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A Revised Geological Model and Hydrostratigraphic Framework for the Kelowna-Mission Aquifers

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Cover Photographs:
Stewart, M.L. Exposed Greater Kelowna Aquifer above Mission Creek, looking west near Gallagher's Canyon.

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EXECUTIVE SUMMARY

The Kelowna-Mission aquifer mapping project was started in 2017 with the objective of building a comprehensive regional hydrostratigraphic model of the Kelowna area. Understanding the character of aquifers in priority areas such as Kelowna is an important component of groundwater resource assessment in the province and provides critical support to British Columbia's *Water Sustainability Act*.

A three-dimensional (3D) modelling approach was utilized to generate digital representations of aquifers and their confining units, to add aquifer information to the wells database and to summarize the regional hydrostratigraphy of the local overburden. The model presented in this report extends from Ellison lake, south to bedrock slopes below Myra Canyon, and from Lake Okanagan, east to where Mission Creek enters the Okanagan valley upstream of Gallagher's Canyon. Data including 1,373 well locations, 8,218 lithology descriptions, surface geologic and topographic mapping, seismic sections and airphoto interpretation were incorporated into a 3D Leapfrog^{TM} model. The following report outlines results of the additional mapping including revised aquifer boundaries, aquifer descriptions and 3D modelling.

Three main aquifers in the Kelowna area have been defined based on results of the modelling including, in order from shallowest to deepest:

1. The Mission Creek Aquifer, a shallow unconfined aquifer comprising alluvium and flood deposits associated with the meandering channel of Mission Creek and Mill Creek;
2. The Central Kelowna Aquifer, a semi-confined aquifer comprising proglacial outwash sediments overlying Fraser-age till, but predating deposition of late glacial lacustrine sediments; and
3. The Greater Kelowna Aquifer, a deep confined aquifer comprising highly productive alluvial sediments (Bessette Sediments) from the non-glacial period between the Okanagan Centre glaciation and Fraser glaciation.

Also defined are the Bellevue and Glenmore Basal Aquifers, which are assemblages of discontinuous water-bearing strata of variable age and uncertain provenance. The three main aquifers comprise deposits from the three periods separated by two confining layers of glacial origin. The deepest aquifer is overlain by clay-rich till deposited during the peak of the Fraser glaciation. Proglacial outwash deposits representing the second aquifer group overlie this till. This aquifer is confined by lacustrine sediments associated with ancient Lake Penticton, a late glacial lake that filled much of the Okanagan Valley.

The shallow, unconfined alluvial aquifer below Kelowna is hydraulically connected with surface water and is characterized by significant variability in yield and water quality. This aquifer is utilized primarily by small individual users. The Greater Kelowna Aquifer comprises predominantly Bessette Sediments and some early glacial ice contact deposits. This deeper, mostly confined aquifer is utilized by large water utilities and community water suppliers for groundwater supply due to a higher probability of realizing greater yield with lower vulnerability to biological pathogens typically associated with shallow aquifers. The trade-off is that wells completed in the deeper aquifers have a higher probability of intercepting poor water quality or flowing artesian conditions, which have been problematic in the region.

The modelled geometry of the Kelowna aquifers provide important insights on hydraulic conditions as groundwater flow is topographically driven. Where topographic gradients are steep in relation to the orientation of the top of a confined aquifer (e.g. Greater Kelowna Aquifer below Hall Road), groundwater pressures can result in significant flowing artesian conditions within wells. In other areas, permeable sediments exposed at higher elevations can result in significant thicknesses of unsaturated

aquifer grade material and deep water tables. At the University of British Columbia, Okanagan (UBCO) and near Black Mountain, these deposits are exposed at surface and provide opportunity for precipitation and surface water to recharge the deeper aquifers.

Significant uncertainty remains with respect to the thickness and composition of deeper stratigraphy below Kelowna, however, this is believed to provide little influence on the hydraulics of the aquifers currently being utilized. The hydrostratigraphic model presented here provides a reasonable conceptual model of aquifers below Kelowna that fits with the current understanding of the lithostratigraphy and glacial history of the Okanagan Region. It provides a framework for future investigations to improve understanding of the current utilization of groundwater resources below Kelowna, and risks associated with future development and aquifer management.

CONTENTS

1. BACKGROUND

1.1 Objectives

The objective of this work is to provide a comprehensive study that synthesizes the hydrostratigraphic information available for the Kelowna-Mission area to produce a rigorous, defensible and updateable geologic model. This geologic model is intended to provide a foundation both for future groundwater allocation decisions and for regional or site specific hydrogeologic studies. The components of this study have included the following:

- gather and summarize all relevant data available for the study area;
- identify key stratigraphic units/sequences;
- correlate all non-bedrock wells in the study area to specific units/sequences;
- develop a 3D overburden geological model;
- develop an interpretation of depositional environments and geological history;
- identify data gaps;
- characterize all reconciled aquifers using the B.C. aquifer classification system; and
- prepare a detailed report and provide all geological models formatted to specifications of the B.C. Ministry of Environment and Climate Change Strategy.

An overview of key geomorphological features is provided in Figure 1. Key locations referred to in the following text are presented in Figure 2.

1.2 Historical Hydrogeological Mapping

Nasmith (1962) completed the earliest comprehensive mapping of the glacial geology of the Okanagan Valley. Important components of this work included development of the sequence and geometry of onset of glaciation, mapping the progression of glacial erosion and deposition, and defining the character of late glacial outwash. The late glacial processes identified include the development and draining of glacial Lake Penticton and related water bodies. Nasmith suggested that most of the surficial deposits filling the valley bottom were derived from deposition during and following the last (Fraser) glaciation. Recent work in the North Okanagan and Kelowna area (e.g. Fulton and Smith, 1978; Nichol et al., 2015; Thomson, 2010) suggest that significant volumes of older deposits reside below more recent deposits and along valley margins in the area which extend back to the penultimate glaciation.

The Geological Survey of Canada (GSC) completed detailed mapping of overburden and completed a 3D model of surficial geology in the Kelowna area using GoCAD, a proprietary software for geological and reservoir modelling (Paradis, 2009 and Paradis et al., 2010). This study included compilation of surficial mapping (Paradis, 2009; Figure 3), drilling, geochemistry, grain-size analysis, radiometric dating, seismic surveys across numerous transects through the Kelowna area, and 3D computer modelling. A detailed stratigraphic column was developed (Figure 4) in upper overburden based on an 88 m deep well drilled in the Mission Creek Regional Park. This column forms a key type section for assigning stratigraphy to wells assessed in this study. Additional details of mapping, radiocarbon dating and assessment of seismic survey data are also available through S. Thomson's thesis (2010) completed in conjunction with the work carried out by the GSC. Details of the seismic program are provided by Pugin and Pullan as an appendix to the GSC report by Paradis et al. (2010).

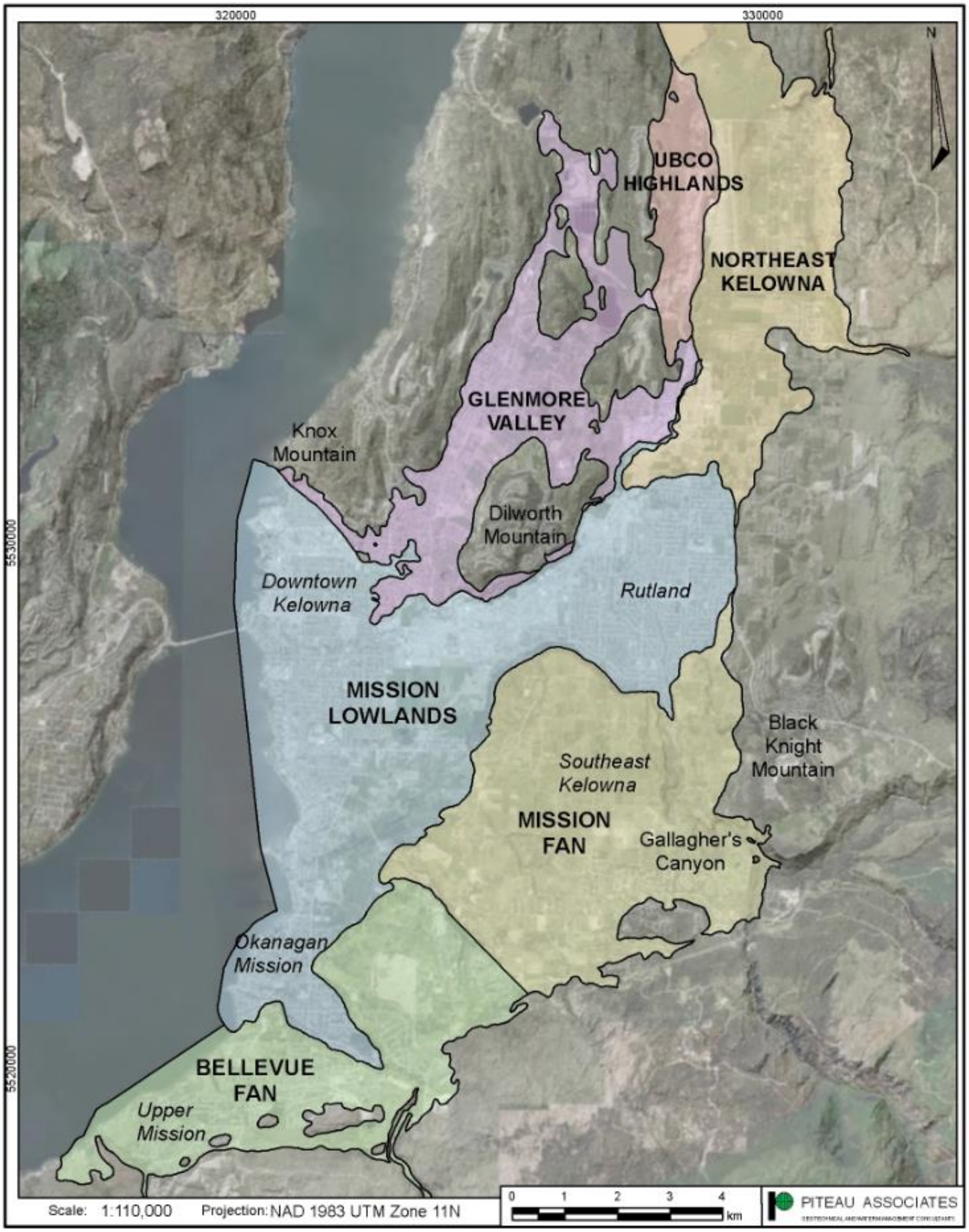


Figure 1: Physiographic areas in the Greater Kelowna Region.

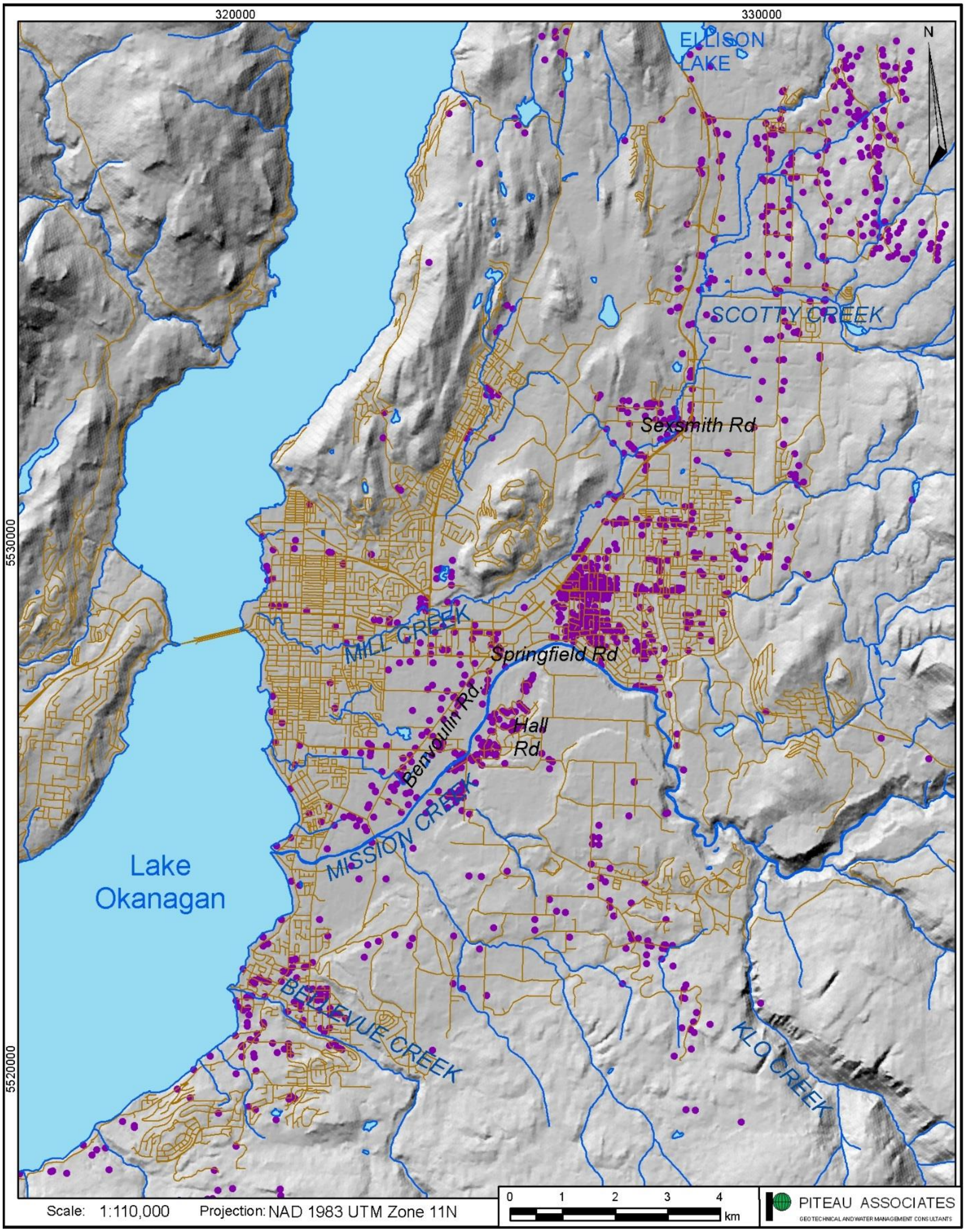


Figure 2: Key locations referred to in the text in the Greater Kelowna Region. (wells in purple).

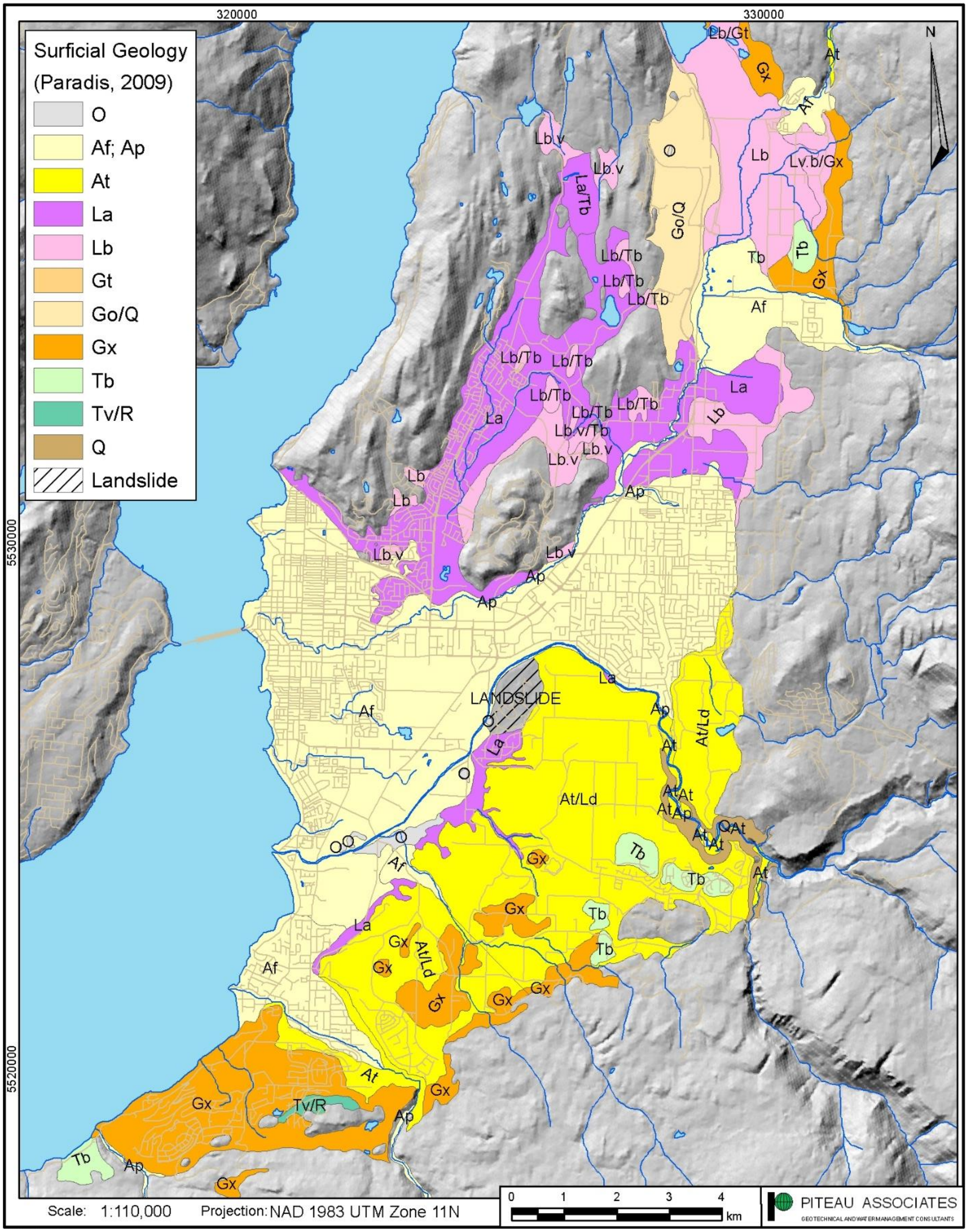


Figure 3: Surficial geology map of the Greater Kelowna Region. Lithology regions and codes correspond to Paradis (2009), the source of mapping. Pink/purple = lacustrine, yellow = alluvium, orange = glacio-fluvial and green = glacial till deposits.

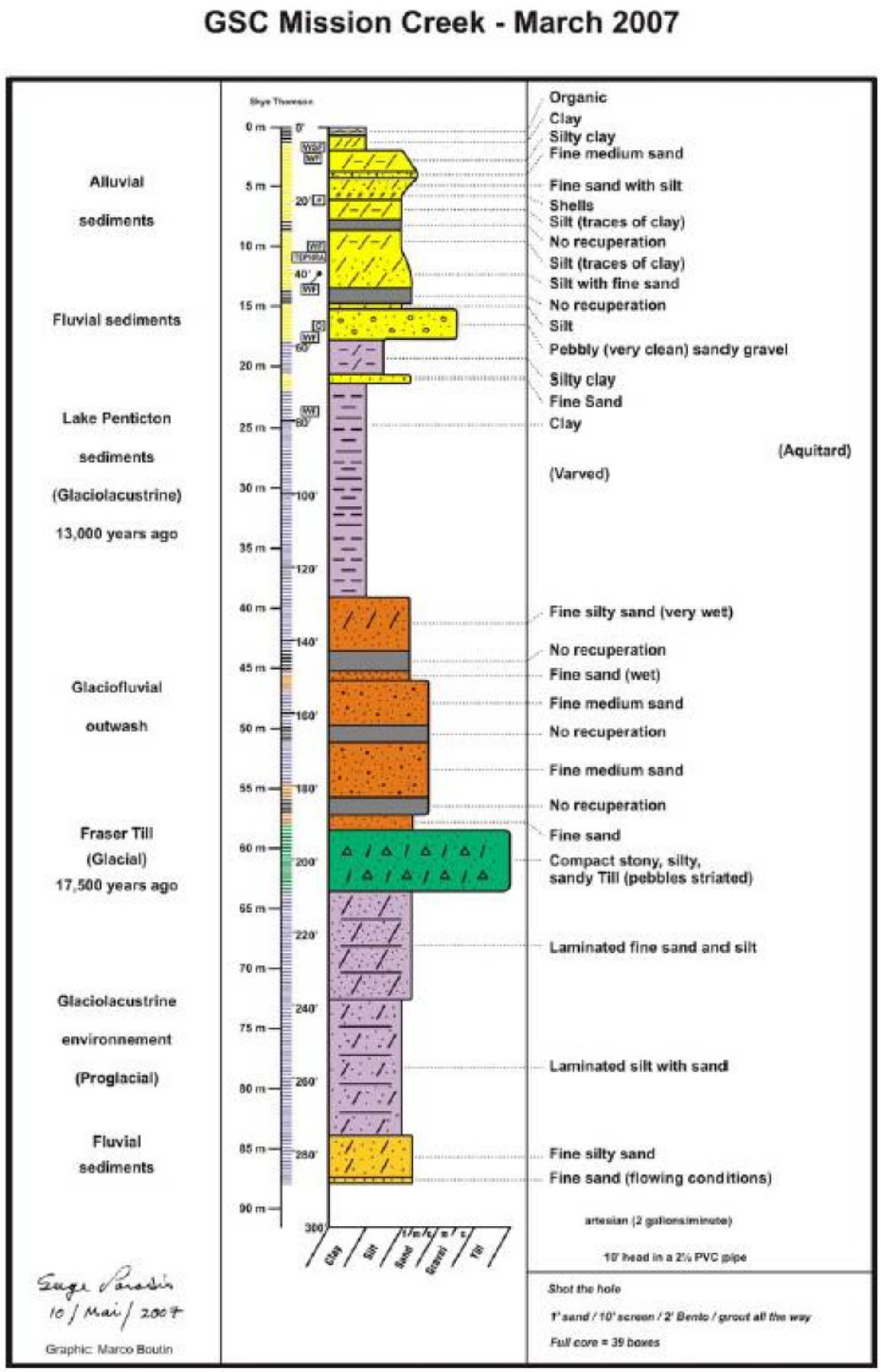


Figure 4: Borehole stratigraphy from GSC exploration drilling in Mission Creek Park (reproduced from Paradis et al., 2010). This borehole log illustrates key stratigraphy for the Kelowna region between the top of the lowermost recognized aquifer and surface. Intervals representing major aquifer units include the lower fluvial sediments (light orange; Bessette Sediments), glaciofluvial outwash (dark orange; Fraser age) and upper alluvial sediments (yellow; Holocene deposits).

Church (1981) completed the first detailed bedrock mapping in the Kelowna area. His mapping highlighted the widespread occurrence of tertiary volcanic deposits, volcanic centres and structures which form significant local geomorphologic features (e.g. Mt Boucherie, Mt Dilworth, etc.). Detailed mapping by Okulitch (2013) expanded understanding of the regional bedrock geology surrounding Lake Okanagan and extended structural and stratigraphic interpretations in bedrock below Kelowna. Major discontinuities were identified during mapping including the Tertiary – basement metamorphic contact. Tertiary age stratigraphy and volcanic centres were refined, and Tertiary extensional faulting was identified in West Kelowna and Kelowna. This character of faulting resulted in deposition of significant thicknesses of sediment and likely played a major role in in generating the shape of the bedrock surface on which the Pleistocene overburden stratigraphy is deposited.

Eyles et al. (1990) completed seismic surveys exploring the depth of overburden and shape of the bedrock surface below Lake Okanagan. Roed and Greenough (2014) add additional insight into this seismic study, and provide a comprehensive review of bedrock and glacial geology, and related issues affecting the central Okanagan Valley.

Various studies of the hydrogeology of the Kelowna area have been completed over many decades focussed on developing groundwater resources for communities and agriculture. No attempt has been made to summarize these for this report. Reasonable efforts were made to integrate as much data as possible into the models developed during this study. Important recent hydrogeological studies are summarized below.

In 2004 the Kelowna Joint Water Committee (KJWC) initiated a study in pursuit of developing a groundwater protection plan (GWPP) for the major groundwater users in the Kelowna area. The first phase of this study (Golder, 2004) assessed the hydrogeologic character of the aquifers in the area and developed a preliminary water balance including estimates of annual recharge and withdrawals. The GWPP provides a detailed compendium of well drilling reports and logs for significant groundwater development programs in the region up to 2004. Phase II of the GWPP (Golder, 2008) includes assessment of short-term time of travel (< 1 yr) capture zones for the KJWC wells in the area and a preliminary contaminant inventory within these capture zones.

Simon Fraser University completed a regional scale groundwater flow model to characterize groundwater flow in the Kelowna area (Smerdon and Allen, 2009). The flow model was developed using a simplified aquifer assemblage which relied predominantly on the character of bedrock in the area. The model suggests that contributions to the Kelowna aquifers from mountain block recharge may be considerable. The University of British Columbia, Okanagan (UBCO) (Pyett and Nichol, 2013; Pyett, 2015) completed a detailed field and modelling study examining groundwater discharge from the Kelowna aquifers to Lake Okanagan. Their results suggest that measurable discharge along the lakeshore is low in comparison to extraction rates from the aquifer, although annual variability in discharge is significant. A groundwater budget model was developed by Alloisio and Smith (2016) in support of resource management for the region. They defined 42 water budget zones in 2-dimensions based on existing aquifer outlines, surficial geology, geomorphology and surface water catchments. Piteau (2016) represents the most recent attempt to delineate and resolve uncertainty related to the hydrogeology of the Kelowna aquifers and their relationship to surface water and water resources in the study area.

2. METHODS

Well logs for the study were compiled from the BC WELLS database (ENV, 2006). Geology intervals were categorized according to a simplified set of lithology categories based loosely on the Unified Soil Classification System (ASTM Standard D2487, 2000). This dataset was then imported into a Leapfrog™ model to provide 3D spatial context for aquifer sediments, and ultimately delineate regional scale aquifers and aquitards. A total of 4,872 lithology entries from 1,257 well records were utilized in the model, representing about 60% of available data.

Surface topography and surficial geology from GSC mapping (Paradis, 2009) were integrated into the 3D models to assist in interpretation of geomorphology of the subsurface. Water levels, well production flow rates, noted artesian conditions and occurrences of unique markers noted in logs (e.g. "organics", "hardground", etc) were imported as point data. Hydraulic data helped define hydraulic gradients which were used to estimate the direction of groundwater flow, and assess possible sources of recharge and discharge. Physical features aided in correlation of strata.

Surface topography was used to project bedrock surfaces to reasonable depths below the overburden. These trends were combined with borehole bedrock intercepts to generate a bedrock-overburden contact surface for the model, on which the overburden volumes were built. A conceptual hydrogeological model was generated, based on the interpolated results from Leapfrog™ and key stratigraphic columns interpreted from boreholes in the study area. This conceptual model was then applied to the digital models to clean up the interpolation in areas of uncertainty (e.g. sparse data), or adjust the models where the interpolation generated geologically unrealistic results. The completed models were then assessed to:

- generate hydrogeological interpretations of the aquifers in the Study Area,
- interpret which aquifer existing wells are completed in (Appendix B),
- characterize the aquifers and aquifer parameters,
- modify existing or generate new aquifer boundaries, and
- inform the aquifer summary sheets (Appendix B)

3. OVERVIEW OF GEOLOGY

3.1 Tectonic Setting and Bedrock Geology

In and around the Okanagan valley there are a significant number of N-S, NE-SW and E-W faults (Okulitch, 2013) which are interpreted to control the geometry of the topography, including the Okanagan Valley fault (Roed and Greenough, 2014). This topography controls the shape and thickness of overburden filling the valley bottom, which hosts many of the groundwater aquifers that valley residents, farms and industries rely on. Faults controlling the valley system are not exposed but are generally inferred to be of steep normal, or gently west-dipping orientation. Along the Okanagan valley, detachment faults can be observed sporadically in outcrop along which older basement mylonitic rocks are juxtaposed against later tilted and faulted Eocene strata.

Eocene volcanic and sedimentary rocks preserve a complex array of extensional basins and volcanic centres mapped in the west Kelowna area and in the highlands east of Kelowna. These same features are inferred to exist below Kelowna and may provide significant local variability in the paleotopography of the bedrock on which the Eocene White Lake formation, and later overburden, were deposited. Local extensional basins allowed local accumulations of the White formation to exceed 1,000 m depth in places (Hamblin, 2011). The composition and character of these deposits could make them difficult to distinguish from consolidated overburden deposits, where they are inspected visually from drill cuttings in rotary boreholes.

3.2 Overburden Geology

Nichol et al. (2015) provide the most comprehensive overview of overburden stratigraphy and glacial history in the Okanagan valley based on their work in the North Okanagan. Analysis of stratigraphy in the Kelowna area indicates that it is analogous to that region, and thus shares a similar depositional history (with some notable variations due to the geometry and elevation of the valley). Most of the stratigraphy mapped at surface and intercepted in boreholes was deposited within the last 70,000 years as summarized in Table 1.

Leapfrog Unit No.	Period	Environment	Hydraulic Unit	Aquifer Number	Diagnostic Character
1	Holocene	modern	Mission Creek Aquifer	467	modern shallow deposits; <30 m depth
4	Late Fraser Glaciation (Late Wisconsin)	glacial lake	Lake Penticton aquitard		varved silts and clays; Lake Penticton highstand 360 m-elev; higher elevation perched lakes in Glenmore, Airport and Black Mountain
5		proglacial outwash fan	Central Kelowna Aquifer	1191	sand and gravel aquifer overlying till
6	Fraser Glaciation (Late Wisconsin)	glacial ice sheet	Fraser till aquitard		diamicton (clay + gravel, sand etc), hardground; at surface or up to 100m deep
6		ice contact	Bellevue and Greater Kelowna Aquifers	462, 464	sand and gravel interlayered or closely associated with till; kame, esker or other glacial morphology
8	Bessette Sediments (Mid-Wisconsin)	non-glacial, subaerial			highly productive sand and gravel aquifer bracketed by glacial deposits; artesian below low lying areas
10	Okanagan Center Glaciation (Early Wisconsin)	glacial ice sheet	Basal till aquitard		deeper diamicton separated from Fraser till by interglacial sediments; may be greenish colour, overconsolidated; mantles bedrock along valey margins
8	undefined	unknown	Glenmore Aquifer	469	basal gravel and sand deposited on bedrock

Table 1: Summary of the geologic period, environment, hydrostratigraphic unit and diagnostic features of overburden stratigraphy mapped for this study in the Kelowna area.

Strata preserve evidence of deposition during alternating glacial and non-glacial periods. The most extensive and most productive aquifer sediments in the region were deposited during the Olympia non-glacial period, between the Fraser and Okanagan Centre glaciation. These deposits are associated with the Bessette sediments and comprise much of the Greater Kelowna Aquifer (GKA, aquifer 464), which is defined in this report. The type section for these deposits is exposed along Bessette Creek north of Lumby (Smith, 1969). Deeper portions of the Bellevue Aquifer (462) comprise deposits probably associated with Bessette sediments, and may provide the most hydraulically productive portion of the Bellevue Fan.

The GKA is physically defined as a significant continuous thickness of sand and gravel to sandy silt below the most recent glacial till deposits. Typically, Bessette sediments contain significant organic content (wood, grass etc). The GKA below UBCO contains organics, however, organics are less abundant or absent elsewhere (e.g. below Rutland).

The predominant glacial deposits preserved in the region are attributed to the last two glacial episodes, the Okanagan Centre glaciation (70-50 ka) and the more recent, the Fraser glaciation (25-12 ka), which bracket the GKA. Age dating of volcanic materials overlying till in west Kelowna indicate remnant glacial deposits older than one million years (Ma) exist in the Okanagan valley (Roed et al., 2014). Pre-Okanagan Centre glacial deposits are inferred to have been largely eroded away and would be very difficult to differentiate from the two most recent glacial deposits where they may be preserved overlying bedrock along the margins of the valley. Okanagan Centre and Fraser glacial deposits are differentiated primarily by superposition of strata. Fraser deposits are generally exposed at or near surface below higher elevation areas and along valley margins at the bedrock contact, or underlie lacustrine deposits below the mission Lowlands. Okanagan centre deposits underlie the Fraser deposits, and are generally separated from them by the Bessette Sediments. These earliest deposits are assumed to be only partially preserved.

The two most significant and extensive aquitards defined in the region are clay-rich sediments related to the Fraser glaciation, the most recent glacial period. The older of these two layers is a relatively continuous clay-rich till unit that was deposited at the base of the glacier likely during the peak of the glaciation. This unit acts as the lower confining layer above the GKA. The younger confining layer is a thick sequence of varved silts and clays deposited in ancient Lake Penticton, a glacial lake which filled much of the Okanagan valley late in Fraser glaciation. These deposits underlie the Mission lowlands over approximately 30 km^2. An ancient shoreline is delineated by peat deposits intercepted in boreholes in the Mission lowlands at approximately 360 masl. Between Rutland and the airport, lake sediments are observed in boreholes at increasing elevation, up to 425 masl north of the airport below the valley floor. Lake sediments may be locally present at higher elevations up to the lake high-stand of 457 masl (Roed and Greenough, 2014). These deposits confine both the GKA and aquifers overlying the Fraser till.

Shallow aquifers in the study area include ice-contact deposits related to Fraser glaciation (GKA at UBCO, 464), late glacial outwash (Central Kelowna Aquifer, 1191) and modern alluvial fan material (Mission Creek Aquifer, 467). The GKA is largely unconfined below UBCO. The Central Okanagan and Mission Creek aquifers are complex and are confined in places and exposed in others. These deposits appear to comprise much of the shallow sediments in the Kelowna area, however they are only saturated where they are found below the Mission lowlands. Groundwater levels are generally at or near surface in these aquifers, distinguishing them from the deeper GKA, which is consistently artesian where intercepted below the Mission Lowlands.

Equivalent sediments (glacial outwash and modern alluvium) exist in the upper portions of the Mission Fan, the Bellevue fan and along Mill Creek up to Ellison Lake (Mill Creek fan). These deposits are generally unsaturated and therefore do not constitute significant aquifers in the region.

4. HYDROSTRATIGRAPHY AND AQUIFER DELINEATION

Aquifers presented in the following sections are referred to by common name (e.g. Greater Kelowna Aquifer) and/or aquifer number (e.g. Aquifer 464) assigned by the Province using B.C. Aquifer Classification System (Kreye et al., 1994). Table 1 presents the proposed assemblage of aquifers in the Kelowna area. Key features of these aquifers are provided in the following sections. Complete detailed descriptions of the aquifers are provided in the attached aquifer worksheets provided in Appendix B.

4.1 Greater Kelowna Aquifer (Aquifer 464)

The GKA underlies an area of greater than 90 km^2 below Kelowna and the surrounding valleys east of Lake Okanagan. Aquifer sediments include clean sand and gravel, but can grade into silty with some interlayered silt and clay. The aquifer may be overlain by till, lacustrine clays or may be unconfined. Portions of the aquifer (e.g. lower sections below UBCO) may contain abundant wood and plant debris.

Ages from carbon dating of woody debris below UBCO range from 35,000 to 23,000 years before present, indicating Bessette age (Thomson, 2010). The younger end of this age range was determined from organic material that was extracted from middle levels in aquifer. This age limit and the depositional structures (e.g. esker morphology) mapped at surface by Thomson (2010) suggests that upper portions of the aquifer may be glacially reworked Bessette Sediments or glacially derived materials. This aquifer is therefore a composite of two distinct lithologic units, interglacial alluvial Bessette Sediments and Fraser-age ice-contact deposits. The unique exposure of the aquifer below suggests that other portions of the GKA may also be composite units, but are less well exposed.

The size of the GKA, changing geometry and relationship to surrounding terrain and geology result in portions of the aquifer having distinct hydrogeologic character. Geographic sections of the aquifer defined in Figure 5 are described below. In some cases, the nomenclature of sections of the GKA is inherited from common names previously used to describe the aquifer (e.g. the Rutland Aquifer below Rutland and Southeast Kelowna).

4.1.1 Rutland Section

The Rutland Section of the GKA covers approximately 30 km^2 below Southeast Kelowna and Rutland (Figure 6). The northern boundary of the Rutland Section reflects a distinct change in groundwater flow direction (Golder, 2008), north of which groundwater originates from recharge areas to the north and northeast of Kelowna. The western margin reflects the boundary across which the aquifer dips below thick confining layers under the Mission Lowlands. West of this boundary hydraulic heads within the aquifer become artesian. (Figure 6)

The Rutland Section is an alluvial fan that radiates out from the outlet of Mission Creek where it enters the Okanagan Valley. It dips to the west and to the north consistently between 2.5 and 3 degrees. To the east and south it is bounded by bedrock along the edge of the valley. To the southwest, it is interlayered with till and alluvial material associated with the Bellevue Fan. Contact relationships suggest the lower portion of the Bellevue Fan is of comparable age and geometry.

Okanagan centre till lies directly on bedrock of the Eocene age White Lake formation below the Rutland Section, and is the lowermost identifiable unit at surface and in well logs. The GKA conformably overlies the till and is overlain by the younger Fraser till. It is also interpreted to onlap White Lake formation bedrock. The top of the GKA is capped by late glacial outwash and till. It is characterized by kame-kettle topography and erosional channels. These features suggest it was partially incised by an earlier east-west orientation of Mission Creek, prior to it downcutting the fan along its current course to the north.

Water levels are very deep at the proximal portion of the fan (east) comprising the Rutland Section, but transition to artesian conditions below the Hall Road neighbourhood and Benvoulin Road. Absolute water elevations change very little over this distance (-50 m over 2 km) due to the high hydraulic conductivity and continuity of the formation. However, because the unit dips towards the lake, the relative depth of water changes with the decrease in surface elevation. Hydraulic gradients indicate that groundwater flow is topographically controlled, flowing from recharge areas along Mission Creek between Gallagher's Canyon and Rutland, east towards Lake Okanagan.

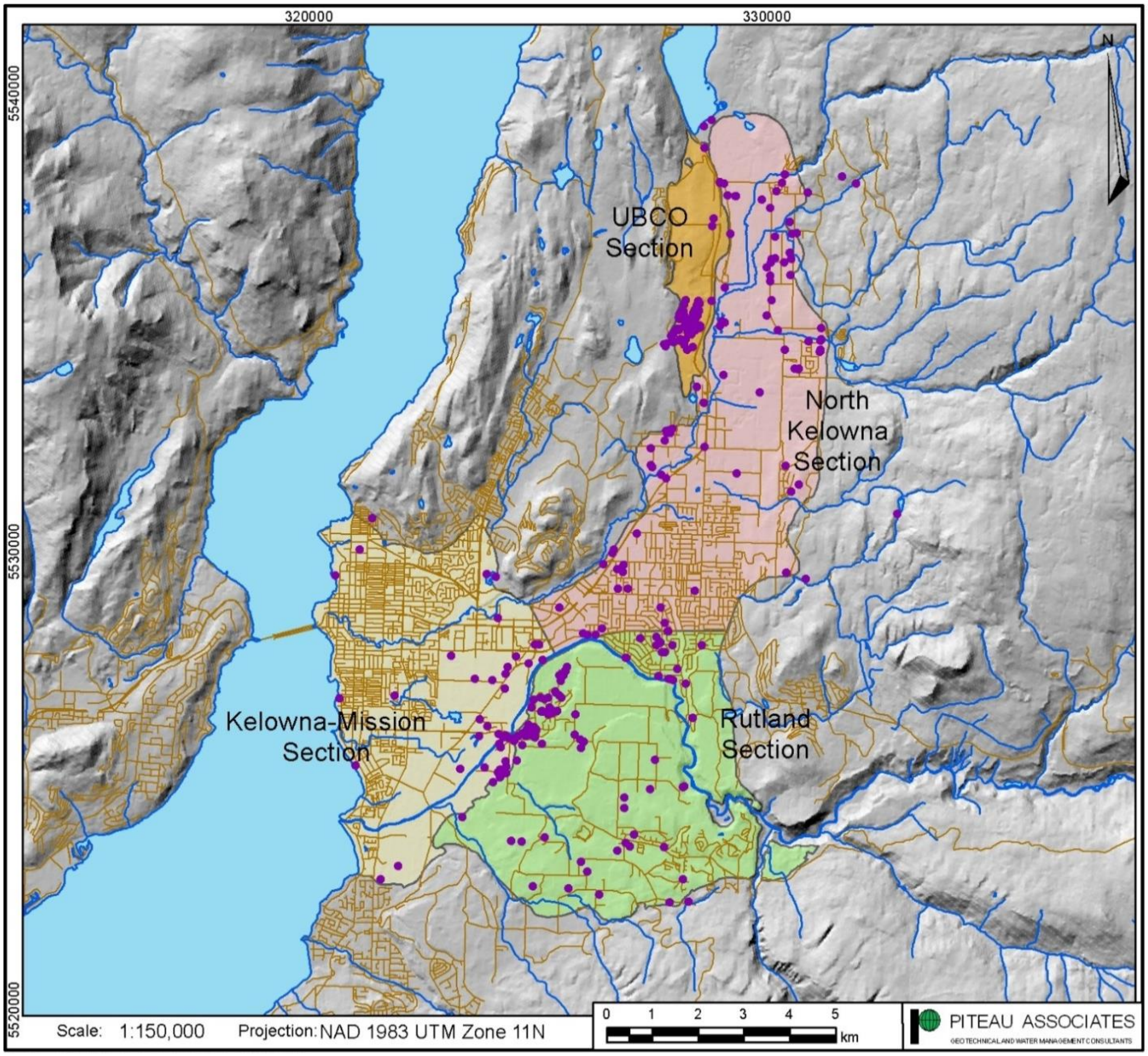


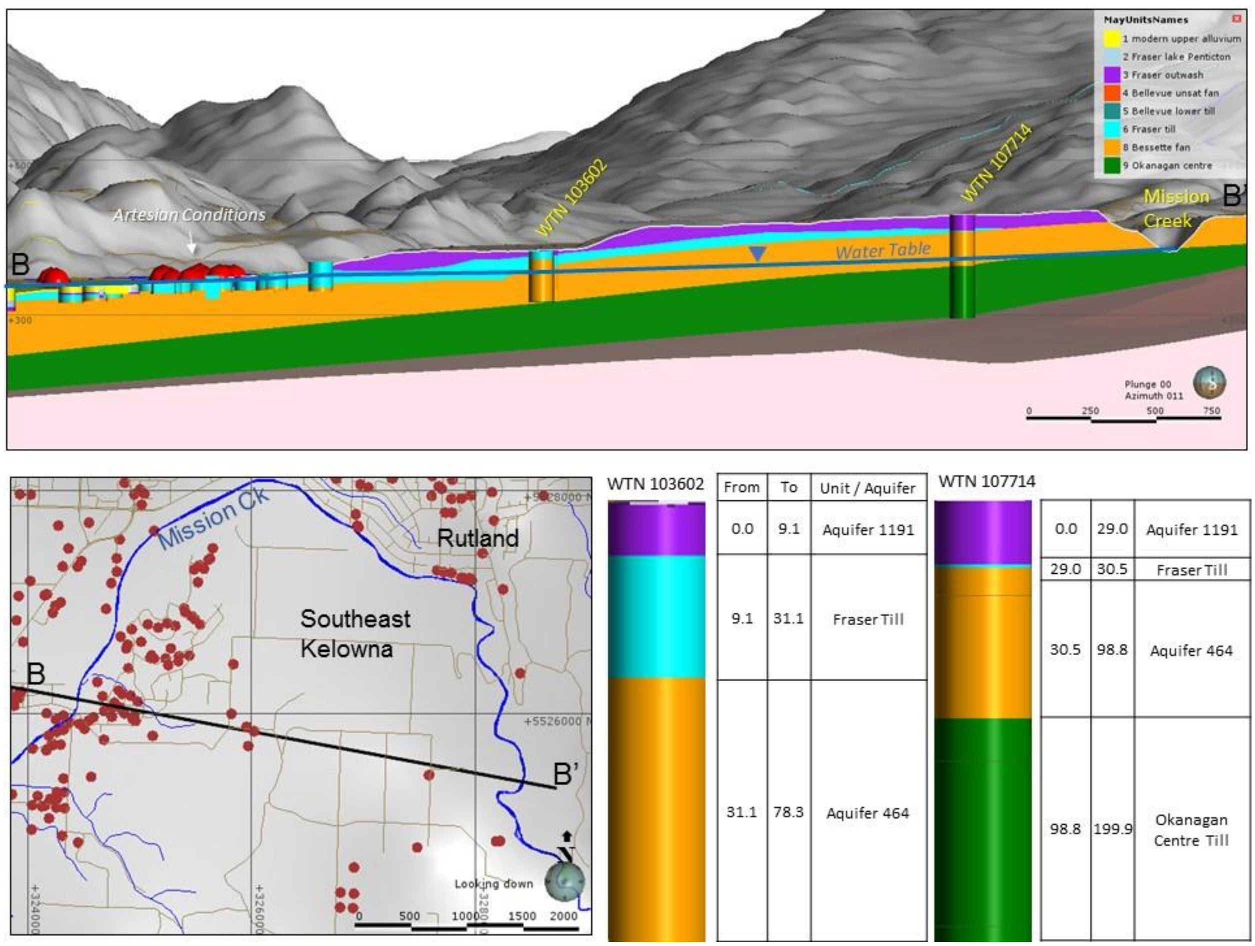
Figure 5: Distribution of the Greater Kelowna Aquifer, subdivided by geographic area. Location of wells with intercepts of Bessette Sediments shown in purple.

Average yields from wells completed in this aquifer are high at about 12.6 L/s (200 USgpm; average of 74 wells), with individual well yield being as high as 126 L/s (2,000 USgpm). The Rutland Waterworks District (RWWD) and the former Southeast Kelowna Irrigation District (SEKID) are significant users of groundwater from the Rutland Section. Irrigation and domestic users (e.g. Hall Road neighbourhood) also rely on the aquifer for water supply.

4.1.2 Kelowna-Mission Section

The footprint of the Kelowna-Mission Section of the GKA covers approximately 30 km^2 below the Mission Lowlands (Figure 5). The boundary with the Rutland Section is based on surface topography and a transition to artesian groundwater conditions below the Mission Lowlands (Figure 6). The aquifer continues under or becomes interfingered with glacial deposits of the Bellevue Fan at its southern boundary (Figure 7). To the west, the mapped aquifer is bounded by the lake, however the GKA is inferred to extend deep below the lake and may connect with equivalent sediments below the western margin of the lake.

Eastern and southern portions of the aquifer dip between 2.5 to 3 degrees to the west, which is consistent with the dip of the Rutland Section (Figure 8). The dip becomes from shallow to between 0 and 1 degree below downtown Kelowna (Figure 7). Below the shoreline of Lake Okanagan, from downtown Kelowna to Okanagan Mission, the aquifer dip is flat in a north south direction and is at a constant depth below ground. Likely due to the predominant artesian conditions in the aquifer, no wells are known to penetrate the full depth of the formation. Consequently, there are no data to confirm the thickness or stratification of the aquifer, or underlying units.



WTN 103602

From	To	Unit / Aquifer
0.0	9.1	Aquifer 1191
9.1	31.1	Fraser Till
31.1	78.3	Aquifer 464

WTN 107714

0.0	29.0	Aquifer 1191
29.0	30.5	Fraser Till
30.5	98.8	Aquifer 464
98.8	199.9	Okanagan Centre Till

Figure 6: Cross section showing the Rutland Section of the Greater Kelowna Aquifer (464) below Southeast Kelowna (2x vertical exaggeration). Note the change from a deep water table at the head of the Mission Fan (Mission Creek) transitioning to artesian conditions below the Benvoulin Road area (at left). (2x vertical exaggeration, looking north)

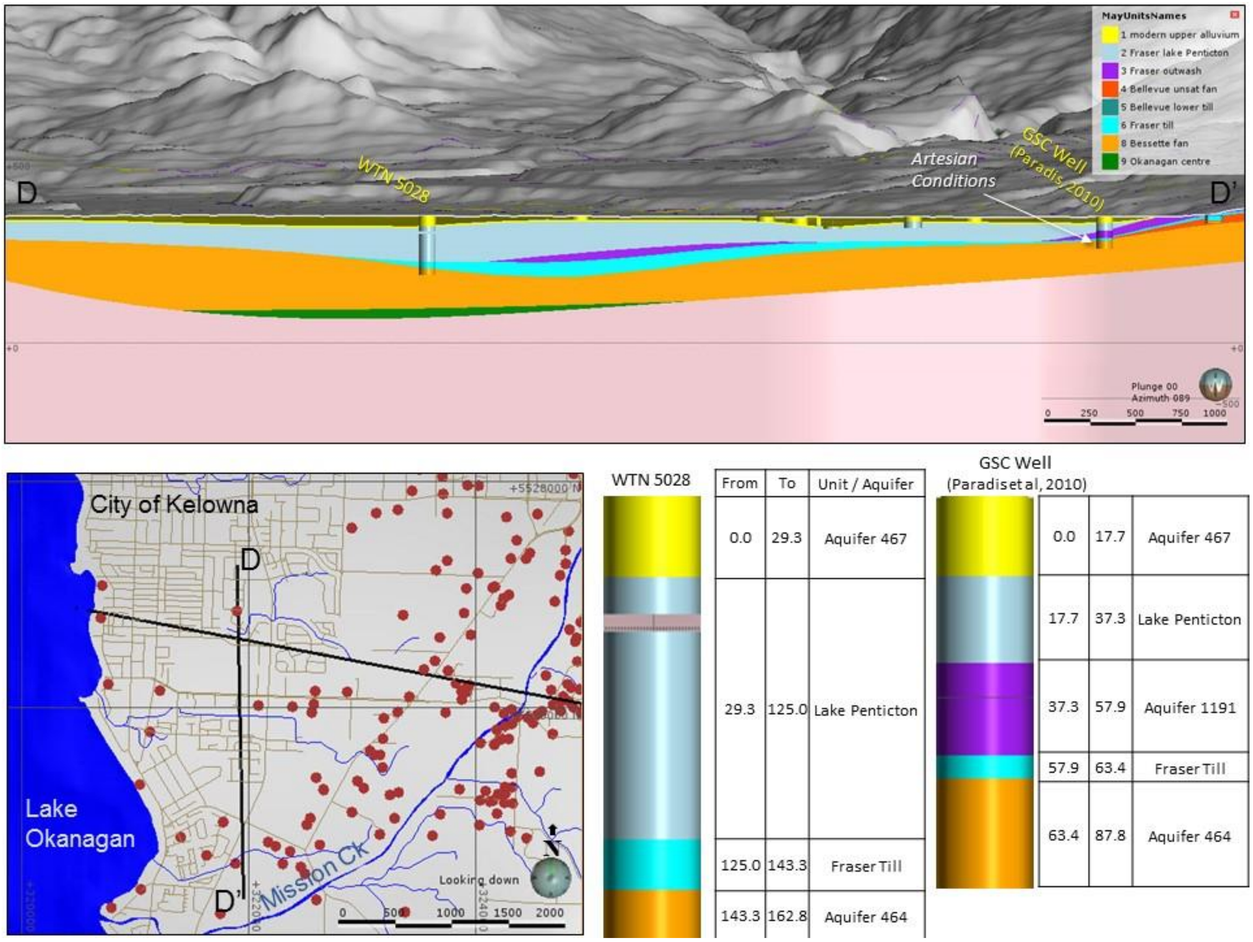


Figure 7: Cross section through the Greater Kelowna Aquifer (464) below Gordon Drive. The City of Kelowna is at left and Upper Mission / Bellevue Fan area is at right. (2x vertical exaggeration, looking east)

The Kelowna-Mission Section has the lowest reported average yield of the GKA. There are 45 wells that yield an average of 4.2 L/s (67 USgpm) and range up to a maximum yield of 44.1 L/s (700 USgpm). Groundwater users include irrigation for hobby farms, golf courses and other individual users.

Little data exists documenting water levels, and thus hydraulic gradients are poorly understood in the Kelowna-Mission Section. It is assumed that groundwater originates from upgradient areas including the Rutland and North Kelowna Sections of the GKA, and the Bellevue Aquifer. Roed and Greenough (2014) speculate that irregular features observed on the bottom of Lake Okanagan may be evidence of groundwater discharge from the aquifer to the deep portions of the lake. The aquifer may be discharging below the lake, or groundwater may remain largely stagnant due to thick confinement and no clear point of discharge. It may also provide some recharge to overlying aquifers generating or exacerbating local artesian conditions there.

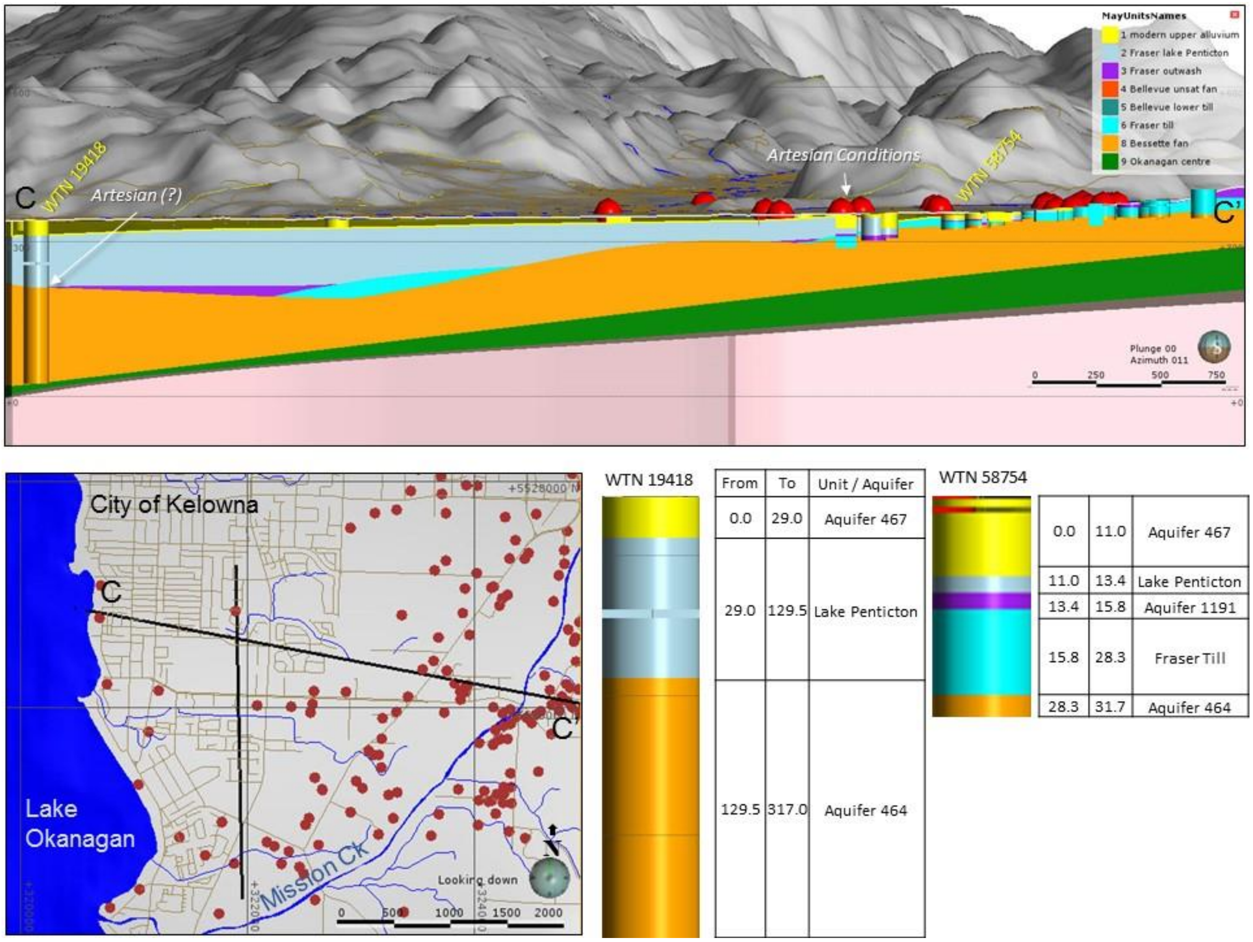


Figure 8: Cross section through the Greater Kelowna Aquifer (464) and Central Kelowna Aquifer (1191) from the Lake Okanagan shoreline at left to the Hall Road area at right. (2x vertical exaggeration, looking north)

4.1.3 North Kelowna Section

The North Kelowna Section of the GKA covers an area of 32 km^2. The aquifer dips between 0 to 0.5 degrees south along the axis of the valley, and dips between 1 and 4 degrees from the east and west towards the centre of the valley. Dipping strata may indicate that the aquifer is a composite of alluvial fans along the margins of the valley, or it may be the result of over-consolidation of initially flat-lying strata under glacial load (Figure 9).

The North Kelowna Section is mapped to be continuous across the length and width of the valley from Ellison Lake to Rutland (Figure 5), where the GKA is confined. The aquifer is unconfined below UBCO and is described separately as the UBCO Section of the GKA. The North Kelowna and UBCO Sections represent a continuous lithologic unit and are hydraulically in complete connection (Figure 9).

West dipping clay deposits overlie the aquifer in the east half of the valley below the airport, and covers the remainder of the aquifer to the south. This confining unit appears to be a mix of glacial till, kame/kettle, and lacustrine sediments related to the Long Lake Stage of Glacial lake Penticton (Fulton, 1969; Paradis et al., 2010). The confining layer is locally overlain by largely unsaturated alluvial fan material deriving from Mill Creek and Scotty Creek.

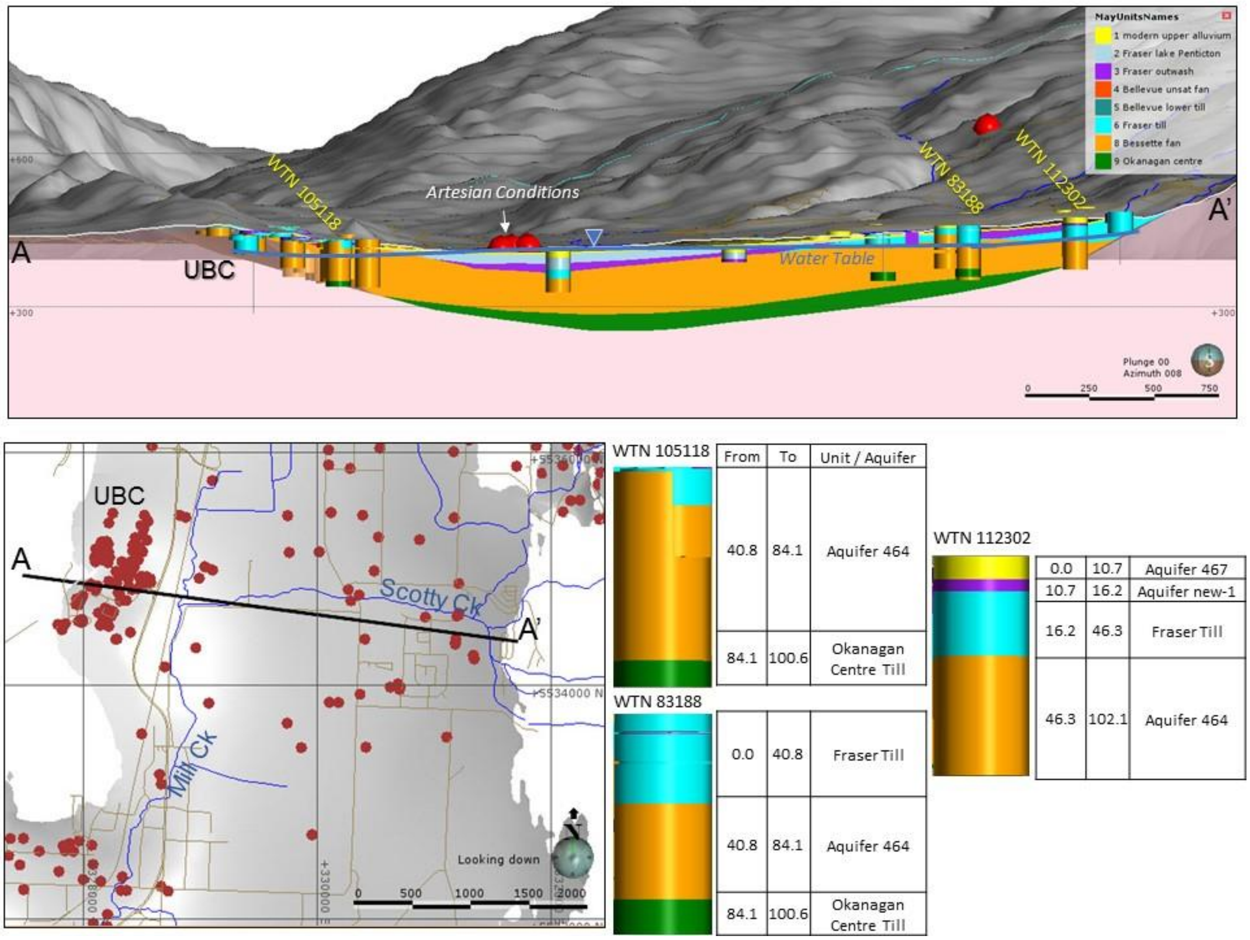


Figure 9: Cross section through the North Kelowna Section of the Greater Kelowna Aquifer between UBCO at left and the head of Scotty Creek at right. (2x vertical exaggeration, looking north)

Water levels are generally at the top of the aquifer where it is exposed along the course of Mill Creek. The levels suggest that the aquifer may be exchanging water with the creek, however the aquifer appears to be confined where it underlies it. Hydraulic gradients are steep from the valley sides to the centre of the valley, mimicking the orientation of strata. The elevated groundwater levels appear to coincide with strata which may be perching groundwater. Therefore, despite the gradient, limited recharge is expected to be derived from infiltration along valley margins. The primary hydraulic gradient is relatively flat (10 meters of head over 8 km) from the airport to Rutland. The gradient steepens as the aquifer transitions from the North Kelowna Section and Rutland Section, to the Kelowna-Mission Section below the west Rutland area (Leathead – McCurdy Road area).

Artesian conditions documented in the North Kelowna Section include:

- localized conditions below bedrock slopes above the airport, where groundwater discharges to local alluvium/colluvium
- below UBCO where the confining clay is thickened (WTN56485), and
- south of UBCO, below the center of the valley in (WTN42285 and WTN23703).

Well WTN42285 is a backup well for Black Mountain Irrigation District and is not currently being utilized. The artesian flow in WTN23703 appears to reflect strong artesian conditions in the aquifer deep below the valley.

The average recorded yield from 64 wells completed in the North Kelowna Section is high at 20.3 L/s (321 USgpm), and individually are up to 158 L/s (2,500 USgpm). This section of the GKA is utilized by several major water purveyors including Rutland Waterworks, Black Mountain Irrigation District and Glenmore-Ellison Irrigation District. Some wells completed by these groups are not currently being utilized, in many cases due to water quality issues (e.g. manganese). Numerous other individual users are present in the valley, most of which utilize groundwater for irrigation.

4.1.4 UBCO Section

The UBCO Section of the GKA poses a unique risk to the GKA due to a lack of, or reduced, confinement over its footprint. The UBCO Section underlies an area of approximately 5 km^2 between Ellison Lake and Sexsmith Road, along the western margin of the valley (Figure 5). The UBCO Section has the highest average yield reported for the GKA at 64.2 L/s (1018 USgpm). This average is based on yields reported from 6 wells, which reflects the limited usage of the aquifer in this Section.

4.2 Glacial Aquifers

4.2.1 Bellevue Aquifer (Aquifer 462)

The Bellevue Aquifer comprises sediments interpreted to be deposited during multiple interglacial and glacial periods. The overall geometry of overburden and relationship to neighbouring deposits suggests that the aquifer is a fan complex like the Mission Fan hosting the Rutland aquifer. The aquifer defined in Figure 10 is a composite of several thin, poorly defined, discrete water bearing units (Wei, 1984) spanning several geologic periods that cannot be resolved at the scale of the model generated for the study.

Aquifer sediments include sand and gravel, and gravel deposits. These deposits are interlayered with sand, silt and clay. The lowermost units in the succession likely include Okanagan Centre till, but these units are poorly understood. Till is found in most holes, at most elevations, but varies significantly in thickness and stratigraphic position. The Bellevue fan is separated from Mission fan by distinct ridge/thickness of till observed in borehole and mapped at surface by Paradis (2009).

Till is present at shallow depths below the incised channel of Bellevue Creek in the Okanagan Mission area. A substantial thickness of unsaturated clean sand and sand and gravel overlie this till unit on either side of the Bellevue channel. Discontinuous lenses of clay and sandy/silty clay cap the top of the Bellevue fan. The top of the fan comprises kettle lakes and hummocky terrain consistent with deposition during the waning stages of the Fraser glaciation. The complex interlayering of multiple fan and till deposits suggests deposition of the portion of the Bellevue fan that is above the elevation of Lake Okanagan was dominantly a subglacial process.

Many wells are completed in alluvial material deep in the Bellevue Fan, but pre-glacial and syn-glacial alluvium cannot be distinguished in well logs or from modelling. There are no discernable discrete aquifer units, although groundwater levels are consistently at a similar elevation to Bellevue creek along the slope, suggesting there is reasonable hydraulic connection within the aquifer and between the aquifer and the creek. Artesian conditions are uncommon, but present. Artesian flow is likely driven by local complexity of layering, and not by extensive confinement of a regional aquifer. The average reported well yield is 2.8 L/s (44 USgpm), with a maximum yield 18.9 L/s (300 USgpm). The aquifer is therefore of moderate to low productivity.

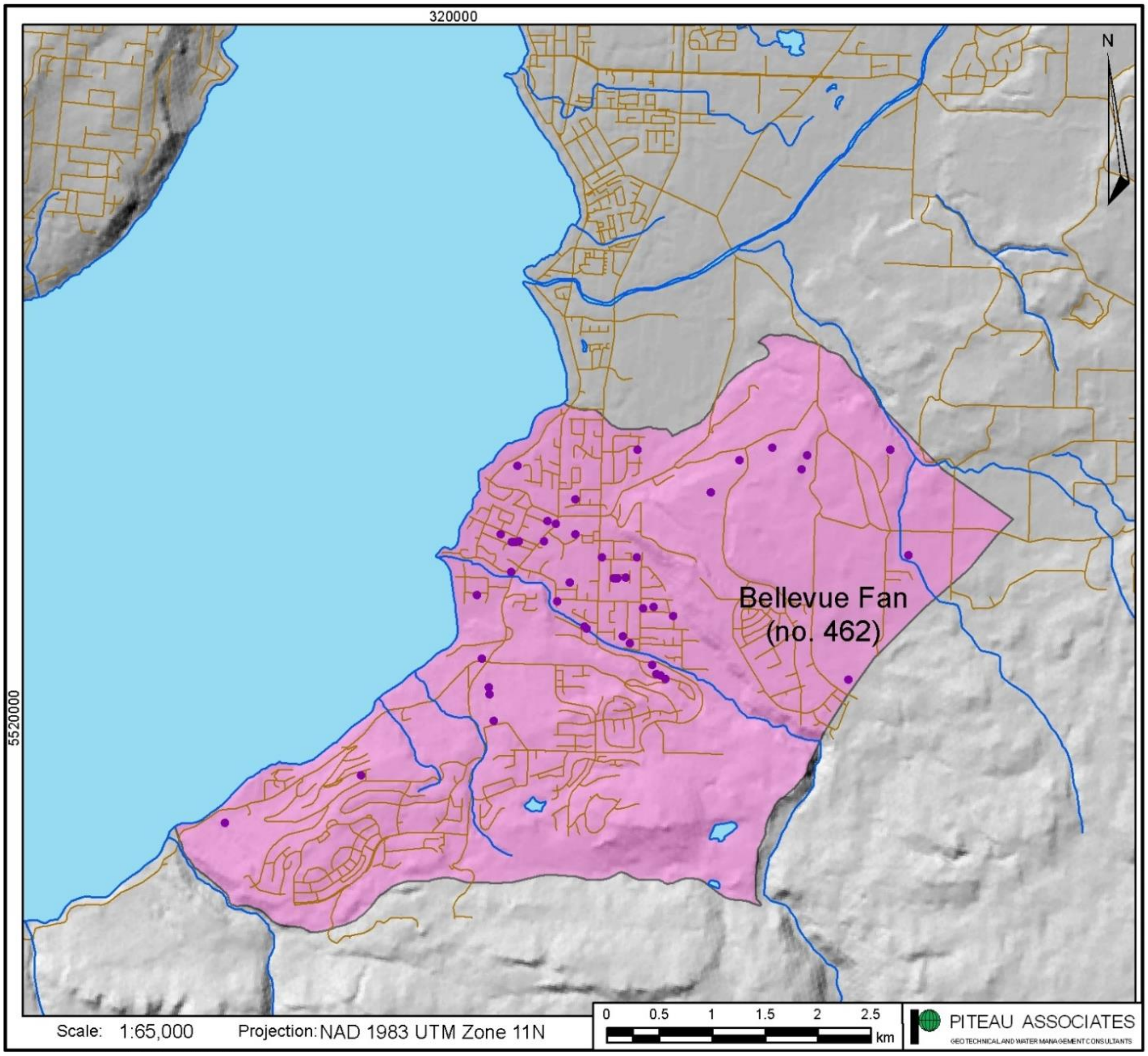


Figure 10: Limits of the Bellevue Aquifer in the Okanagan Mission area.

4.2.2 Central Kelowna Aquifer (Aquifer 1191)

Paradis et al. (2010) first recognized the presence of late glacial outwash overlying till in the Mission Creek Regional Park test well (Figure 4). Although the late glacial outwash is relatively thin, it appears to be a continuous layer of aquifer quality material and is saturated below a wide area of Kelowna covering almost 40 km^2 (Figure 11), and so is defined here as the Central Kelowna Aquifer. Equivalent sediments extend to higher elevations on top of the Mission Fan and Bellevue Fan, but are unsaturated. The mapped extent of the aquifer is defined by the presence/absence of saturated aquifer-grade material overlying Fraser-age till.

The aquifer comprises a mix of sand and gravel and may contain silt. Below the Mission Lowlands, the aquifer is dominantly confined by the overlying Lake Penticton lacustrine sediments. Lacustrine sediments include varved silts and clays, and may locally contain peat or wood fragments, particularly near the interpreted ancient shoreline. These confining layers pinch out below the bluffs defining the exposed margins of the Mission Fan, assumed to be the ancient shoreline to Lake Penticton. Confining layers below Northeast Kelowna are discontinuous and outwash deposits may be confused with recent alluvium.

Groundwater levels in the aquifer are generally at or near surface, but can be artesian below the Benvoulin Road area. Artesian conditions may be driven by recharge to the aquifer where it is unconfined below slopes of the Mission fan, or by upward leakage from the underlying confined greater Kelowna Aquifer. The average reported well yield from the aquifer is a moderate 4.5 L/s (71 USgpm) based on data from 65 wells. The maximum reported well yield is 50.5 L/s (800 USgpm).

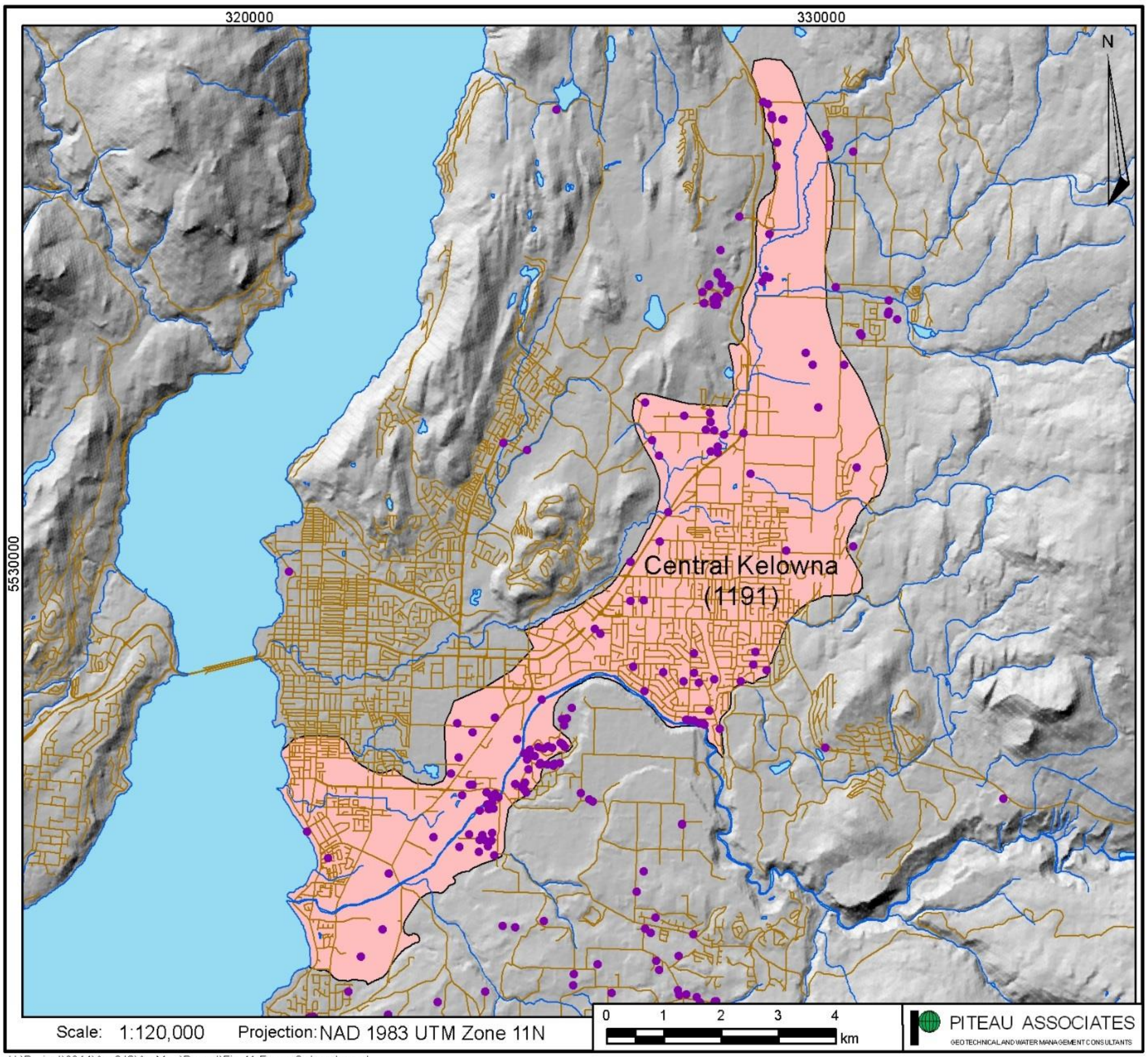


Figure 11: Distribution of the Central Kelowna Aquifer, comprising late Fraser glacial outwash deposits associated with glacial recession prior to formation of glacial Lake Penticton.

4.3 Holocene Aquifer

4.3.1 Mission Creek Aquifer (Aquifer 467)

The shallowest and most recent age aquifer defined in the Kelowna region is loosely based on the presence of saturated aquifer material at or near ground surface. The mapped aquifer limit covers 46 km^2 below the Mission Lowlands and part of Northeast Kelowna (Figure 12). Sediments comprise sand and gravel, or gravel deposits interlayered with sand silt and local clay. Wood, plants and other organics are common in well logs.

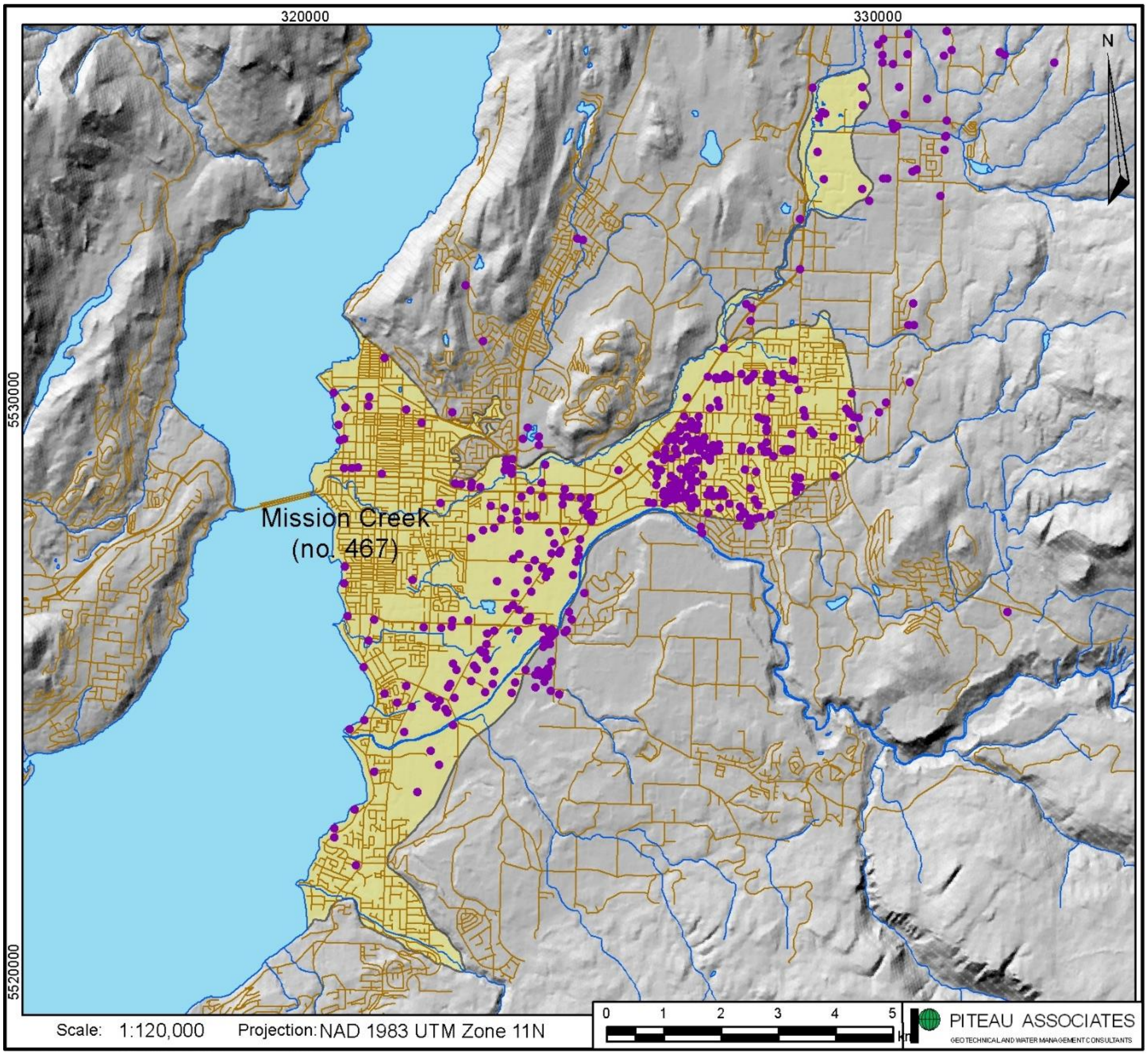


Figure 12: Mission Creek aquifer, a composite of Holocene age meandering alluvial channel aquifers and confining overbank flood deposits in low-lying areas.

Aerial photographs which predate significant development in the Kelowna area (Figure 13) highlight the probable origins of these deposits. Visible in the photo are landforms (oxbow lakes, point bars, etc.) consistent with the meandering channel of Mission Creek and spillage during high flow events. Mission Creek and Mill Creek likely migrated across the width of the Mission Lowlands and Northeast Kelowna since Lake Okanagan reached its current state after the last glaciation. Meander has left a complex assemblage of sinuous alluvial aquifers and confining overbank and flood deposits. Depending on their location, sources of recharge and utilization, these deposits appear to provide reasonable aquifers for smaller users.

The average reported yield of wells in the Mission Creek aquifer is 3.8 L/s (61 USgpm) in 94 wells. Most of these wells are probably smaller diameter for smaller users which could skew the observed yield potential of the aquifer. Conversely, many wells may be hydraulically connected to surface water, resulting in abnormally high flow rates. Historically there have been a substantial number of hand dug wells along the floodplain of Mission Creek. The maximum recorded flow rate for the aquifer is 41.0 L/s (650 USgpm).

Figure 13: Airphoto mosaic from 1938 of the Lower Mission area between Guisachan Road and KLO Road (courtesy R. Allard) showing the wide meander belt of Mission Creek.

4.4 Other Aquifers

4.4.1 Glenmore Basal Aquifer (Aquifer 469)

The Glenmore valley north of Kelowna is notorious for its paucity of groundwater resources and geotechnically challenging overburden (swelling clays). Despite these challenges, several wells in the valley have intercepted groundwater in sufficient quantity to service small scale irrigation and residential needs. These wells generally intercept thin (1 to 5 m) gravel beds lying on the bedrock overburden contact. Although drilling records are sparse, it is believed that these represent isolated pockets of aquifers which are severely limited in recharge and groundwater storage.

The mapped aquifer area (Figure 14) outlines possible locations of these pockets of aquifer material, but not their actual extent. Gravel beds are confined by thick layers of clay. Lower portions of the clay unit appear to be till deposits left by glacial advance. These are overlain by a thick accumulation of lacustrine clay deposited in an elevated proglacial lake formed during the recession of the Fraser glaciation (Paradis, 2010).

Only one well reported a yield of 3.2 L/s (50 USgpm). It is likely that yield is of a short-term nature only, and is not sustainable over longer periods of pumping. Due to the thickness of overburden, it is likely that recharge is limited to groundwater discharged to the gravel from the underlying bedrock.

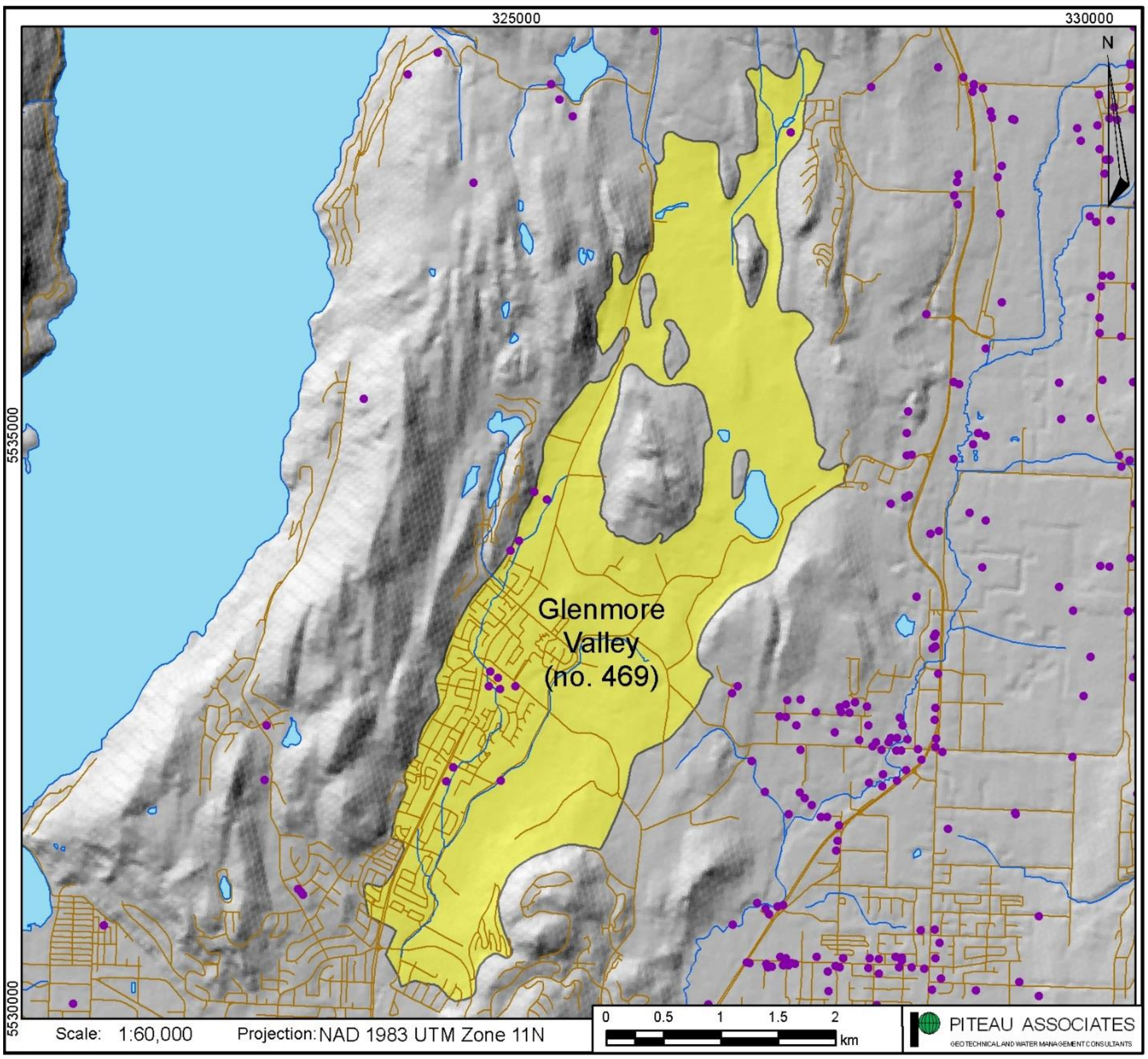


Figure 14: Glenmore valley region hosting isolated, discontinuous, low-productivity and low storage water bearing units comprising the Glenmore Basal Aquifer.

5. DATA GAPS AND UNCERTAINTY

The most conspicuous data gap for the study is highlighted by the distribution of bedrock intercepts in well logs (Figure 15). Although the lack of bedrock intercepts in wells appears significant, it does not substantially affect the quality of the aquifer interpretations as most of the aquifers are hosted within the upper half of the overburden assemblage. Contacts between the aquifer and bedrock are limited to shallow depths along the margins of the valley where there is a reasonable density of bedrock intercepts in well logs. Very little is known about the deep overburden and currently no aquifers have been defined at significant depth below the study area.

A preliminary model of the bedrock-overburden contact incorporated point intercepts from the wells database and section polylines. Polylines were drafted in section view to extend the planar orientation of exposed bedrock slopes underneath the overburden. The preliminary model was then checked against seismic survey data to test the quality of the interpretation provided by Leapfrog. Where seismic data extended to bedrock, the Leapfrog model was accurate to within +/- 15 m. Confidence in the leapfrog interpretation is therefore high. Integrating the seismic data into the model further improved confidence in the interpretation. However, deep seismic data reaching the bedrock surface below Kelowna and below Lake Okanagan (Eyles et al., 1990) are not available.

Whereas, intercepts of the GKA in the wells database are evenly distributed across much of the study area (Figure 16), few of these boreholes penetrate the full depth of the aquifers. Except for wells in the Rutland Section of the GKA, most wells only penetrate the upper portion of the aquifer. Consequently, little is understood regarding the thickness and composition of much of the GKA. Reported well yields suggest there is significant variability in the hydraulic conductivity of the aquifer, and hence composition of the sediments. Even less is known about the geology assumed to underlie the GKA. The superposition of Bessette Sediments over a lower till unit along Mission creek (Figure 17) suggests that sediments from the penultimate glaciation (Okanagan Centre drift), and possibly earlier, are likely preserved.

Well logs incorporated into the model suggest that the GKA is unconfined below UBCO and surrounding the eastern reach of Mission Creek between Hollywood Road and Gallagher’s Canyon (Figure 18). These two locations may therefore be important sites of recharge to the GKA. The reported water depth in well WTN107714 is below the level of Mission Creek and below the base of the aquifer where it crosses Mission Creek in the east. If the regional groundwater hydraulic gradient is projected through this point, the water table would intersect the base of the creek, suggesting the creek may be influencing water levels in the aquifer. Figure 18 highlights areas of potential recharge to the Rutland Section and North Kelowna Section of the GKA from vertical infiltration of precipitation over unconfined deposits. Figure 19 highlights potential areas of mountain block recharge from the White Lake Formation and related Eocene structures in the highlands to the east of Kelowna, based on model geometries.

Hydraulic gradients below UBCO are relatively flat and do not point to any clear source of recharge. Given the extent of the unconfined section of the GKA here, there is likely significant vertical recharge from infiltration of precipitation and runoff over the aquifer. Ellison Lake could potentially be a source of recharge to the GKA, depending on the presence and extent of confining layers below the lake. Currently there is insufficient drilling to understand the nature and extent of any hydraulic connection between Ellison Lake and the aquifers.

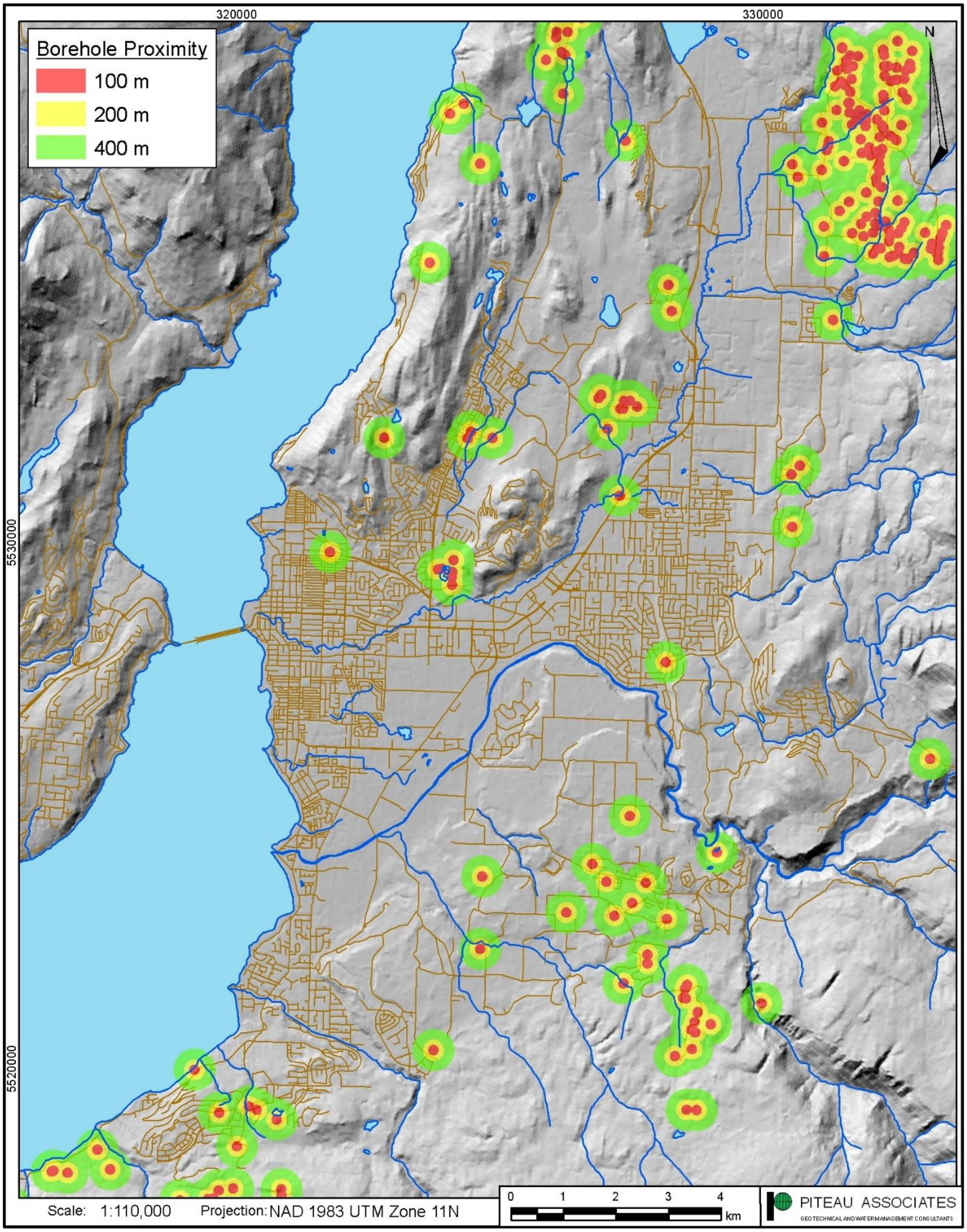


Figure 15: Plot of well locations where bedrock is intercepted. Note the distinct absence of bedrock intercepts below most of the overburden cover in the Kelowna area.

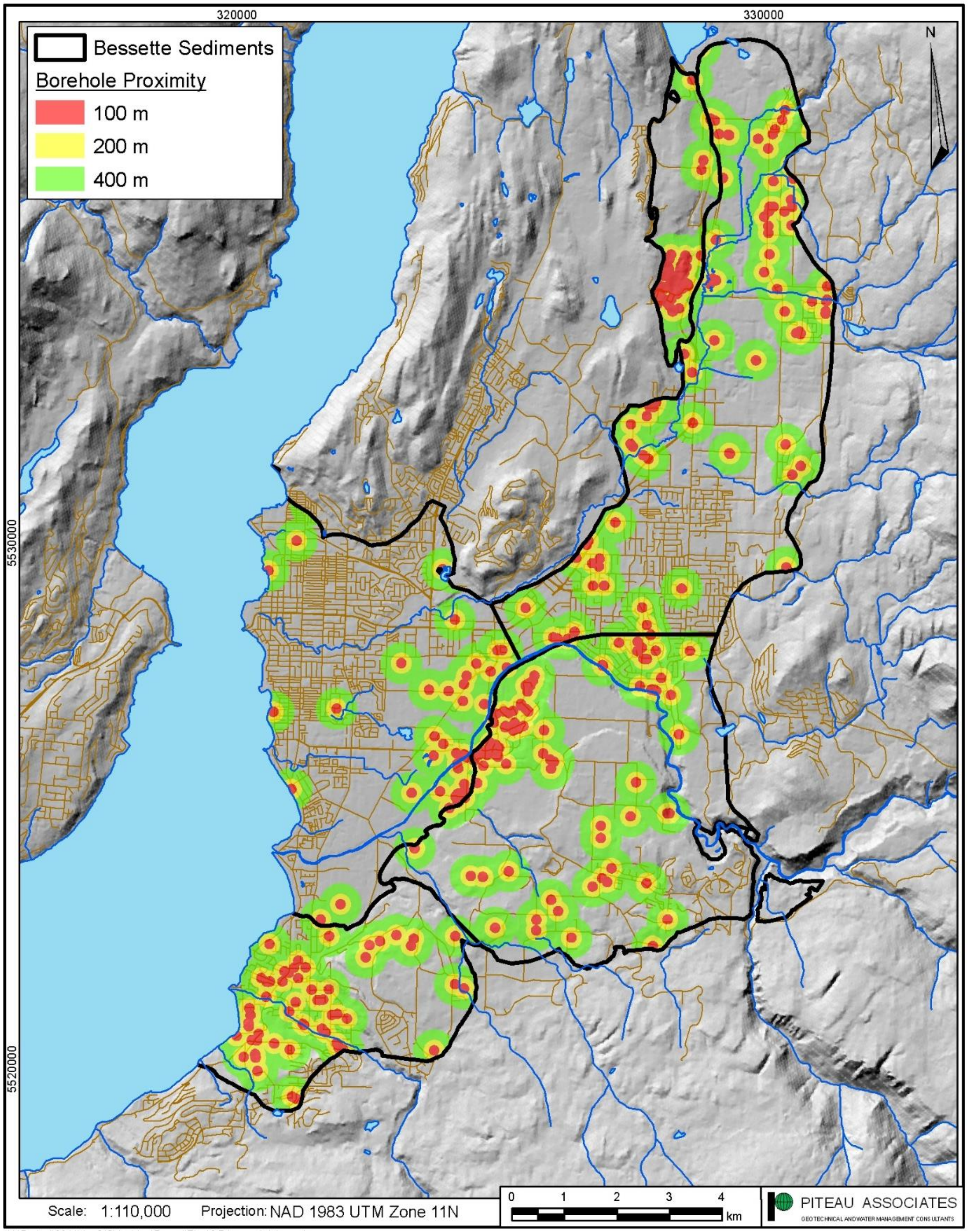


Figure 16: Plan of proximity to borehole intercepts of the top of the Greater Kelowna Aquifer. Significant gaps in data exist below Southeast Kelowna and downtown Kelowna. Overall confidence in the distribution of the top of the aquifer is high due to the significant number of wells in the Project Area.

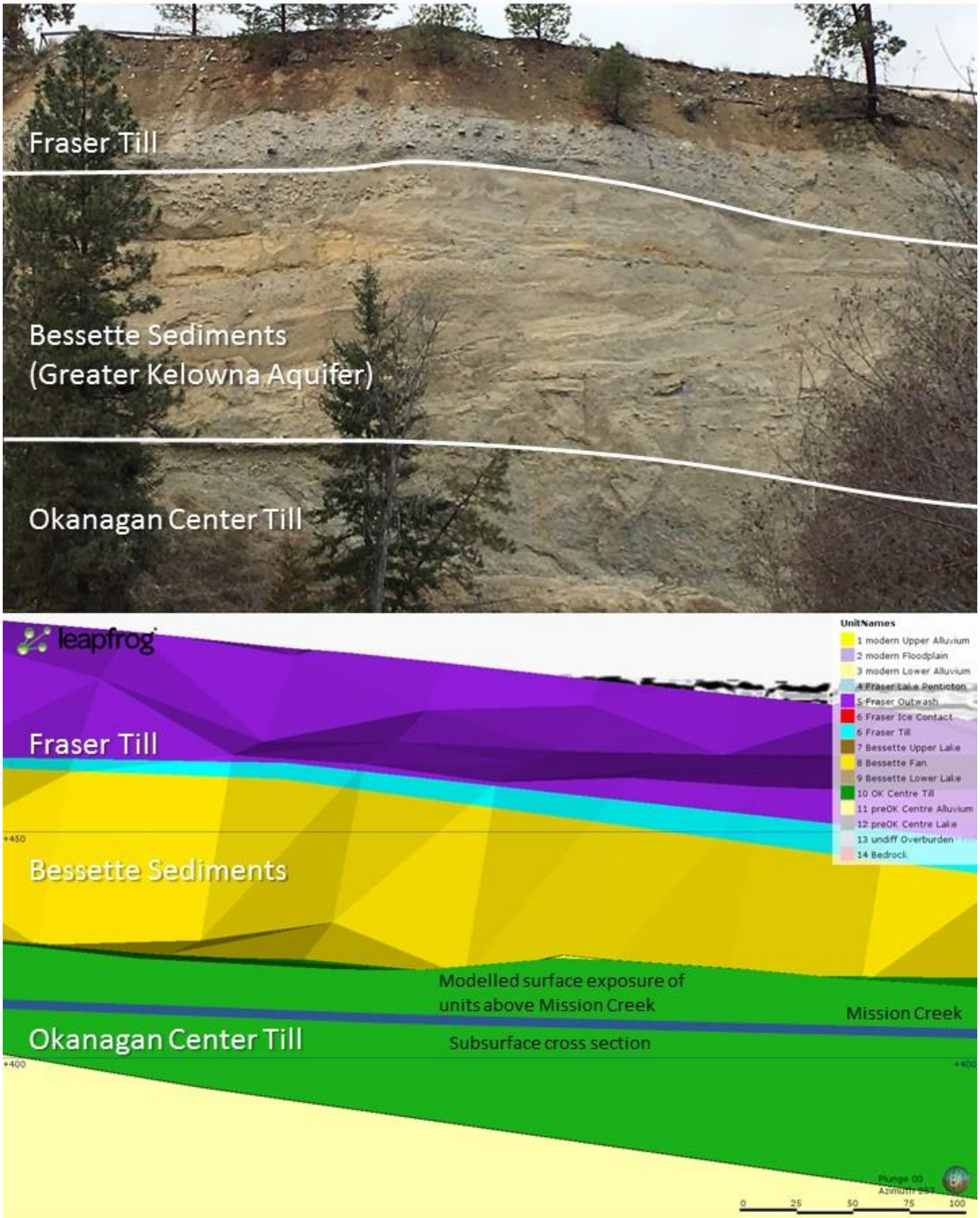


Figure 17: Observed (top) and modelled (bottom) section through exposure of the Rutland Section of the Greater Kelowna Aquifer, looking west from the Mission Greenway path, north of Gallagher's Canyon. Note the reasonable match between the observed and modelled section, highlighting the quality of the Leapfrog interpretation.

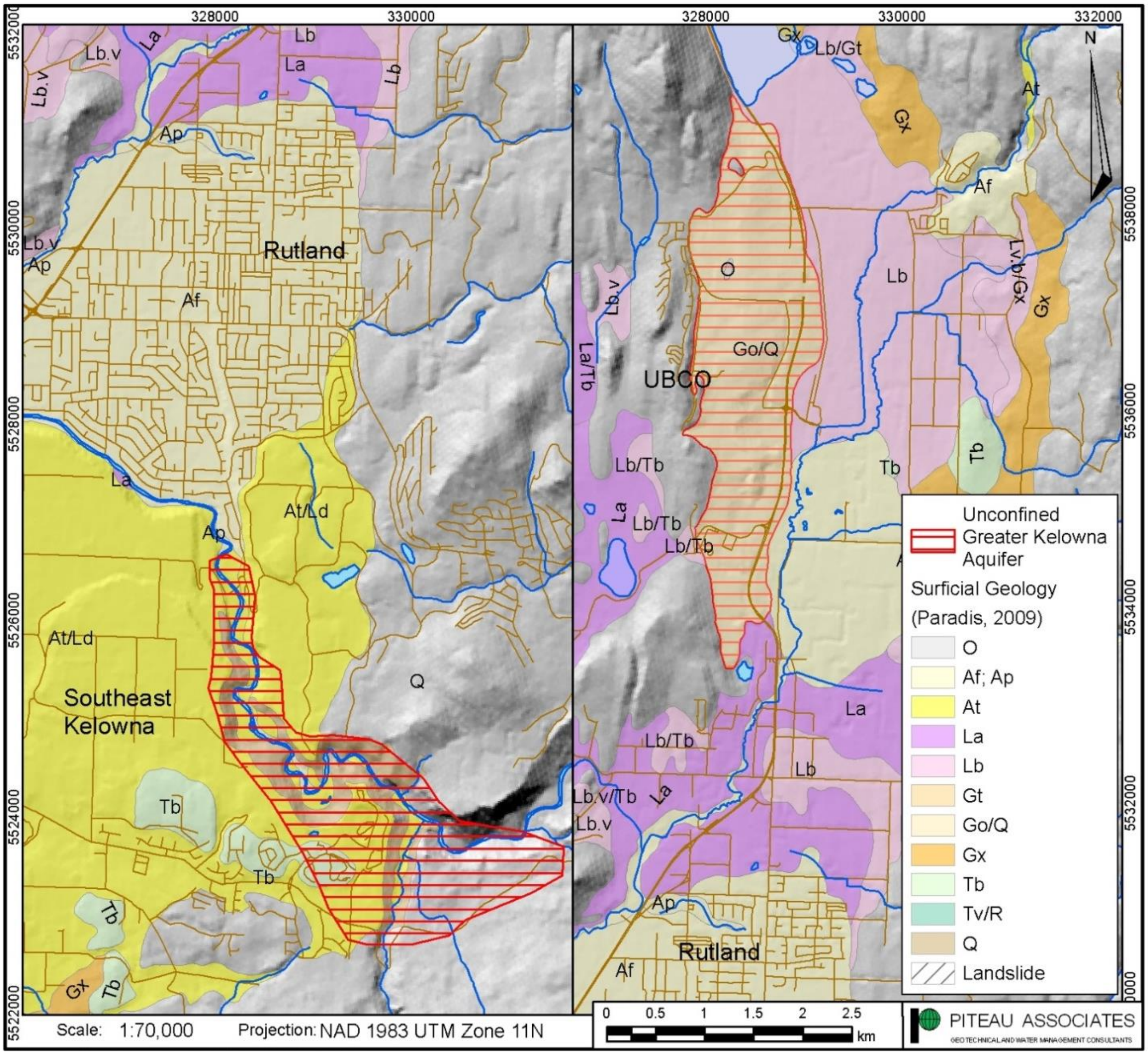


Figure 18: Plan highlighting areas of exposure of unconfined Greater Kelowna Aquifer in Southeast Kelowna (left) and below UBCO (right). Modern alluvial deposits are indicated by "A", glaciolacustrine deposits are indicated by "L", glaciofluvial sediments are indicated by "G" and glacial till is indicated by "T". See Paradis (2009) for descriptions of detailed lithology codes.

The modelled geometry of the Central Kelowna Aquifer suggests that it is exposed at surface where it transitions from being confined below the Mission Lowlands to being fully exposed and unsaturated at the top of the Mission Fan. It is not clear where the aquifer becomes sufficiently confined to become hydraulically disconnected from surface water, which can have important implications for understanding recharge and managing risk to the aquifer. From well logs alone, it is difficult to distinguish modern alluvium or littoral sediments of the glacial Lake Penticton shoreline from the glacial outwash sediments which compose the aquifer.

As described above, the structure of the Bellevue Fan remains unclear. The lack of resolution of stratigraphy leaves uncertainty with respect to aquifer recharge and the potential for groundwater interaction with Bellevue Creek. Similar uncertainty exists with respect to the potential for mountain block recharge to deeper units. The water table is relatively deep below the top of the Bellevue Fan due to the presence of permeable sediments exposed along the steep margins of the fan, however significant clay and till confining layers could limit potential recharge either from vertical infiltration, or lateral groundwater discharge from bedrock.

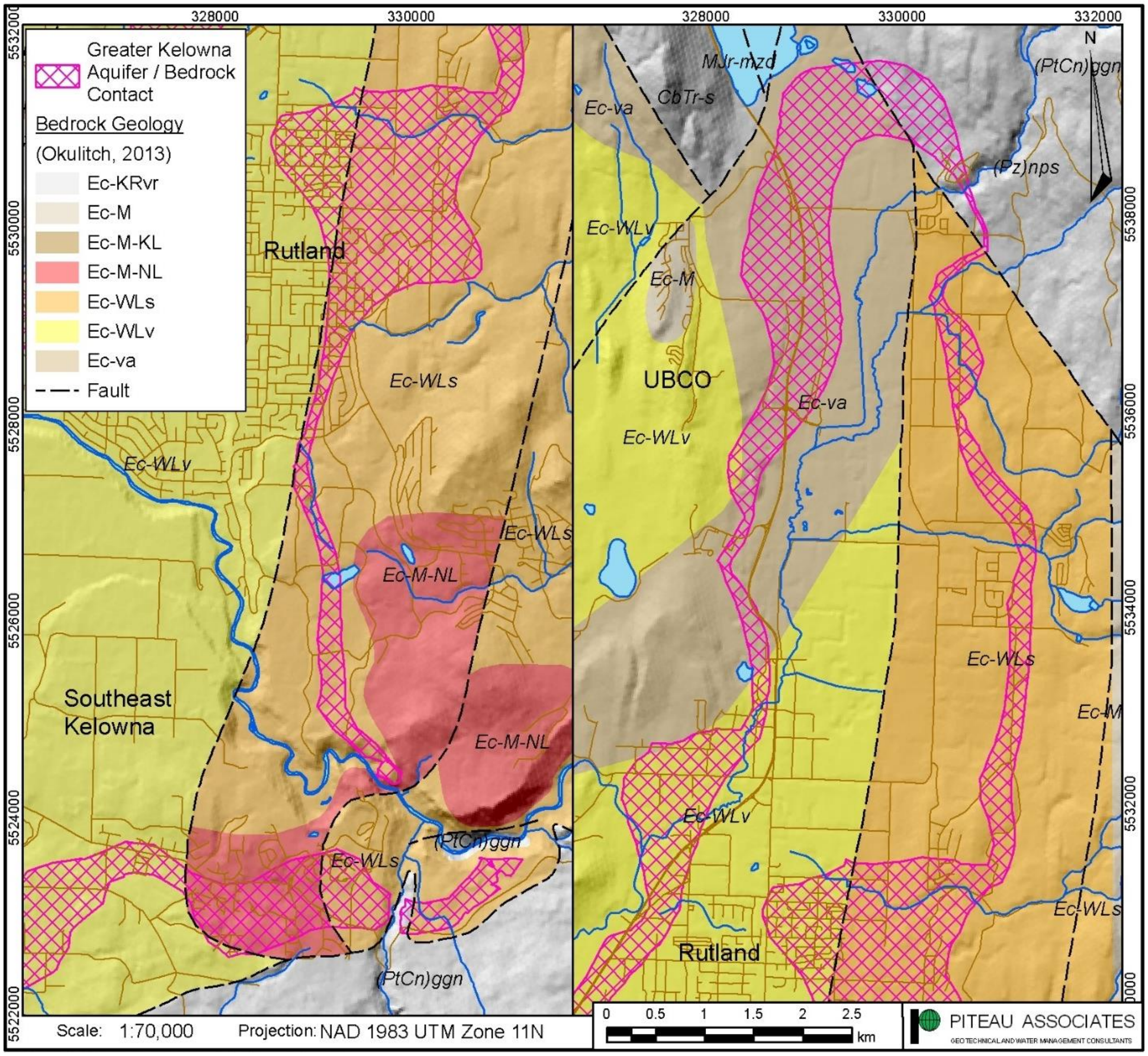


Figure 19: Plan of bedrock geology below the head of the Mission Creek Fan in Southeast Kelowna (left) and east of UBCO (right). The hatched area outlines the contact between the Greater Kelowna Aquifer and Eocene bedrock of the White Lake Formation where mountain block recharge may occur. The following Eocene-age units are shown from mapping by Okulitch (2013): White Lake Formation volcanic and volcaniclastic rocks (Ec-WLv), White Lake Formation sedimentary rocks (Ec-WLs), Marma Formation (Ec-M) and Marron Formation volcanic rocks (Ec-va & Ec-M-NL).

6. CONCLUSIONS

The hydrostratigraphy of the Kelowna area can be represented by a relatively simple assemblage of three regional aquifers, separated by two continuous confining layers. The deepest and most productive aquifer, the Greater Kelowna Aquifer (464), is associated with the Bessette Sediments which were deposited during the non-glacial period between the earlier Okanagan Centre and more recent Fraser glacial periods. This aquifer is described in detail in this report by sections, recognizing that it is distinct in character below geographical areas of Kelowna.

The next youngest regional aquifer, the Central Kelowna Aquifer (1191) is associated with deposition of sand and gravel from proglacial outwash during recession of the Fraser glaciers, prior to damming of the Okanagan valley and formation of ancient Lake Penticton. Postglacial alluvial and flood deposits from the meandering channels of Mission Creek and Mill Creek form the Mission Creek Aquifer (no. 467). This is the most recent regional aquifer which is generally unconfined below the Mission Lowlands and low-lying areas of Northeast Kelowna.

The two units confining the Greater Kelowna Aquifer and Central Kelowna Aquifer are related to two distinct stages of the Fraser glaciation. The lowermost unit is a semi-continuous layer of clay-rich till that overlies Greater Kelowna Aquifer. This unit is interpreted to have been deposited during the peak of the Fraser glaciation when the thickest ice sheets covered the region. The Central Kelowna Aquifer directly overlies this unit, which in turn is overlain and confined by lacustrine deposits of Lake Penticton. This lake is believed to have been formed by blockage of the Okanagan Valley during waning stages of the Fraser glaciation. Thick accumulations of varved silts and clays confine the two aquifers below low-lying areas of Kelowna. Below northeast Kelowna, these two confining units are difficult to distinguish in places and may not contain the intervening glacial outwash. Thus, they form a single confining layer comprising lithostratigraphic units of unique origins which are not easily distinguished in well logs.

Water-bearing units within the Bellevue Aquifer likely share a similar geologic history to the larger Mission Creek Fan. However, the Bellevue Fan contains a higher proportion and more complex interlayered assemblage of till and clay. These features limit the yield of wells in the fan and may limit recharge and lateral flow within and between water-bearing units. Thus, the Bellevue Aquifer is delineated as an aquifer-aquitard complex, rather than discrete aquifers. Similarly, the gravel aquifer lenses below the Glenmore valley are too small and discontinuous to accurately delineate. The boundaries provided for the Glenmore Basal Aquifer represent the maximum likely extent of where saturated water-bearing sediments may be present, but do not reflect the extent of a single discrete aquifer.

Understanding the geometry of the aquifers and aquitards underlying Kelowna aids in resolving the origin of hydraulic gradients observed from water levels in wells, and the clustering of wells experiencing artesian conditions. Regional recharge appears to originate from highlands to east and northeast of Kelowna, converging in Rutland and below southeast Kelowna, before flowing east towards Lake Okanagan. Hydraulic gradients appear relatively flat and consistent within the highly permeable and thick Greater Kelowna Aquifer. Where hydraulic head elevations in the aquifer converge with the topographic elevation in low-lying areas, and where the host aquifer is sufficiently confined, groundwater tends to be under strong artesian pressures.

A significant proportion of the groundwater resource in the Kelowna area is stored in the deeper Greater Kelowna Aquifer. This water certainly flows southward below UBCO and the Airport, and westward below the Mission Fan. It is unclear whether it remains stagnant in deeply confined layers below the mission lowlands, or if it flows to surface discharging to the bottom of Lake Okanagan.

The thickness and characteristics of the overburden underlying the Greater Kelowna Aquifer is poorly understood. Groundwater resources remain untested at those depths (and thus are not utilized) and likely do not significantly influence the shallower systems which groundwater users rely on for water supply. Additional work is needed to reconcile aquifer geometry, hydraulic gradients and implications for recharge and discharge to/from the aquifers documented in this report.

7. RECOMMENDATIONS

While modelling has increased clarity of the hydrostratigraphy in the study area and relationships between the known aquifers, several points of uncertainty remain. These uncertainties may limit the ability to assess the hydraulic conditions within the aquifers that control groundwater flow and interaction with surface water, and ultimately limit the ability to identify and mitigate risk to water quality and aquifer sustainability.

Interpretations of stratigraphy at the proximal (east) end of the Mission Fan are based on the superposition of strata in well logs and visual interpretation of strata exposed in cut banks along Mission Creek. Given the potential importance of understanding the geometry of the Greater Kelowna Aquifer at this location, and the potential for recharge from Mission Creek, detailed mapping of the geology and groundwater seeps along Mission Creek between Hollywood Road and Gallagher's Canyon is recommended. In particular, traverses down the exposed bluffs pictured in Figure 17 are recommended to allow detailed inspection of visible stratification and sampling of soils for radiocarbon or palynology analysis. Mapping of stream flow along KLO Creek above its confluence with Mission creek is recommended to determine if stream losses may be occurring where the stream bed crosses from bedrock onto alluvial overburden.

Groundwater geochemistry and isotope studies are recommended for the three main regional aquifer groups (GKA, Central Kelowna Aquifer and Mission Creek Aquifer). The objective of this assessment is to assess possible recharge sources and evolution of water composing the groundwater resources in the area. Historical geochemical data from published assessments should be compiled and new samples taken to fill gaps in data. The objective of this study is to determine possible recharge sources to the three regional aquifers in the Kelowna area.

Clearly, significant uncertainty remains regarding the depth and composition of Okanagan Centre drift and earlier sediments below deeper portions of the valley. Previous geophysical surveys were not able to penetrate the full depth of the overburden. The potential for increasing the depth of resolution of geophysical (seismic) surveys in the area should be assessed. Surveys completed in Southeast Kelowna should be extended deeper into overburden and farther east to the head of the Mission Creek Fan. Fault zones in the underlying bedrock could be important pathways for mountain block recharge to reach the deeper aquifers in the area. Resolution of the bedrock overburden interface through seismic surveys could highlight potential fault zones or deep basins that are speculated to exist below Kelowna.

Deep overburden drilling is recommended at four locations to fill significant gaps in stratigraphy, and to provide additional monitoring wells in the deeper aquifers. If drilling can be conducted safely under strongly artesian conditions, a deep well near the Lake Okanagan shoreline is recommended to assess the thickness and composition of the Greater Kelowna Aquifer and any underlying strata. A deep well below Rutland is recommended to assess the thickness of older till below the Rutland aquifer, and to determine the depth and composition of underlying bedrock as a possible source of recharge to the aquifer. An installation of grouted-in vibrating wire piezometers will provide valuable information regarding vertical hydraulic gradients through overburden and into bedrock. A deep well is recommended south of Ellison Lake to assess the potential for hydraulic connection with Ellison Lake, and to monitor groundwater level changes relative to changes in lake levels. A deep hole is also recommended under Gallagher's Canyon to assess groundwater in an area potentially providing significant recharge to the Greater Kelowna Aquifer.

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Thomson, S., 2010. Quaternary stratigraphy and geomeorphology of the central Okanagan Valley, British Columbia. M.Sc. Thesis, Simon Fraser University, 173 pages.

Wei, M., 1984. Okanagan Mission South water users community A.R.D.S.A. Project 271141, Test well drilling and production well construction, cabletool method, contract no. 77. Province of British Columbia.

APPENDIX A: KELOWNA AREA WELLS.

Well – aquifer relation table assembled in an Excel workbook called ‘Report table.xlsx is included as a companion electronic file to this report.

APPENDIX B: AQUIFER SUMMARY SHEETS.

AQUIFER DESCRIPTION FOR AQUIFER TAG 0462

Aquifer Name: Bellevue Fan Aquifer

Date of Mapping: March 2018

1.1 Conceptual Understanding of Hydrostratigraphy

1.1.1 Aquifer Extents
Confined aquifer below Upper Mission in south Kelowna. Terminates uphill against the bedrock slope to the southeast. Its northwest limit is defined by the extent of clay till deposits projecting out under the lakeshore near Bellevue Creek. Its northeastern limit is defined by an over-thickened portion of the Fraser till west of Priest Creek, the approximate contact with the Greater Kelowna Aquifer (Aquifer 464). The mapped aquifer boundary represents the extent of composite stratigraphy of the fan, including aquifer sediments and confining units. A single discrete aquifer is not clearly evident from well logs.

1.1.2 Geologic Formation (Overlying Materials)
Confined by colluvium, lacustrine clay to silty sand, and till. Varved silt and clay associated with glacial Lake Penticton cover low-lying areas of the Bellevue fan near the shoreline of Lake Okanagan. Till deposits interlayered within the fan are associated with the Fraser glaciation, although lower till units deposited near bedrock may be earlier.

1.1.3 Geologic Formation (Aquifer)
Sand with lesser gravel. Ice contact deposits associated with Fraser glaciation and non-glacial alluvium of Bessette sediments, deposited between the two most recent glacial periods.

1.1.4 Vulnerability
The vulnerability of the aquifer is low based on a relatively thick (average confining thickness = 51 m) till confining layer and unsaturated fan overlying the aquifer. The water table is relatively deep below this elevated terrain.

1.1.5 Productivity
The productivity of the aquifer is moderate based on an average well yield of 2.2 L/s and sand-dominated aquifer composition.

1.2 Conceptual Understanding of Flow Dynamics

1.2.1 Groundwater Levels and Flow Direction
Groundwater flow direction is inferred to be topographically controlled, flowing from uphill to the east and southeast, westward towards Lake Okanagan.

1.3 Recharge

Recharge is likely from infiltration of runoff to upper slopes and discharge of bedrock groundwater into alluvium and colluvium at the bedrock-overburden interface. Some recharge may originate via leakage from the overlying unsaturated fan and till.

1.3.1 Potential for Hydraulic Connection

Bellevue Creek has eroded down to the top of a confining till layer overlying the main aquifer. There appears to be limited opportunity for infiltration from the creek. However, groundwater levels in the fan surrounding the creek are similar in elevation to the creek elevation, thus the aquifer may contribute baseflow to it. The Greater Kelowna Aquifer (Aquifer 464) appears to be a distal alluvial equivalent of the Bellevue and Mission Creek Fan where it underlies the Kelowna lowlands. Thus, the Bellevue aquifer is interpreted to be hydraulically connected to Aquifer 464 and may provide recharge to it. The Bellevue Creek fan is stratigraphically analogous to the Mission Creek Fan although it may be separated from it by overthickened of Fraser age till near Priest Creek, limiting hydraulic connection with it.

1.4 Additional Information on Water Use and Management

Groundwater demand in the aquifer is considered moderate with approximately 4.7 wells/km^2. Groundwater use includes district irrigation (former South Okanagan Mission Irrigation District, or SOMID), local irrigation, and limited domestic water supply. Domestic water use is supplied primarily through the City of Kelowna utilities which is serviced by surface water drawn from the Mission Creek watershed, and from Okanagan Lake (SVS, 2017). Water use in the area is conjunctive, with licences along local creeks and springs.

1.5 Additional Assessments or Management Actions:

A groundwater protection plan has been developed for the Kelowna region through the Kelowna Joint Water Committee (Golder, 2004 and Golder, 2008). Water budgets (Alloisio and Smith, 2016) and a regional groundwater model (Smerdon and Allen, 2009) have been developed for aquifers in the Kelowna area. Detailed stratigraphy of a portion of the aquifer was defined in Wei (1984).

1.6 Aquifer References

Alloisio, S. and Smith, H.R., 2016. Monthly groundwater budget for the aquifers in the Kelowna BC area. Prov. B.C. Ministry of Environment, Water Science Series WSS2016-10.

Golder, 2004. Initial phase groundwater protection planning Greater Kelowna Aquifer, Kelowna, BC. Report to the Kelowna Joint Water Committee. August 10, 2004, 415 pages.

Golder, 2008. Phase II Kelowna Joint Water Committee groundwater protection plan greater Kelowna Aquifer, Kelowna, BC. Report to the Kelowna Joint Water Committee. February 8, 2008, 143 pages.

Smerdon and Allen, 2009. Regional-scale groundwater flow model of the Kelowna Area and the Mission Creek watershed, Central Okanagan, BC. Report to Ministry of Environment – Stewardship Division, June 2009, 52 pages.

SVS, 2017. 2017 Kelowna integrated water supply plan, Kelowna, B.C.. Report to the City of Kelowna, February 2017, 127 pages.

Wei, M., 1984. Okanagan Mission South water users community A.R.D.S.A. Project 271141, Test well drilling and production well construction, cabletool method, contract no. 77. Province of British Columbia.

Statistical Summary of Well Data for Aquifer

Total number of wells available for statistical analysis: 104

	Depth to Bedrock (m bgs)	Well Depth (m bgs)	Depth to Water (m bgs)	Reported Est. Well Yield (L/s)	Est. Thickness of Confining Materials (m)
Number of Wells	5	104	83	84	n/a
Minimum	4.9	4.0	0.6	0.1	n/a
Maximum	99.4	152.4	103.9	31.9	n/a
Median	31.4	19.8	9.1	1.1	n/a
Average	42.1	36.4	17.4	2.2	n/a
Geometric Mean	28.4	25.0	9.4	1.1	n/a

AQUIFER DESCRIPTION FOR AQUIFER TAG 0464

Aquifer Name: Greater Kelowna Aquifer

Date of Mapping: March 2018

1.3 Conceptual Understanding of Hydrostratigraphy

1.1.1 Aquifer Extents

Predominantly confined aquifer found below the City of Kelowna from Okanagan Mission to the south, through Kelowna downtown, east through Southeast Kelowna and Rutland and north to Ellison Lake. The mapped western boundary of the aquifer is limited to the shoreline of Okanagan Lake, but the aquifer likely continues under the lake for an unknown distance. The aquifer is interpreted to terminate against bedrock slopes under overburden at the margins of the valley.

1.1.2 Geologic Formation (Overlying Materials)

Confined by till, varved lacustrine clay and silt, to silty sand, and upper alluvial aquifers (467and 1191).

1.1.3 Geologic Formation (Aquifer)

Sand and gravel associated with the Bessette Sediments (non-glacial alluvium deposited between the two most recent glacial periods), and ice contact deposits from the early Fraser glacial period.

1.1.4 Vulnerability

The vulnerability of the aquifer varies, but is predominantly low based on a relatively thick (average confining thickness = 51 m) clay and silt confining layers and unsaturated fan overlying the aquifer. The aquifer is unconfined and exposed at surface below UBCO and along Mission Creek north of Gallagher's Canyon. These locations represent local areas of high vulnerability, particularly at UBCO where water levels are relatively close to surface.

1.1.5 Productivity
The productivity of the aquifer is high based on an average well yield of 15 L/s and sand to gravel aquifer composition.

1.4 Conceptual Understanding of Flow Dynamics

1.2.1 Groundwater Levels and Flow Direction
The depth to groundwater measured in this aquifer is highly variable due to the extensive area it underlies. This area is characterized by both upland areas in Southeast Kelowna and around the margins of the valley below which groundwater levels are generally deep. Below low-lying areas of Kelowna, (e.g. Benvoulin Road area), elevated pore pressures result in significant artesian conditions in the aquifer.

Groundwater flow direction is inferred to be topographically controlled, flowing from uphill areas in the north, east and southeast, ultimately flowing westward towards Lake Okanagan.

1.3 Recharge

Recharge is likely from infiltration of runoff to upper slopes and discharge of bedrock flow into alluvial fan and colluvium at the bedrock-overburden interface. There may be some hydraulic connection with Mission Creek where it flows over, and next to, exposures of the aquifer downstream of Gallagher's Canyon. Some limited recharge may originate via leakage from the overlying unsaturated fan and till, although nitrate concentrations (Allard, 2011) are low suggesting limited recharge is arriving from irrigation return flow.

1.3.1 Potential for Hydraulic Connection
Water levels within the aquifer in the Okanagan-Mission to City of Kelowna region are generally at surface or artesian, and thus vertical recharge from overlying aquifers or surface water is unlikely. The aquifer appears internally well-connected below upgradient geographic areas including Southeast Kelowna, Rutland and northeast Kelowna.

In Southeast Kelowna, Mission Creek has eroded a significant canyon down to the top of the lower till downstream of Gallagher's Canyon. There appears to be some opportunity for infiltration from the creek where it flows over and next to exposures of the unit, but the proportion of baseflow contributed to Mission Creek at this location is poorly defined.

1.4 Additional Information on Water Use and Management
Groundwater demand in the aquifer is considered low with approximately 2.6 wells/km^2, however, many of these wells tend to be high capacity, servicing municipal supply needs and may reflect a higher demand than other aquifers in the region. Groundwater use in low-lying areas of Kelowna includes irrigation, industrial water supply, and some domestic water supply. Domestic water use is also provided through the City of Kelowna utilities which is serviced by surface water drawn from the Mission Creek watershed, and from Okanagan Lake (SVS, 2017). Water use in the area is conjunctive, with licences along the floodplains surrounding Mission Creek, Mill Creek, and lesser creeks and springs.

To the east, groundwater use includes city drinking water supply for Rutland (Rutland Waterworks), district irrigation (Southeast Kelowna Irrigation District, or SEKID), local irrigation (including Harvest Golf Club), and domestic water supply (e.g. the Hall Road neighbourhood).

Domestic water use is also supplied through the City of Kelowna utilities. Water use in the area is conjunctive, with licences along local creeks and springs, particularly along the bedrock slopes to the south.

1.5 Additional Assessments or Management Actions:

A groundwater protection plan has been developed for the Kelowna region through the Kelowna Joint Water Committee (Golder, 2004 and Golder, 2008). An assessment of groundwater potential for the city of Kelowna (Agra, 1998) indicated that potential exists to provide drinking water to the city, but only as a supplemental source. Water budgets (Alloisio and Smith, 2016) and a regional groundwater model (Smerdon and Allen, 2009) have been developed for aquifers in the Kelowna area.

1.6 Aquifer References

AGRA, 1998. Groundwater assessment for drinking water needs. Report to the City of Kelowna, November 9, 1998, 171 pages.

Allard, R.A., 2011. Preliminary characterization of nitrates in groundwater in wells completed in the Mission Creek Fan Aquifer, Southeast Kelowna, BC. Report to SEKID, February 28, 2011, 16 pages.

Alloisio, S. and Smith, H.R., 2016. Monthly groundwater budget for the aquifers in the Kelowna BC area. Prov. B.C. Ministry of Environment, Water Science Series WSS2016-10.

Golder, 2004. Initial phase groundwater protection planning Greater Kelowna Aquifer, Kelowna, BC. Report to the Kelowna Joint Water Committee. August 10, 2004, 415 pages.

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<u>Statistical Summary of Well Data for Aquifer</u>

Total number of wells available for statistical analysis: 245

	Depth to Bedrock (m bgs)	Well Depth (m bgs)	Depth to Water (m bgs)	Reported Est. Well Yield (L/s)	Est. Thickness of Confining Materials (m)
Number of Wells	18	245	159	187	245

Minimum	7.0	7.3	0.0	0.0	0.0
Maximum	97.5	317.0	91.4	157.7	143.3
Median	41.0	42.7	12.5	2.5	26.8
Average	49.5	53.2	17.0	15.0	30.3
Geometric Mean	37.9	43.1	11.1	3.4	25.1

AQUIFER DESCRIPTION FOR AQUIFER TAG 467

Aquifer Name: Mission Creek Aquifer

Date of Mapping: March 2018

1.5 Conceptual Understanding of Hydrostratigraphy

1.1.1 Aquifer Extents
Unconfined aquifer extending from below the city of Kelowna, south through Okanagan-Mission and along the base of the Bellevue Creek floodplain, east to lower Mission Creek and northeast to Rutland with a smaller outlier at the base of the valley east of UBCO.

1.1.2 Geologic Formation (Overlying Materials)
Unconfined. May be locally covered by silt or clay associated with local overbank flood deposits.

1.1.3 Geologic Formation (Aquifer)
Sand and gravel, or gravel deposits interlayered with sand silt and local clay. Wood, plant and other organic materials are common in well logs. Aquifer sediments are interpreted to originate from modern deposition of alluvium along the meandering channels of Mission, Bellevue and Mill Creek, and overbank deposits in their floodplains.

1.1.4 Vulnerability
The vulnerability of the aquifer is high based on the largely unconfined character of the aquifer which resides below urban and agricultural areas. Major streams in the region continue to flow over the aquifer, reworking sediments and exchanging water with the aquifer.

1.1.5 Productivity
The productivity of the aquifer is moderate to high based on an average well yield of 3.0 L/s and sand and gravel aquifer composition.

1.6 Conceptual Understanding of Flow Dynamics

1.2.1 Groundwater Levels and Flow Direction
On average, groundwater levels are relatively shallow, and are generally at or near surface below streams. Groundwater flow direction is inferred to be topographically controlled, flowing from east to west towards Lake Okanagan.

1.3 Recharge

The aquifer is recharged by direct precipitation over its footprint, leakage from Mission, Mill and Bellevue Creeks and irrigation return flow from domestic and agricultural land use.

1.3.1 Potential for Hydraulic Connection

There is significant potential for hydraulic connection between Mission Creek, Mill Creek and Bellevue Creek. Historically there have been a significant number of shallow hand dug wells along the floodplain of Mission Creek which present risk of hydraulic connection with local surface water. Flow rates of up to 41 L/s have been recorded; higher recorded flow rates likely reflect hydraulic connection with nearby surface water bodies.

1.4 Additional Information on Water Use and Management

Groundwater demand in the aquifer is considered moderate with approximately 7.8 wells/km^2. Groundwater use appears to be dominantly domestic as well as local small-scale irrigation for agriculture.

1.5 Additional Assessments or Management Actions:

None noted

1.6 Aquifer References

None

Statistical Summary of Well Data for Aquifer

Total number of wells available for statistical analysis: 325

	Depth to Bedrock (m bgs)	Well Depth (m bgs)	Depth to Water (m bgs)	Reported Est. Well Yield (L/s)	Est. Thickness of Confining Materials (m)
Number of Wells	30	325	238	122	325
Minimum	0.9	1.2	0.0	0.0	0.0
Maximum	160.3	280.4	112.8	41.0	24.1
Median	9.9	9.1	2.4	0.9	0.0
Average	28.5	23.3	6.3	3.0	0.6
Geometric Mean	10.1	10.9	3.0	0.7	1.2

AQUIFER DESCRIPTION FOR AQUIFER TAG 469

Aquifer Name: Glenmore Basal Aquifer

Date of Mapping: March 2018

1.7 Conceptual Understanding of Hydrostratigraphy

1.1.1 Aquifer Extents
Deep confined, discontinuous lenses of water-bearing sediments contained in local pockets at the base of overburden below the Glenmore Valley. The aquifer area, which lies between the Kelowna Golf and Country Club and Glenmore Landfill across the Glenmore valley, is defined as the region in which water-bearing sediments may exist, and not the extent of a single continuous aquifer

1.1.2 Geologic Formation (Overlying Materials)
Confined by thick layers of swelling clay. Lower portions of the clay unit appear to be till deposits left by glacial advance. These are overlain by a thick accumulation of lacustrine clay deposited in an elevated proglacial lake formed during the recession of the Fraser glaciation.

1.1.3 Geologic Formation (Aquifer)
Thin (1 to 5m) lenses of basal gravels lying on the bedrock overburden contact.

1.1.4 Vulnerability
The vulnerability of the aquifer is very low, based on the thick (34 m average) clay confining layer.

1.1.5 Productivity
The productivity of the aquifer is moderate based on an average well yield of 1.9 L/s and gravel-dominated aquifer composition. However, aquifer storage is expected to be low based on the extent and confinement of the deposits, and thus the long-term specific capacity of the aquifer is expected to be low.

1.8 Conceptual Understanding of Flow Dynamics

1.2.1 Groundwater Levels and Flow Direction
Groundwater levels are relatively shallow (1 to 11 m) in comparison to the depth of water-bearing sediments. The direction of groundwater flow is not known, however due to the extensive confinement and discontinuous nature of the aquifer, groundwater flow is expected to be minimal.

1.3 Recharge

Due to the thickness of overburden, it is likely that recharge is limited to groundwater discharged to the gravel from the underlying bedrock.

1.3.1 Potential for Hydraulic Connection
There is limited potential for hydraulic connection with this aquifer.

1.4 Additional Information on Water Use and Management
Groundwater demand in the aquifer is considered low with approximately 0.8 wells/km^2. Groundwater use is limited due to the limited well yields and interpreted lack of groundwater storage. Existing uses include domestic and limited irrigation.

1.5 Additional Assessments or Management Actions:
None noted

1.6 Aquifer References
None

Statistical Summary of Well Data for Aquifer

Total number of wells available for statistical analysis: 10

	Depth to Bedrock (m bgs)	Well Depth (m bgs)	Depth to Water (m bgs)	Reported Est. Well Yield (L/s)	Est. Thickness of Confining Materials (m)
Number of Wells	3	10	9	3	4
Minimum	29.0	9.1	1.2	0.3	19.8
Maximum	54.6	59.4	11.3	3.2	54.6
Median	41.1	19.8	3.7	2.3	31.2
Average	41.6	27.9	5.5	1.9	34.2
Geometric Mean	40.2	22.1	4.1	1.3	32.0

AQUIFER DESCRIPTION FOR AQUIFER TAG 1191

Aquifer Name: Central Kelowna Aquifer

Date of Mapping: March 2018

1.9 Conceptual Understanding of Hydrostratigraphy

1.1.1 Aquifer Extents
Confined aquifer extending from below the terminus of Mission Creek, northeast below the creek, below Rutland and north to Ellison Lake. Equivalent sediments compose upper portions of the Mission Fan in Southeast Kelowna. However, they are largely unsaturated here where they underlie terrain elevated above the floor of the Kelowna-Mission lowlands.

1.1.2 Geologic Formation (Overlying Materials)
Confining layers comprise varved silts and clays, and may locally contain peat or wood fragments. These layers are attributed to deposition of lacustrine sediments from glacial Lake Pentiction during the waning stages of the Fraser glaciation. Confining layers pinch out below the west-facing bluffs that define the exposed margins of the Mission Fan in Southeast Kelowna. This is assumed to be the ancient shoreline of Lake Penticton. Confining layers below Northeast Kelowna are discontinuous and outwash deposits may be in contact with recent alluvium.

1.1.3 Geologic Formation (Aquifer)
Sand and gravel aquifer; may contain silt. Deposits are attributed to late glacial outwash overlying Fraser age till, but predate lacustrine deposits associated with glacial Lake Penticton.

1.1.4 Vulnerability
The vulnerability of the aquifer is moderate to low based on the continuity and thickness of the confining clay/silt unit. The aquifer may be locally vulnerable where it becomes unconfined along its eastern margin in Southeast Kelowna.

1.1.5 Productivity
The productivity of the aquifer is high based on an average well yield of 4.4 L/s and sand and gravel aquifer composition.

1.10 Conceptual Understanding of Flow Dynamics

1.2.1 Groundwater Levels and Flow Direction
Groundwater levels in the aquifer are generally at or near surface, but can be artesian below the Benvoulin Road area. Artesian conditions may be driven by recharge to the aquifer where it is unconfined below slopes of the Mission fan, or by upward leakage from the underlying confined greater Kelowna Aquifer. Insufficient information exists to determine the direction of groundwater flow, but is expected to roughly follow topography, flowing from highlands in the east, west towards Lake Okanagan.

1.3 Recharge

Recharge is likely from infiltration of precipitation and irrigation return flow to lithologically equivalent sediments at higher elevations. The aquifer may be locally recharged by upward flow from underlying Greater Kelowna Aquifer (464).

1.3.1 Potential for Hydraulic Connection
The potential for hydraulic connection is limited by the extent of overlying confining sediments and the relatively high groundwater / artesian conditions in the aquifer. There may be local opportunity for hydraulic connection were Mission Creek flows over the aquifer east of Benvoulin Road.

1.4 Additional Information on Water Use and Management
Groundwater demand in the aquifer is considered low with approximately 2.5 wells/km^2. Groundwater use appears to be dominantly for irrigation.

1.5 Additional Assessments or Management Actions:
None noted

1.6 Aquifer References
None

Statistical Summary of Well Data for Aquifer

Total number of wells available for statistical analysis: 109

	Depth to Bedrock (m bgs)	Well Depth (m bgs)	Depth to Water (m bgs)	Reported Est. Well Yield (L/s)	Est. Thickness of Confining Materials (m)
Number of Wells	25	108	64	64	109
Minimum	0.9	2.7	0.0	0.0	0.0
Maximum	73.2	189.0	53.0	50.5	74.7
Median	12.8	25.6	6.1	1.4	4.6
Average	22.3	38.5	9.3	4.4	10.3
Geometric Mean	11.8	24.3	4.8	1.3	7.2

APPENDIX C: LIST OF DIGITAL PRODUCTS.

Leapfrog model

Kelowna_v7.aproj

Leapfrog viewer files

KLW_LFviewer.lfview

Sections.lfview

Aquifer outline ESRI shape files

20180531_KMAMP_Aquifers.shp

Aquifer surface DXF volumes

Topography:

MayKelownaOB - Topography.dxf

Volumes

Bedrock - Overburden.dxf

Bedrock - BR.dxf

MayKelownaOB - 1 modern upper alluvium.dxf (Aquifer 467)

MayKelownaOB - 2 Fraser lake Penticton.dxf (Lake Penticton Aquitard)

MayKelownaOB - 3 Fraser outwash.dxf (Aquifer 1191)

MayKelownaOB - 4 Bellevue unsat fan.dxf (Aquifer 462)

MayKelownaOB - 5 Bellevue lower till.dxf (Bellevue Aquitard)

MayKelownaOB - 6 Fraser till.dxf (Fraser Till Aquitard)

MayKelownaOB - 8 Bessette fan.dxf (Aquifer 464, 469)

MayKelownaOB - 9 Okanagan centre.dxf (Okanagan Centre Till Aquitard)

Contacts:

Bedrock - BR - Overburden contacts.dxf

MayKelownaOB - 2 Fraser lake Penticton - 1 modern upper alluvium contacts.dxf

MayKelownaOB - 3 Fraser outwash - 2 Fraser lake Penticton contacts.dxf

MayKelownaOB - 6 Fraser till - 3 Fraser outwash contacts.dxf

MayKelownaOB - 4 Bellevue unsat fan - 6 Fraser till contacts.dxf

MayKelownaOB - 5 Bellevue lower till - 4 Bellevue unsat fan contacts.dxf

MayKelownaOB - 8 Bessette fan - 5 Bellevue lower till contacts.dxf

MayKelownaOB - 8 Bessette fan - 6 Fraser till contacts.dxf

MayKelownaOB - 9 Okanagan centre - 8 Bessette fan contacts.dxf