the northwest of the ridgeline, so the latter form part of the aquifer at higher elevations. These consist of conglomerate, sandstone, and argillite, with lesser amounts of limestone, basalt and schistose chert, and have been correlated with the Kent Formation by Monger (1989). Similar rocks are also present in fault contact with the Vedder Complex in small areas on the northwest side of Vedder Mountain, adjacent to the Fraser Lowland (McMillan, 1966; Armstrong et al., 1983).

Overlying sediments consist of Late Wisconsin glaciogenic sediments, mainly Sumas age till, with some sand, gravel and clay, and Holocene colluvium. In the wells in this aquifer, the depth to bedrock varies from 0 to 35 m, with a median of 5 m. In valleys at the northeast end of Vedder Mountain, bedrock is overlain by Sumas and earlier glacial outwash sands and gravels of the Vedder Crossing Aquifer (1205) and till, and depth to bedrock locally exceeds 46 m. On the northwest side of Vedder Mountain, the aquifer locally extends below the Sardis-Vedder Aquifer.

Detailed bedrock and surficial geological maps show significant thicknesses of overlying sediment only in small parts of the aquifer, and over most of it, bedrock is overlain by a thin discontinuous cover of sediment and colluvium (McMillan, 1966; Armstrong, 1980a, b; Levson et al., 1996b).

One hundred wells have been completed in this aquifer and all are on the lower slopes of the mountain. Most are located on Majuba Hill Road in the south-westernmost part of Chilliwack. Well depths range from 7 to 215 m, with a median of 38 m. Depth to water ranges from 2 to 55 m, with a median of 12 m. The principal water-bearing intervals are fractured intervals, both at the bedrock top, or in deeper fractured zones.

Reported flow rates are comparable to other bedrock aquifers in the Skagit Ranges, ranging from 0 to 360 gpm, with a median of 11 gpm. However, the flow rates are generally higher in the wells along and south of Majuba Road than in the wells at the north end of Vedder Mountain. In the former (n=85), flow rates vary from 0 to 360 gpm, and the median is 12 gpm, whereas in the latter (n=15) the range is 1 to 40 gpm, with a median of 5 gpm. The higher flow rates may be related to different bedrock lithologies; primarily gabbro in the higher flow rate area in and south of Majuba Road, and amphibolite and schist in the lower flow rate area to the north, or increased fracturing adjacent to minor faults mapped in the vicinity of Majuba Road (Figure 23; McMillan, 1966; Armstrong et al., 1983).

Recharge is inferred to be primarily from precipitation through areas of bedrock exposure, particularly at higher elevation on Vedder Mountain. The aquifer also likely recharges aquifers in the adjacent valleys, including the Sardis Vedder Aquifer and Sumas Prairie South Aquifer in the Fraser Lowland, and the Chilliwack River Shallow and Chilliwack River Subtill Aquifers in the Chilliwack Valley.

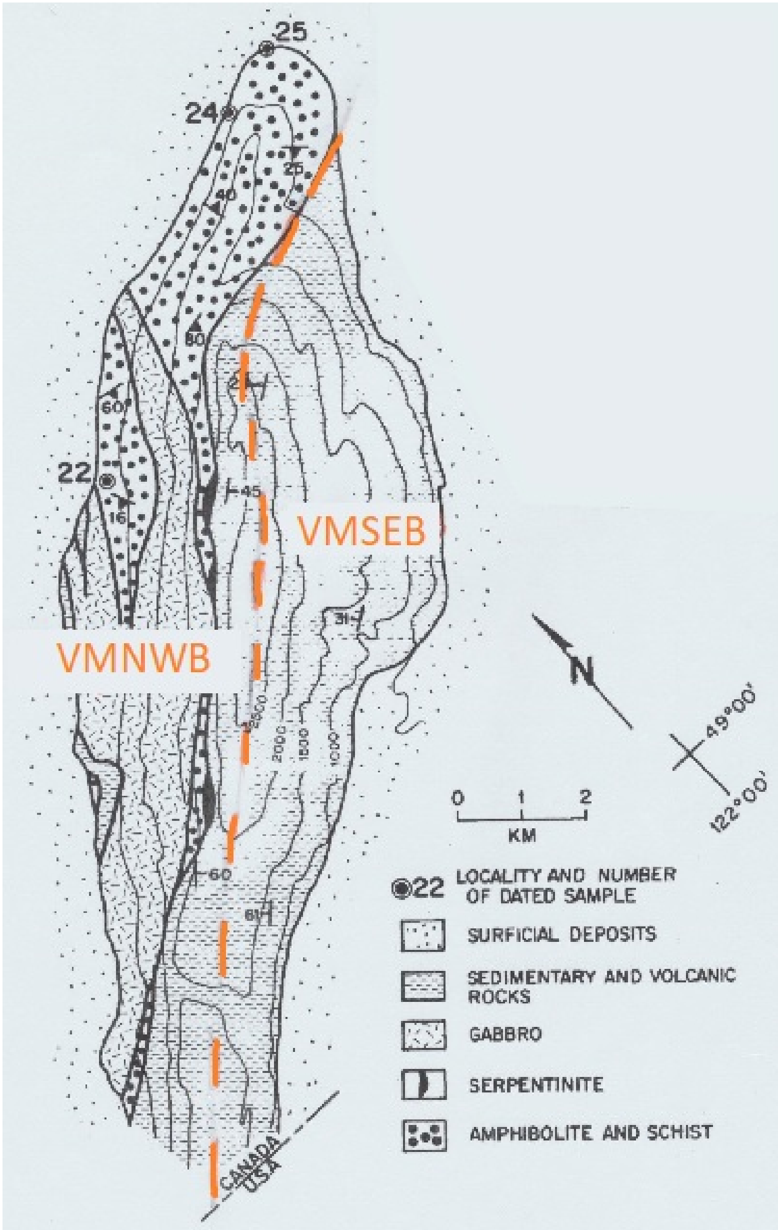

Figure 23: Bedrock geological map of Vedder Mountain. Note: Map shows the boundary between the Vedder Mountain Northwest Bedrock Aquifer (1216) and the Vedder Mountain Southeast Bedrock Aquifer (1217) drawn along the ridgeline of Vedder Mountain, except at the northeast end. The Majuba Hill Road well cluster is southwest of sample point 22 shown on the map. Modified from Armstrong et al., 1983.

4.2.6 *Vedder Mountain Southeast Bedrock Aquifer – Aquifer 1217*

Figures: 9, 18, 22 and 23

The Vedder Mountain Southeast Bedrock Aquifer is located on the southeast side of Vedder Mountain. The northwest boundary with the Vedder Mountain Northwest Bedrock Aquifer is arbitrarily drawn along the northeast-southwest-oriented ridgeline of Vedder Mountain. Where the ridgeline splits at the northeast end of Vedder Mountain, the aquifer boundary follows the divide between Hatchery Creek and Cultus Lake, which coincides with the main lithological boundary between the northwest and southeast sides of Vedder Mountain (Figure 23). The aquifer locally extends beneath the northwest side of Columbia Valley in a shallow bedrock shelf north of the intersection of Columbia Valley and Iverson Roads (Figures 9, 18, 22 and 23). The southern boundary is arbitrarily drawn along the international boundary.

The aquifer consists of Jurassic to Cretaceous conglomerate, sandstone, and argillite, with lesser amounts of limestone, basalt and schistose chert (Roddick, 1965; Roddick and Armstrong, 1965; McMillan, 1966; Armstrong et al., 1983; Monger 1989; Journeay and Monger, 1994). These strata have been correlated with the Kent Formation by Monger (1989).

On the bedrock shelf on the northwest side of the Columbia Valley, the aquifer is overlain by Sumas till and outwash gravel of the deposits of the Columbia Valley Aquifer (Figure 18). All wells reported in the Vedder Mountain Southeast Bedrock Aquifer are located in this area; and depth to bedrock in them varies from 3 to 35 m, with a median of 14m. However, over the rest of the aquifer, detailed bedrock and surficial geological maps show that bedrock is overlain by a thin discontinuous cover of sediment and colluvium (McMillan, 1966; Armstrong, 1980a, b)

Six wells are assigned to this aquifer and well depths range from 24 to 121 m, with a median of 74 m. The depth to water ranges from 1 to 37 m, with a median of 10 m. The principal water-bearing intervals are fractured intervals, both at the bedrock top, or in deeper fractured zones. Reported well yields are 1 to 55 gpm, with a mean of 19 gpm and a median of 11 gpm.

This aquifer is likely in communication with and provides recharge to the Columbia Valley Aquifer. One well deeper in the west side of the valley (WTN 94142) likely produces from both unconsolidated deposits and bedrock and has been assigned to the Columbia Valley Aquifer B unit. This aquifer likely recharges the Chilliwack River Shallow, the Chilliwack River Subtill, and the Cultus Lake Fan Delta E Aquifers, as well as Cultus Lake.

4.2.7 *East Cultus Columbia Bedrock Aquifer – Aquifer 1218*

Figures: 18 and 22

The East Cultus Columbia Bedrock Aquifer is located on the east side of Columbia Valley and Cultus Lake, extending as far north as the Chilliwack River. The eastern limit is arbitrarily defined along the crest of the International Ridge, and the south limit is arbitrarily drawn along the international boundary.

Bedrock in this area consists of mudstones and fine sandstones of the Triassic to Jurassic Cultus Formation (Monger, 1966, 1970a, b, 1989; Monger et al., 1992; Journeay and Monger 1994).

Ten wells are assigned to this aquifer. Six wells are on the eastern margin of the Columbia Valley. In these, the aquifer is overlain by Columbia Valley Aquifer materials (Figure 18). Well depths range from 14 to 170 m, with a median of 75 m. Depth to bedrock varies from 3 to 55 m with a median of 35 m, and the depth to water ranges from 25 to 78 m, with a median of 39 m. Reported well yields are 0 to 75 gpm, with a median of 15 gpm. The aquifer here is likely in communication with and provides recharge to the Columbia Valley Aquifer: several wells include Columbia Valley Aquifer B unit materials below the reported water levels, and deeper in the valley, where water levels are significantly deeper and consistent with those in the Columbia Valley Aquifer, bedrock intervals have been included with the Columbia Valley Aquifer.

The aquifer also locally extends beneath the Chilliwack River Shallow Aquifer and the underlying till east of the village of Cultus Lake, and likely recharges the Chilliwack River Shallow Aquifer and Chilliwack River Subtill Aquifer in this area. In one well in this setting the depth to bedrock is 8 m, well depth is 11 m, and the reported yield is 10 gpm. The aquifer also extends beneath and likely recharges the Cultus Lake Fan Delta A, B, C and D Aquifers in the fan deltas along the shore of Cultus Lake. However, over most of the aquifer, surficial geological maps show that bedrock is overlain by a thin discontinuous cover of sediment and colluvium (Armstrong, 1980a, b). Consistent with this, the remaining 3 wells, which are located outside of the Columbia and Chilliwack River valleys and the Cultus Lake fan deltas have 0 to 3 m of colluvium over bedrock. Well depths range from 26 to 130 m, and the depth to water ranges from 2 to 24 m. Reported flow rates are 1 to 25 gpm.

Recharge is inferred to be primarily from precipitation through areas of bedrock exposure, particularly at higher elevations on International Ridge. In addition to recharging the adjacent unconsolidated aquifers, the East Cultus Columbia Bedrock Aquifer recharges Cultus Lake.

4.2.8 *Other bedrock aquifers.*

At Lindell Beach, a 50 m deep well (WTN 33939) has been reported. Depth to bedrock and to water are 34 and 38 m respectively, and the reported flow rate is 3 gpm. The well is offset by a dry hole. Bedrock is uncertain but could be either the Cultus or Kent Formation.

A 106 m deep well has been reported at the mouth of Tamihi Creek (WTN 52462). Bedrock depth is 19 m, and the reported flow rate is 50 gpm, apparently from bedrock. “Little water” was reported from the gravel overlying bedrock. Bedrock is mapped as mudstones of the Triassic to Jurassic Cultus Formation, but the logs report limestone, more typical of the Chilliwack group. The well may have encountered fault slivers of the Chilliwack group.

Although no wells have been reported in Mount Shannon, in the central part of the Fraser Lowland in Chilliwack, a bedrock aquifer is likely present. Bedrock in the area is mapped as the middle Jurassic Harrison Lake Formation, which consists primarily of intermediate to felsic pyroclastics and flows (Roddick, 1965; Roddick and Armstrong, 1965; Monger, 1970a, b. 1989; Journeay and Monger, 1994; Mahoney et al., 1995). This aquifer would be similar to the Chilliwack Mountain Bedrock Aquifer and Cannor Road North Bedrock Aquifer, which are also in these rocks. Surficial geological mapping shows that bedrock in Mount Shannon is overlain by a thin discontinuous sedimentary cover (Armstrong, 1980b).

5. RECOMMENDATIONS FOR ADDITIONAL WORK

5.1 Additional Subsurface Data

The subsurface geology is known primarily from water well and geotechnical borehole logs. While useful, many questions remain regarding the age and depositional environments of the sediments penetrated. With the notable exception of the work by Tunnicliffe et al. (2012) in the Vedder Alluvial Fan, no borehole samples have been radiocarbon dated. Additional information would greatly assist the understanding of the aquifers, their relationships and their continuity. Areas of uncertainty include:

- The maximum thickness of the Sardis Vedder Aquifer.
- The connection between the Sardis Vedder and Chilliwack Rosedale Aquifers.
- The depositional environment of the westward thinning wedge of the Chilliwack-Rosedale Aquifer B unit.
- The depositional environments, lateral continuity, facies and age of the Chilliwack River Subtill Aquifer, particularly the deeper parts, and its potential connection with Upper Chilliwack River Aquifer on Larson’s Bench at the confluence of Chilliwack River and Slesse Creek.

Techniques to improve the knowledge of these aquifers include geophysical techniques, to establish continuity, stratigraphic relationships and structure of the aquifers; and cored boreholes, to determine facies and obtain samples for radiocarbon dating.

These activities could be supported by provincial or federal research programs. However, new boreholes drilled for groundwater production, monitoring, observation or exploration by the Province, municipalities or other agencies also provide opportunities for obtaining such information. This would be facilitated by developing and maintaining relationships with local governments and other agencies to know when these projects are undertaken and coordinate work of mutual benefit.

5.2 Hydrogeologic Studies

The conceptual model of the hydrostratigraphy of Chilliwack area presented in this report provides a basis for the design of further studies that could be used to better understand water availability and hydraulic connectivity between aquifers and streams. Field studies of water levels could be conducted to better understand the flow dynamics of the groundwater system and seasonal variability in flow directions and availability. These studies would ideally be paired with targeted hydrometric monitoring in streams with water availability concerns to better understand paired sustainable management of groundwater and surface water systems.

5.3 Water Quality Studies

High Vulnerability Aquifers

Water quality studies in aquifers mapped as high vulnerability and which underlie agricultural areas would be helpful in understanding agricultural impacts on aquifers. The results of water quality studies could be used to target outreach efforts and encourage best management practices such as environmental farm plans. The Code of Practice for Agricultural Environmental Management (B.C. Reg. 8/2019) came into force in February 2019. The Code specifies that requirements for nutrient management planning will be phased in throughout BC with the highest risk areas prioritized first. The Code specifies that by the spring of 2022, livestock and poultry operations in the majority of the Chilliwack area will be required to have a Nutrient Management plan. Long term groundwater quality monitoring could be strategically implemented to understand the time scales required to observe corresponding groundwater quality improvements once nutrient management planning has been implemented. Ideally, this monitoring would begin before nutrient management planning is implemented to obtain a baseline level.

Mount Tom Bedrock Aquifer

Water quality issues have locally been reported where the bedrock in the Mount Tom Bedrock Aquifer consists of marine mudstones of the Cultus Formation. Further investigation would be useful to determine if this aquifer can be subdivided based on the bedrock type and water quality.

5.4 Groundwater Wells and Aquifers (GWELLS) Database Improvements

5.4.1 *Mapping of GWELLS database wells to aquifer units*

The mapping contained in this report provides the framework for correlating GWELLS wells to aquifers and approximately 1,000 wells were directly interpreted and correlated to aquifer units in the course of this study. Correlating the remainder of the wells in the GWELLS application to these aquifer units could support aquifer scale water use and availability estimates. Improvements in this information would also support the quality of information available for evaluation of groundwater license applications.

5.4.2 *Well Closure Documentation*

During the initial phases of this study it was identified that some historic wells present in the GWELLS application may no longer be in use due to expansion of the municipal water service areas. A review of the wells that are located within the municipal water service area and a study to determine if any of these wells are no longer in use would improve the quality of information available for evaluation of groundwater license applications. Wells that have been closed could be updated in GWELLS. However, it is anticipated that such a study may also identify wells that are no longer in use and have not yet been closed. In these cases, outreach to well owners to notify them of the legal requirements for well closure, could also improve groundwater protection.

5.4.3 *Corrections to the GWELLS database*

As described above, numerous errors were identified in GWELLS within the study area. These apparent errors should be vetted and corrected where necessary to better support groundwater licensing under the Water Sustainability Act. Other errors are likely to be present, both here and in other areas. We recommend a system be established for identifying and correcting errors in GWELLS.

6. STUDY LIMITATIONS

Hydrostratigraphic mapping is an interpretative science. Subsurface conditions are not known between the specific investigation locations but have been inferred based on the hydrogeologic data sources available. In future, as additional data becomes available, these interpretations should be reviewed and revised as appropriate. Site specific conditions may vary from those described in this report; however, the hydrostratigraphic interpretations described here provide the most thorough regional scale hydrogeological review completed to date in this study area. These interpretations provide a foundational conceptual model that can inform site scale assessments when supplemented with specific site hydrogeologic information and which future regional studies may build upon.

The interpretations presented in this report are based on subsurface data sources of variable data quality. The results of previous work referenced in this report have been relied on to build the hydrostratigraphic understanding contained herein, the authors are not responsible for any errors or omissions in the information reviewed.

SIGNATURES

ORIGINAL SIGNED BY

Patrick Monahan, PhD, P.Geo.

ORIGINAL SIGNED BY

Emilia Young, B.Sc.

ORIGINAL SIGNED BY

Christine Bieber, M.Sc., P.Geo.

ORIGINAL SIGNED BY

Theodore Back, B.Sc.

ORIGINAL SIGNED BY

Michele Lepitre, M.Sc., P.Geo.

ORIGINAL SIGNED BY

Mike Simpson, M.Sc., P.Geo.

7. LIST OF APPENDIXES

Additional information is available in the following appendices which are available in accompanying digital files.

Appendix 1: Master Project database from GWELLS

Appendix 2: Coordinate Acquisition Codes from GWELLS

Appendix 3: Chilliwack Data Sources Documentation

Appendix 4: Chilliwack New Well Data

Appendix 5: City of Chilliwack wells.

Appendix 6: Scanned cross-sections of geotechnical logs of Chilliwack (Monahan, 1995)

Appendix 7: Scanned images of the interpreted cross-sections

Appendix 8: Fraser Lowland and Marble Hill Road Aquifer Table

Appendix 9: Cultus Chilliwack Ryder Aquifer Table

Appendix 10: Bedrock Aquifer Tables

Appendix 11: Scanned image of the map of aquifer outlines and shapefiles for Chilliwack Aquifers

Appendix 12: Aquifer Sheets

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