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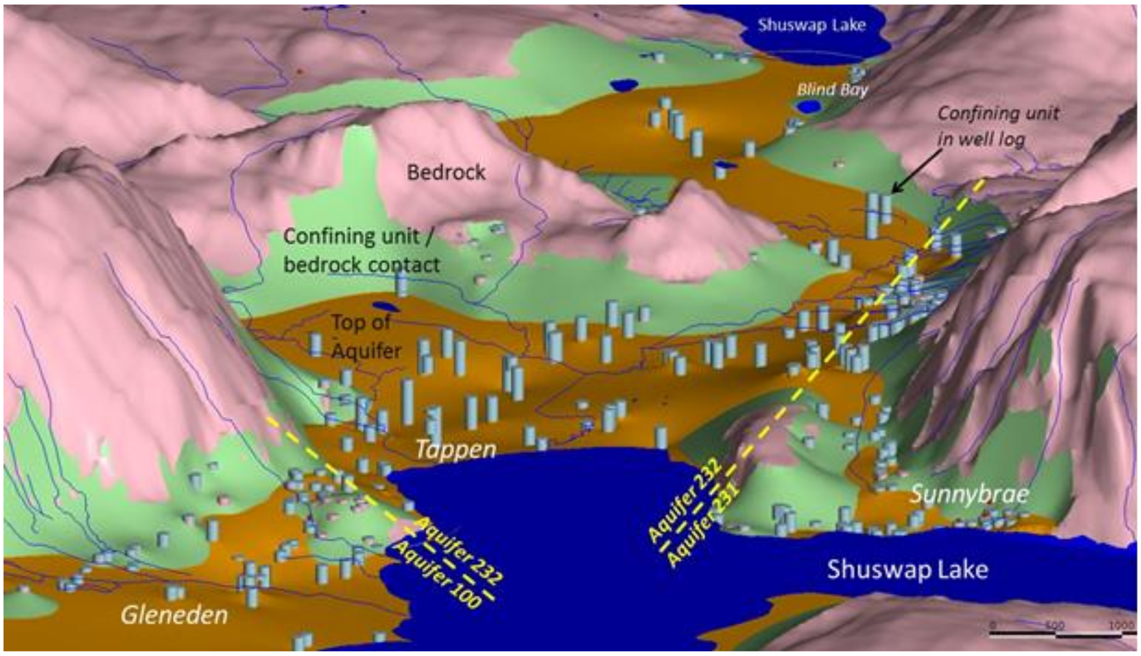
North Okanagan Aquifer Mapping and Geologic Modelling Phase II: Tappen, Westwold and Coldstream Areas

Martin Stewart and Remi Allard



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Stewart, M.L., 2017. Study Area

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EXECUTIVE SUMMARY

Work on this project commenced in 2016 and initially included an assessment of the hydrostratigraphy in the northern portion of the Okanagan Basin, extending from Vernon, northwest to Salmon Arm, and north to Mara Lake. The extent of coverage was expanded in 2017/2018 to include 14 pre-existing aquifers in the Upper Salmon River area from Glenemma to Westwold, the Coldstream Valley from Vernon to Cherryville, and the Tappen Area from Salmon Arm to Blind Bay. These aquifers were added due to elevated concern regarding flowing artesian, high demand versus supply, and ecological considerations. Data including 1,686 well locations, 7,805 lithology descriptions, surface geologic and topographic mapping, and airphoto interpretation were incorporated into three 3-dimensional (3D) Leapfrog^{TM} models. The following report outlines results of the additional mapping including revised aquifer boundaries, aquifer descriptions and 3D modelling.

The extents of existing aquifers were modified to reflect new data, and five new aquifers were defined. The geometry, character, spatial and hydraulic relationships of the aquifers are summarized in the following report, and outlined in detail in the appended summary sheets. Aquifers utilized by wells in the area are tabulated by well tag number. Aquifer outline shapefiles, lithology intercepts and digital contact surfaces accompany this report.

Based on the results of modelling, aquifers across the study region can be classified into two broad groups:

- Shallow sand and gravel aquifers which tend to be confined towards the valley margins and unconfined at the center of larger valleys or near incised creeks and rivers; and
- Deep sand, to sand and gravel aquifers which are confined by significant thicknesses of lacustrine clay and/or silt, overlying aquifers or glacial till.

Shallow aquifers are interpreted to be either glacially reworked alluvial sediments or ice contact deposits associated with the last (Fraser) glaciation, modern alluvial/fan complexes, or a mix of these. Deep aquifers are generally associated with Bessette Sediments, widespread alluvium and lacustrine deposits associated with the inter-glacial Wisconsin Period, or basal sediments of uncertain age lying on the bedrock contact. Shallow aquifers are generally well-developed, providing reasonable certainty with respect to the distribution and geometry. Deeper aquifers are generally penetrated by fewer, more disperse wells and hence have inherently greater uncertainty associated with their interpreted geometry.

Shallow depths and the unconfined, or poorly confined, character of some shallow aquifers render many vulnerable to hydraulic connection with surface water, or at risk of contamination. Utilization of these aquifers is predominantly by domestic and irrigation wells. Water use in these areas is generally conjunctive, with widespread surface water licences present along creeks and springs throughout the Study Area. Shallow aquifers may be tapped by smaller communities and for industrial purposes. However, these users more often utilize the deeper aquifers 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 these deeper wells have a higher probability of intercepting poor water quality or flowing artesian conditions, which have been a problematic condition in the region.

Artesian conditions are relatively common across all project areas, specifically where local confinement of a shallow aquifer occurs below recharge areas on steep slopes and where significant thicknesses of low conductivity confining material, or complexly layered confining units, cover deeper aquifers. (e.g. Coldstream Ranch and Westwold). Flowing artesian conditions are difficult to predict due to sparse data from a limited number of deep wells in the Study Area.

CONTENTS

1. BACKGROUND

Work on this project commenced in 2016 and initially included an assessment of the hydrostratigraphy in the northern portion of the Okanagan Basin, extending from Vernon, northwest to Salmon Arm, and north to Mara Lake (Stewart and Allard, 2017). The extent of coverage was expanded in 2017/2018 to include 14 pre-existing aquifers in the Upper Salmon River area from Glenemma to Westwold, the Coldstream Valley from Vernon to Cherryville, and the Tappen Area from Salmon Arm to Blind Bay (Figure 1). This report describes the results of the additional mapping including revised aquifer boundaries, aquifer descriptions and three-dimensional (3D) geologic modelling for the Study Areas in Figure 1.

Mapping by Fulton et al. (1974a, and 1974b) is the most recent assessment of overburden geology in the Study Area. The mapping is summarized in a memoir documenting the glacial history and geomorphology of the region (Fulton, 1975). Additional, larger scale mapping in the Study Area was completed by Fulton and Smith (1984). The stratigraphy of the region is described in Fulton (1975) and Fulton and Smith (1978).

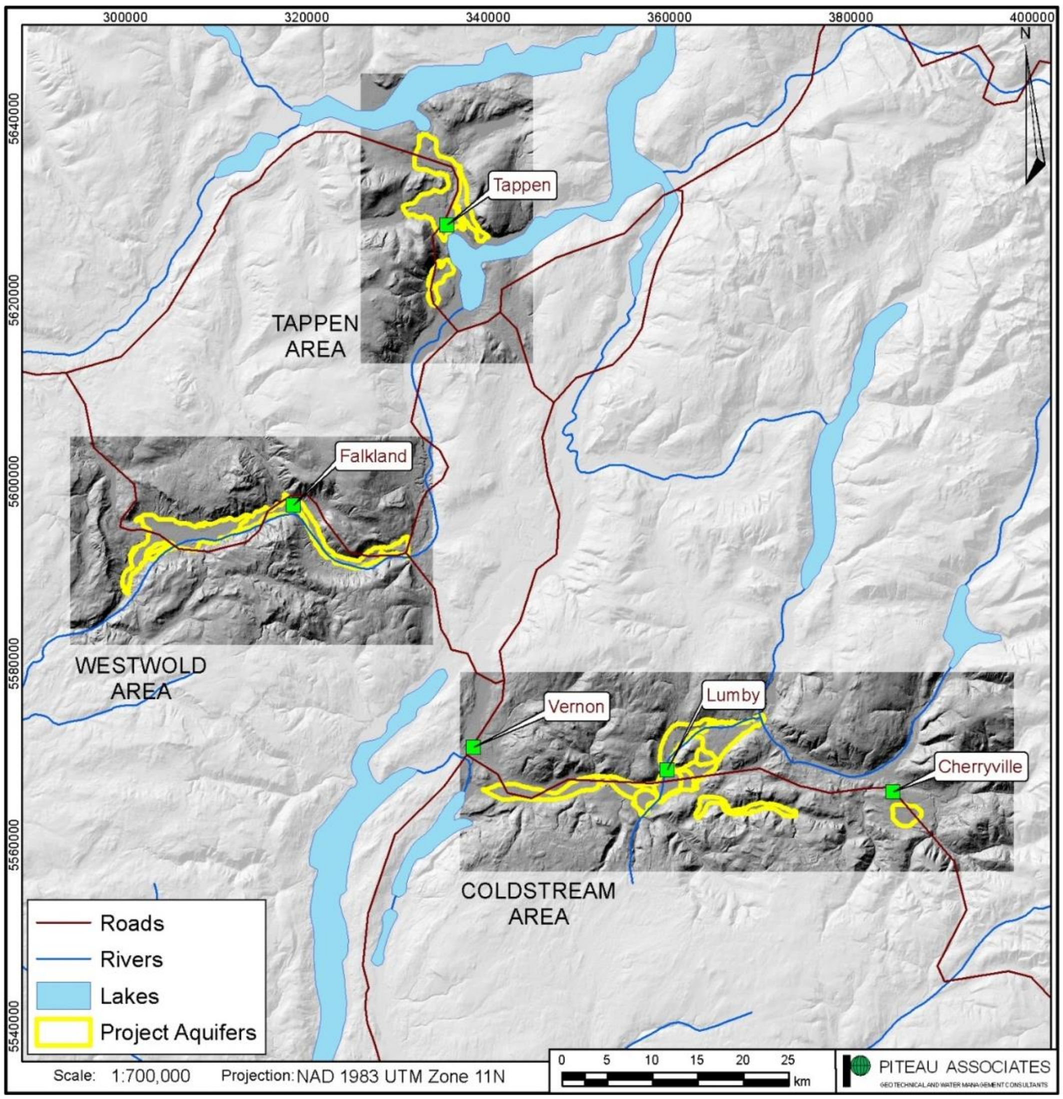

Figure 1: Project study areas and pre-existing overburden aquifer areas.

This study builds on aquifer interpretations presented in Stewart and Allard (2017). Portions of the Salmon River Upper and Lower Aquifers (0097 and 0098) to the east of the Westwold area were assessed in the previous study and completed as part of this study. The remaining aquifers documented in this report are similar in provenance and hydrogeology to those in the 2017 study, but are hydraulically separated from them.

The lowermost intercepted aquifer units in the study area are the Bessette sediments, which were defined by Smith (1969). Older units, including Westwold sediments and Okanagan Center glacial deposits in the Westwold Area, are described by Fulton and Smith (1978). Additional reports of interest in the region include water balances developed for the Westwold area (Bennett, 2012; British Columbia Water Resources Service, 1976), groundwater protection/management plans for the communities of Whitevale (Golder, 2008a), Coldstream (Golder, 2006 and 2008b) and Lumby (Golder, 2007), and well reports for Coldstream Ranch (Scott, 1968; Golder, 2016). The Regional District of North Okanagan led a watershed management assessment for the Shuswap River watershed, which included a regional scale assessment of the distribution of aquifers and groundwater flow below the Shuswap River (Golder, 2012).

2. METHODS

Borehole logs for the project were compiled from the BC WELLS database and categorized according to a simplified set of lithology descriptions. This dataset was then imported into three Leapfrog^{TM} models (one for each project area) to provide 3D spatial context for aquifer sediments, and ultimately delineate regional scale aquifers and aquitards. A total of 7,805 lithology entries in 1,686 well records were utilized in three separate models, representing about 75% of available data. Approximately 25% of the lithology entries were ignored primarily due to the entries with unusable lithological descriptions. Additional omissions include data without proper depths, duplicate boreholes, insufficient resolution of geologic intervals or data which is clearly anomalous relative to nearby wells and the conceptual model.

Surface topography and surficial geology from Geological Survey of Canada (GSC) mapping (Fulton, 1974a and 1974b) were integrated into the 3D geologic models to assist in interpretation of geomorphology of the subsurface. Water levels, well production flow rates, noted artesian conditions and occurrences of unique marker features 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 to locate areas 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 each of the three models, on which the overburden volumes were built. A conceptual hydrogeological model was generated based on the interpolated results from Leapfrog^{TM} and the most recent regional stratigraphic understanding. This conceptual model was then applied to the digital models to clean up the interpolation in areas of uncertainty (i.e. 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 wells are completed in (Appendix A),
- characterize the aquifers and aquifer parameters,
- modify existing or generate new aquifer boundaries, and
- inform the aquifer summary sheets (Appendix B).

3. GEOLOGICAL OVERVIEW

A detailed overview of the geologic history and groundwater hydrology of the region is available in the Stewart and Allard (2017). There is limited information available regarding the deepest overburden in the Study Area. Eroded bluffs west of Westwold preserve remnants of Okanagan Centre glacial till (early Wisconsin age) and older underlying non-glacial deposits, named the Westwold sediments by Fulton and Smith (1978). Since these deposits are present in exposures at surface, it is assumed that similar age sediments are likely present at the base of overburden throughout the Salmon River Valley, and the comparable Coldstream Valley.

To date, based on the bedrock surfaces developed, no wells have penetrated the deepest reaches of the valley overburden in all three project areas. The deepest sediments intercepted include sand and gravel alluvium and finer-grained lacustrine deposits. Abundant organic materials within the sediments and superposition of deposits associated with the latest glacial period (Fraser) which overly these sediments, indicate they originate from the last major nonglacial period, the Olympia interglaciation. These deposits are known in the North Okanagan Region as the Bessette Sediments, the type locality of which is along the eroded banks of Bessette Creek, within the Study Area north of Lumby.

Available well data indicate that the deep wells which encounter the Bessette Sediments do not penetrate the base of these sediments. Therefore, the base of the Bessette, and the aquifers it contains, cannot be accurately assessed, and no attempt was made to differentiate it from older units in the models.

In contrast to the geology and geomorphology of the Okanagan Valley and main tributary valleys, deposition of the uppermost units and geomorphology of the Upper Salmon River and Coldstream-Shuswap River valleys was largely complete by the late stages of the Fraser glaciation. The period of late glaciation was relatively quiescent; ice became stagnant, damming up valleys to form lakes, including Lake Hamilton in the upper Salmon River Valley, and Coldstream Lake in the Coldstream Valley. It appears there was limited sediment deposition during the residence of these lakes and significant local erosion occurred during drainage. Sediment eroded from the Salmon River Valley was deposited in the O'Keefe and Hullcar valleys, whereas sediment eroded from Bessette Creek north of Lumby was likely deposited in the Shuswap River Valley between Shuswap Falls and Mabel Lake. Following the late glacial period, changes to that landscape included local migration of alluvial channels with streamflow, as well as limited deposition of colluvium and alluvium where tributary streams enter the Salmon River and Coldstream-Shuswap valleys.

The geomorphology and geology of overburden in the Tappen Area is mixed. To the east, in the Sunnybrae Area, a low plateau preserves extensive till cover over basal sediments. This is in turn partially covered by local colluvium and alluvial fan(s) originating from Farrell Creek and lesser streams emanating from steep hillsides. Along the valley bottom between Tappen and Blind Bay, the till is extensive but not as thick. The primary confining unit in the base of the valley appears to be an extensive and relatively thick blanket of lacustrine sediments originating from the presence of a higher stage of Shuswap Lake, likely formed during the waning stages of the Fraser Glaciation.

An overview of the aquifers modelled during this assessment is presented in the following sections, and is summarized in Table 1. Detailed descriptions of aquifer composition and hydrogeology are presented in Appendix B.

Table 1: List of aquifers and key data modelled for this assessment.

Aquifer Number	Revised Number	Name	Descriptive Location	Lithostratigraphic unit	Vulnerability	Level of Development	SubType	Materials	Artesian Conditions	Observation Wells	Comment
97		Salmon River - Upper Aquifer	Salmon River from Falkland to Salmon arm	glacial outwash and post-Fraser alluvium	A	2	1a/4a	sand and gravel		OW185	extended up Bolean creek by 2.5km, from Falkland (may go
98		Salmon River - Lower Aquifer	Salmon River - Westwold to Salmon Arm	Bessette and earlier	B	2	4b	sand and gravel		OW185	
100		Gleneden	Gleneden	pre-glacial fan	C	1	4b	gravel	yes	none	
231		Sunnybrae	Sunnybrae	pre-glacial fan	C	2	4b	sand and gravel	yes	none	possibly linked to Tappen
232		Tappen	Tappen	preglacial fan, Bessette alluvium and possibly basal aquifer	C	2	4b	gravel	yes	none	
289		Westwold	Westwold Valley	glacial outwash and post-Fraser alluvium	A	2	4a	sand and gravel	yes	OW045	extension of 97
310		Creighton	Creighton Valley	mixed kame, fan and modern alluvium	B	2	1c/4a/4b	sand and gravel	yes	none	
311		Upper Cherryville	South Cherryville upland	preglacial, early Bessette?	B	2	4b	gravel	no	none	
314	314	Lumby - Lower Aquifer	Lavington to Lumby	deep basal (early Bessette?)	C	1	4b	sand and gravel	yes	none	
315			Whitevale	deep basal/fan (early Bessette?)					yes		same as 314, farther west; combine with 314
316	316	Lumby - Upper Aquifer	Lavington to Lumby	late Bessette to early glacial	A	2	1c/4a/4b	sand and gravel	yes	OW294	shallow aquifer, partially confined
317					A				yes		indistinguishable from 316, combine
318		Bessette Creek	Lumby to Shuswap Falls	deep basal (early Bessette?)	C	2	4b	gravel	yes	none	
319		Trinity Valley	north of Lumby	late Bessette to early glacial	A	1	1c/4a/4b	gravel	yes	none	
352		Coldstream	Coldstream to Lavington	reworked Bessette, early glacial outwash	C	2	4b	sand and gravel	yes	none	
1002		Rawlings Lake	south and west of Rawlings Lake	Kame - Fraser glaciation	A	1	4a	sand and gravel	no	none	Kame - equivalent to 316 and 319
new	1158	Sugar Lake	Sugar lake Road	mixed kame, fan and modern alluvium	A	3	1b/4a/4b	sand and gravel	no	none	local fan deposit
new	1159	Lower Cherryville	Cherryville - Shuswap	mixed kame, fan and modern alluvium	A	2	1b/4a/4b	sand and gravel	yes	none	shallow alluvium
new	1160	Bear Valley Perched	Bear Valley / Blue Springs Creek	mixed englacialdeposits, outwash and recent fan	A	2	4a/4b	sand and gravel	no	none	thin fan
new	1161	Falkland Perched	Falkland Upland	basal colluvial gravels, below Till	C	1	4b	gravel	yes	none	thin perched fan below till
new	1162	Cedar Hill Perched	Cedar Hill	basal colluvial gravels, below Till	C	1	4b	gravel	no	none	thin perched fan below till

4. AQUIFER RECONCILIATION AND HYDROGEOLOGY

Aquifers presented in the following sections are referred to by common name (e.g. Westwold Aquifer), relative position in stratigraphic column and a 4 digit number (e.g. Aquifer 0097) assigned by the Province using B.C. Aquifer Classification System (Kreye et al., 1994).

4.1 Upper Salmon River Valley

Five aquifers are currently defined in this region, including:

- Salmon River Upper Aquifer (0097),
- Salmon River Lower Aquifer (0098),
- Westwold Aquifer (0289),
- Falkland perched Aquifer (1161), and
- Cedar Hill perched Aquifer (1162).

Outlines of aquifers and modifications made to existing aquifer boundaries are illustrated in Figure 2. A summary of the age and hydraulic connectivity relationships between neighbouring or overlapping aquifers in this area is presented in Table 2.

Aquifer 0097 was extended north from Falkland along Bolean Creek to include several wells installed in a tributary of the same aquifer. Aquifer 0289 was expanded towards Falkland to include intercepts in recently drilled wells. A portion of Aquifer 0098 in highlands southeast of Westwold was transferred to Aquifer 0097 as a local confined area of the aquifer. It is possible that Aquifer 0289 and 0097 are physically and hydraulically connected west of Falkland; insufficient data exists to determine the relationship between these aquifers.

The deep aquifer in the valley, Aquifer 0098, is identified in wells west of Falkland only. It is assumed that the unit continues below the Salmon River across the remainder of the valley, connecting with deeper aquifers below the lower Salmon River outside the Study Area.

Aquifer 0289 in the Westwold area is confined along the southern and northern margins of the valley by a clay-rich till unit that is typically 10 to 15 m in thickness, but can exceed 30 m close to the valley walls (Figure 3). Extensive areas of the aquifer around Westwold and along the Salmon River remain unconfined; this exposure may be due to erosion, although there are no significant erosional features visible in current topography. The aquifer remains unconfined to approximately 4 km east of Westwold. Downstream of this point, the confining clay and till layers overlying Aquifer 0289 and Aquifer 0097 (the equivalent aquifer to the east) can be greater than 50 m thick below the base of the valley, and appear continuous as far as Glenemma. The Salmon River flows over significant portions of the aquifer where it is unconfined. In these same areas, well production rates can be anomalously high (>200 USgpm). Thus, there is significant potential for surface water to interact with groundwater, and for shallow wells to draw water from the river and nearby wetlands.

The top of Aquifer 0098 can be deeper than 100 mbgs in places but on average is about 50 m depth in wells. Overlying materials include confining clay and overlying aquifers (Aquifer 0097 and 0289). The low permeability confining unit is generally present in wells. However, model projections suggest this unit may thin east of Westwold providing the potential for hydraulic connection between the upper and lower aquifers.

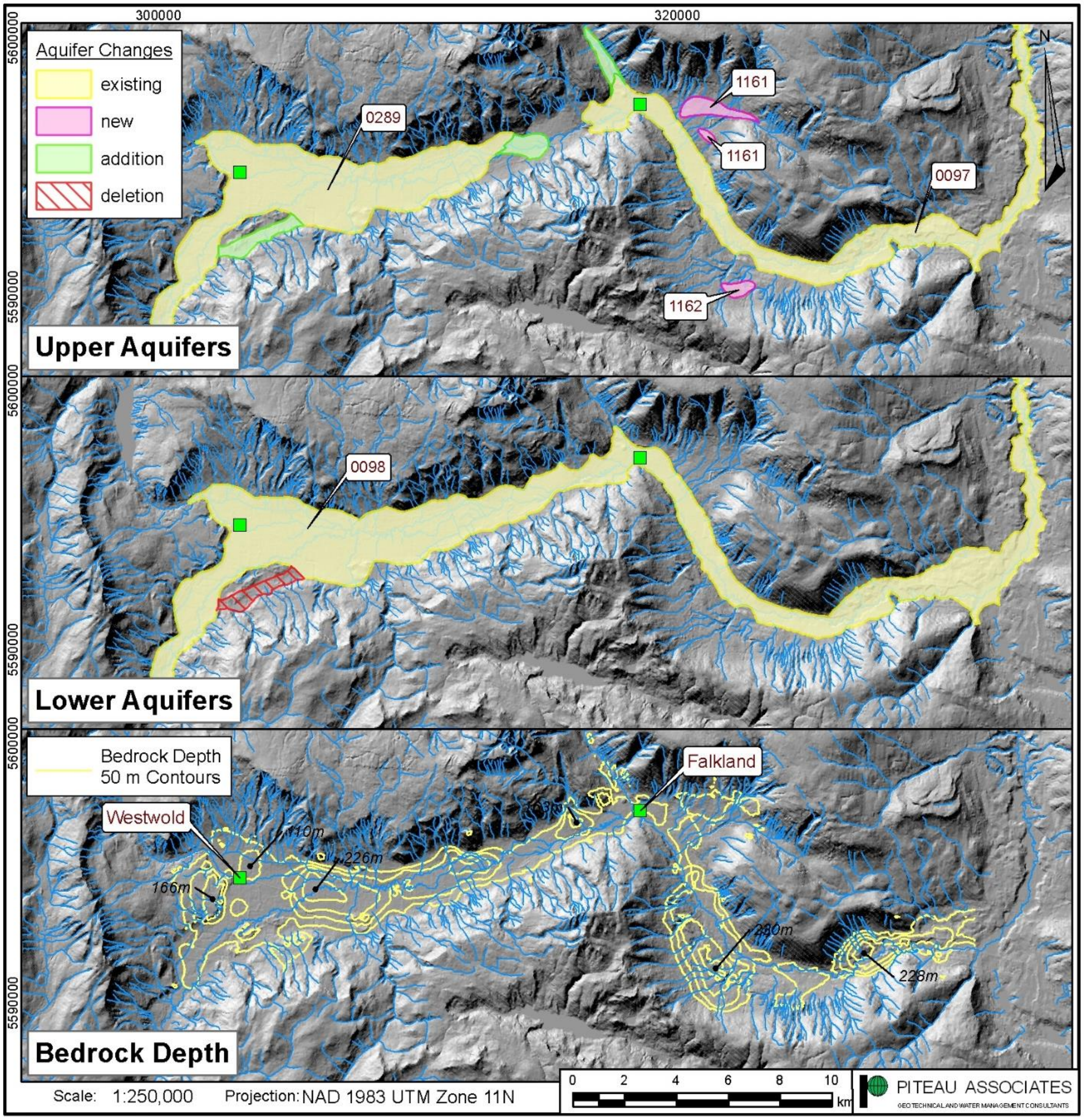

Figure 2: Limits of upper and lower aquifers in the Upper Salmon River Valley and contours of depth to bedrock from surface.

Two new aquifers were identified during compilation of the 3D models (Figure 2). Aquifer 1161 underlies the highlands east of Falkland below Warren Creek and Aquifer 1162 underlies similar highland terrain south of Falkland near Bishop Creek (southwest of Sweetsbridge). These aquifers comprise thin accumulations of basal gravel deposited on the bedrock surface, which were subsequently buried under a significant thickness of till cover. These aquifers are limited in size and recharge, but are sufficiently continuous and utilized to warrant definition as aquifers.

Table 2: Summary of age and hydraulic connectivity relationships for neighbouring aquifers in the study area, including pre-existing (revised) aquifers, newly defined aquifers and aquifers studied in the previous assessment (Stewart and Allard 2017).

		Aquifer Name	No	97	98	289	1161	1162	310	311	314	316	318	319	352	1002	1158	1159	1160	100	231	232
NOMP III	Salmon River	Salmon River - Upper Aquifer	97																			
NOMP III	Salmon River	Salmon River - Lower Aquifer	98	S (green)																		
NOMP III	Salmon River	Westwold	289	A (red)	S (green)																	
NOMP III	Salmon River	Falkland Perched	1161	(yellow)	(yellow)																	
NOMP III	Salmon River	Cedar Hill Perched	1162	(yellow)	(yellow)																	
NOMP III	Coldstream	Creighton	310																			
NOMP III	Coldstream	Upper Cherryville	311						A (red)													
NOMP III	Coldstream	Lumby - Lower Aquifer	314																			
NOMP III	Coldstream	Lumby - Upper Aquifer	316						A (green)		S (green)											
NOMP III	Coldstream	Bessette Creek	318								A (green)											
NOMP III	Coldstream	Trinity Valley	319									A (red)	S (green)									
NOMP III	Coldstream	Coldstream	352								A (green)											
NOMP III	Coldstream	Rawlings Lake	1002									S (green)		A (red)								
NOMP III	Coldstream	Sugar Lake	1158																			
NOMP III	Coldstream	Lower Cherryville	1159							A (red)			(magenta)				A (green)					
NOMP III	Coldstream	Bear Valley Perched	1160															(yellow)				
NOMP III	Tappen	Gleneden	100		A (red)																	
NOMP III	Tappen	Sunnybrae	231																			
NOMP III	Tappen	Tappen	232																	A (red)	A (green)	
NOMP II		Hullcar Lower	102		A (green)																	
NOMP II		Hullcar Upper	103	A (green)																		
NOMP II		Tuhok Upper	108	A (red)																		
NOMP II		Tuhok Lower	109		A (red)																	
NOMP II		Vernon Upper	346																			
NOMP II		Vernon Lower	347												A (green)							
NOMP II		Okeefe Upper	354	A (green)																		
NOMP II		Okeefe Lower	1150		A (green)																	

A (green)	age equivalent, some hydraulic connection
A (red)	age equivalent, no hydraulic connection
S (green)	stacked, some hydraulic connection
S (red)	stacked, no hydraulic connection
(magenta)	unknown age relationship, possible hydraulic connection
(yellow)	unknown age relationship, no hydraulic connection

Note: associations are described only for neighbouring or overlapping aquifers

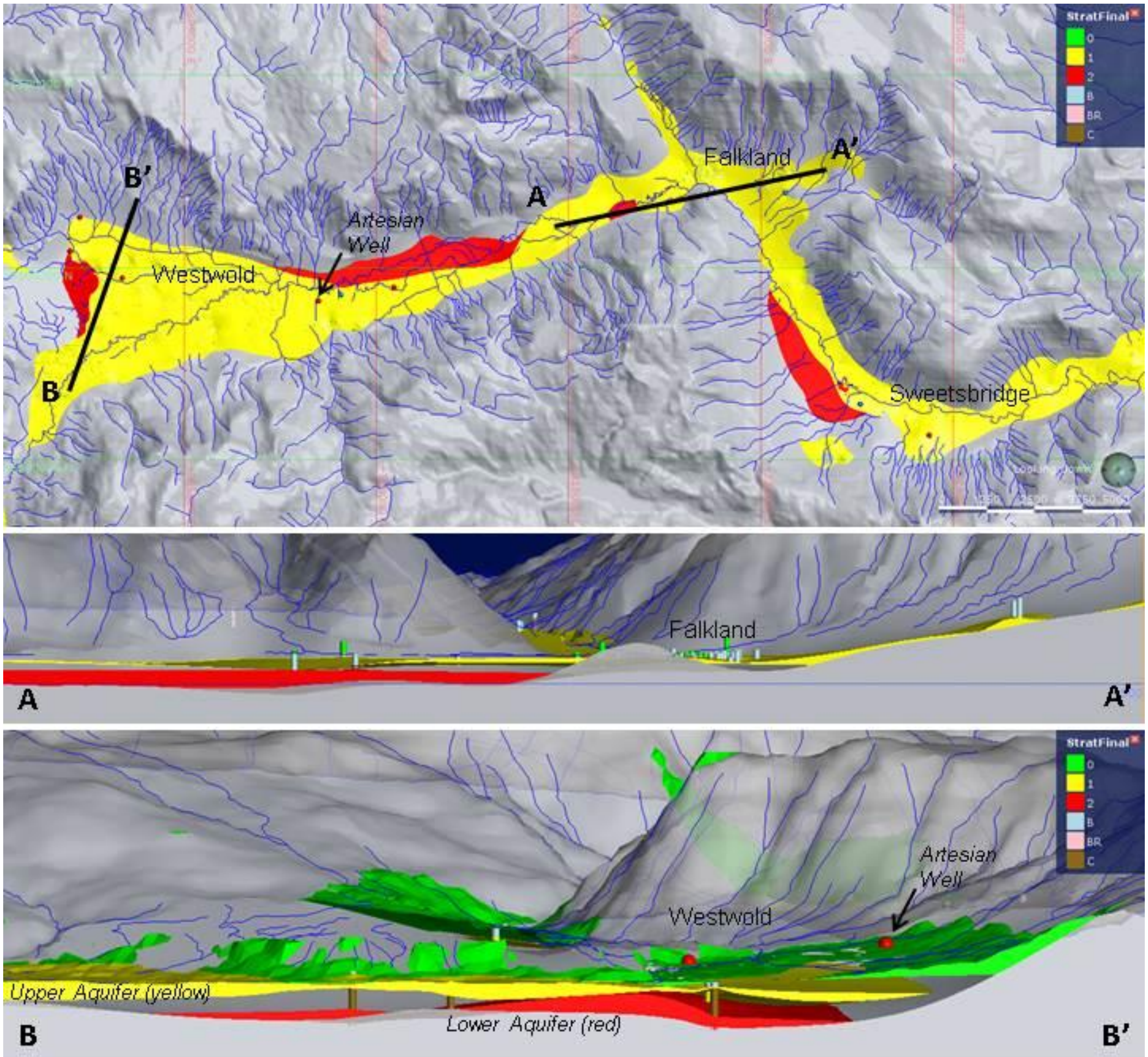

Figure 3: Plan view of the Upper Salmon River aquifers, including the upper Aquifers 0097 and 0289 (both in yellow), and lower Aquifer 0098 (red). Cross sectional views include A-A', an east-west oriented section (looking north) through Falkland and highlands to the east, and B-B', a north-south oriented cross section (looking west) through Westwold. Unsaturated sand and gravel cover is shown in green.

4.2 Coldstream

Eleven aquifers are currently defined in this area, including

- Creighton Valley Aquifer (0310),
- Upper Cherryville Aquifer (0311),
- Lumby Lower Aquifer (0314),
- Lumby Upper Aquifer (0316),
- Bessette Creek Aquifer (0318),
- Trinity Valley Aquifer (0319),
- Coldstream Aquifer (0352),

- Rawlings Lake Aquifer (1002),
- Sugar Lake Aquifer (1158),
- Lower Cherryville Aquifer (1159), and
- Bear Valley Perched Aquifer (1160).

Outlines of aquifers and modifications made to existing aquifer boundaries are illustrated in Figure 4. A summary of age and hydraulic connectivity relationships between neighbouring or overlapping aquifers in this Study Area are presented in Table 2.

The Creighton Valley Aquifer 0310 was extended to the east below, and about 1 km past, Echo Lake. There appears to be a coincident surface water and groundwater divide at the centre of this aquifer below Barbe Lake. Stratigraphy is contiguous in both directions. The water table is lower in elevation than both Barbe and Echo Lake, thus these surface water features are likely spring fed from the surrounding hillsides and provide recharge to the aquifer below.

Aquifers 0314 and 0315 were consolidated as Aquifer 0314 and extended north below Lumby, and west towards Lavington. These aquifers comprise similar material and a similar stratigraphic position. However, due to limited deep boreholes in this area, data is limited. Similar aquifers elsewhere in the North Okanagan are interpreted to be regionally continuous with similar geometry.

Aquifers 0316 and 0317 were consolidated as Aquifer 0316 based on a similar footprint and stratigraphic position. The footprint was reduced in the Lumby area (records for Well Tag Number (WTN) 82507 and WTN 34429 do not contain saturated aquifer material). The footprint was extended west of Whitevale to include several shallow high producing wells. Although these wells are completed in Aquifer 0316, the high flow rates and shallow nature of the wells suggest that the aquifer may be only locally utilized and much of the water is likely drawn from Duteau Creek. This relationship suggests that Aquifer 0316 is locally recharged by Duteau Creek.

The footprint of Aquifer 0318 was expanded underneath Aquifer 0319 to where it connects with Aquifer 0314 below Lumby. Few wells are completed deep enough (i.e. >40 m) to penetrate the aquifer north of Lumby. However, the interpreted bedrock geometry and noted intercepts are sufficient to suggest the aquifer is present as mapped. The Village of Lumby relies on deep wells installed in this aquifer for groundwater (Golder, 2007).

Aquifer 0319 remains unchanged, although 3D modelling suggests aquifer-equivalent sediments extend east to Shuswap Falls. These sediments are incised by Bessette Creek and thus are fully drained along Bessette Creek, west of Shuswap Falls. Except for local perched water tables below the northern hillslopes above Bessette Creek (Albers Road), the deep aquifer is utilized for domestic and irrigation groundwater supply.

Aquifer 1002 appears stratigraphically equivalent to, and physically connected with, Aquifer 0316, but resides on a topographic and hydrologic divide. The water table in this aquifer is very deep and drains primarily to the south towards Lumby. The extent of Aquifer 1002 was expanded to include what appear to be the thinning margins to the east and southeast, which transition to Aquifer 0316. To the north this unit is mostly drained. Some discharge from Aquifer 1002 may recharge Aquifer 0318, which underlies it, as the intervening confining unit becomes thin and possibly discontinuous in places.

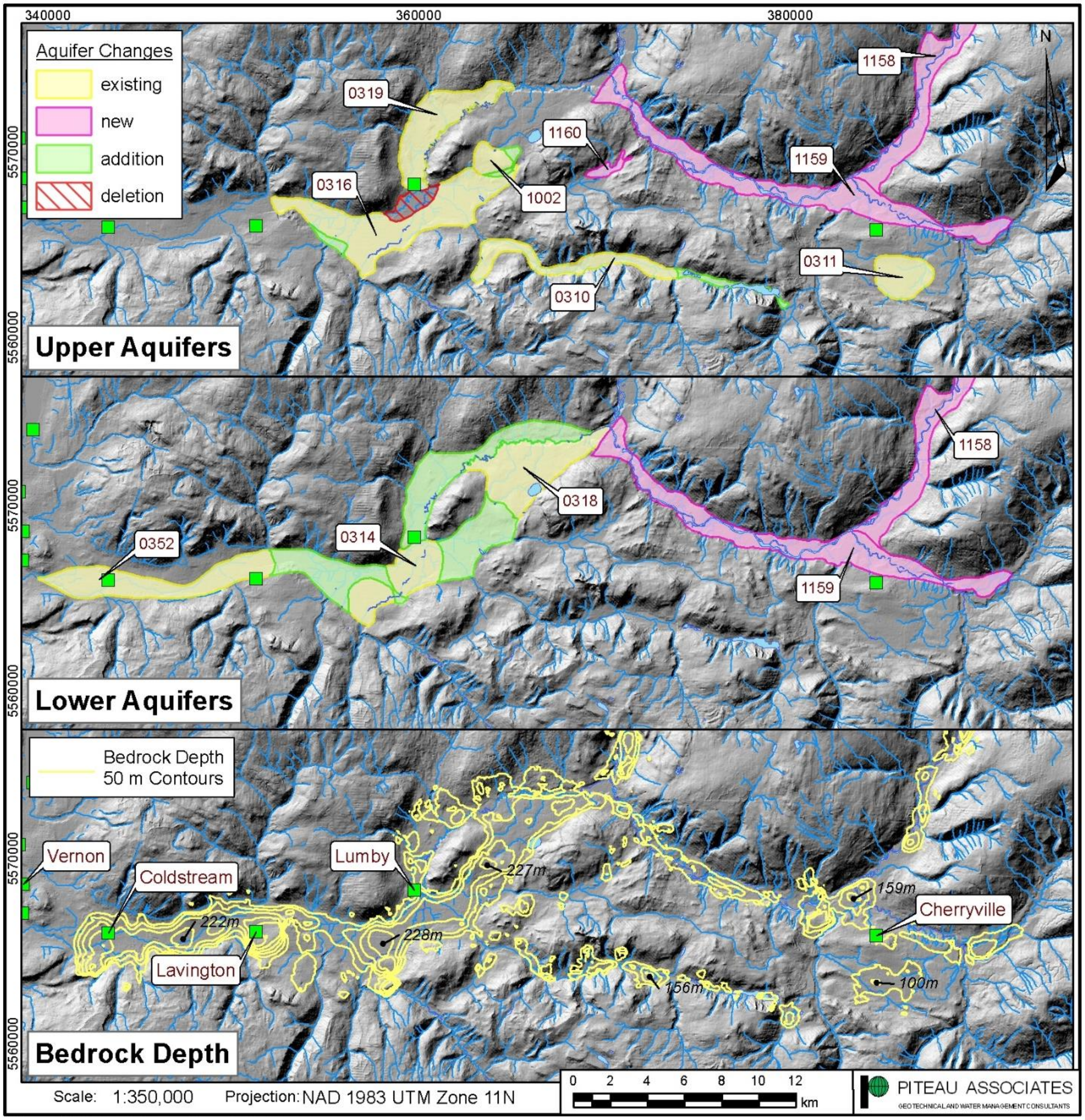

Figure 4: Limits of upper and lower aquifers in the Coldstream to Cherryville area, and contours of depth to bedrock from surface. Note that aquifers 1158 and 1159 are complex aquifers with both locally unconfined and confined aquifers, of mixed age and provenance.

Aquifer 1002 is interpreted to be a kame deposit associated with Fraser glaciation (Figure 5). The kame and kettle lakes to the north (Rawlings Lake) indicate this site was part of a large mass of stagnant ice that developed late in the last glaciation (Figure 6). The inferred direction of groundwater flow and surface water flow within Bessette Creek are opposite to the regional ice flow direction (Figure 6). These features contributed to the formation of Coldstream Lake, a late glacial ice-impounded lake, which filled the Coldstream Valley from Vernon to Lumby (Fulton, 1975).

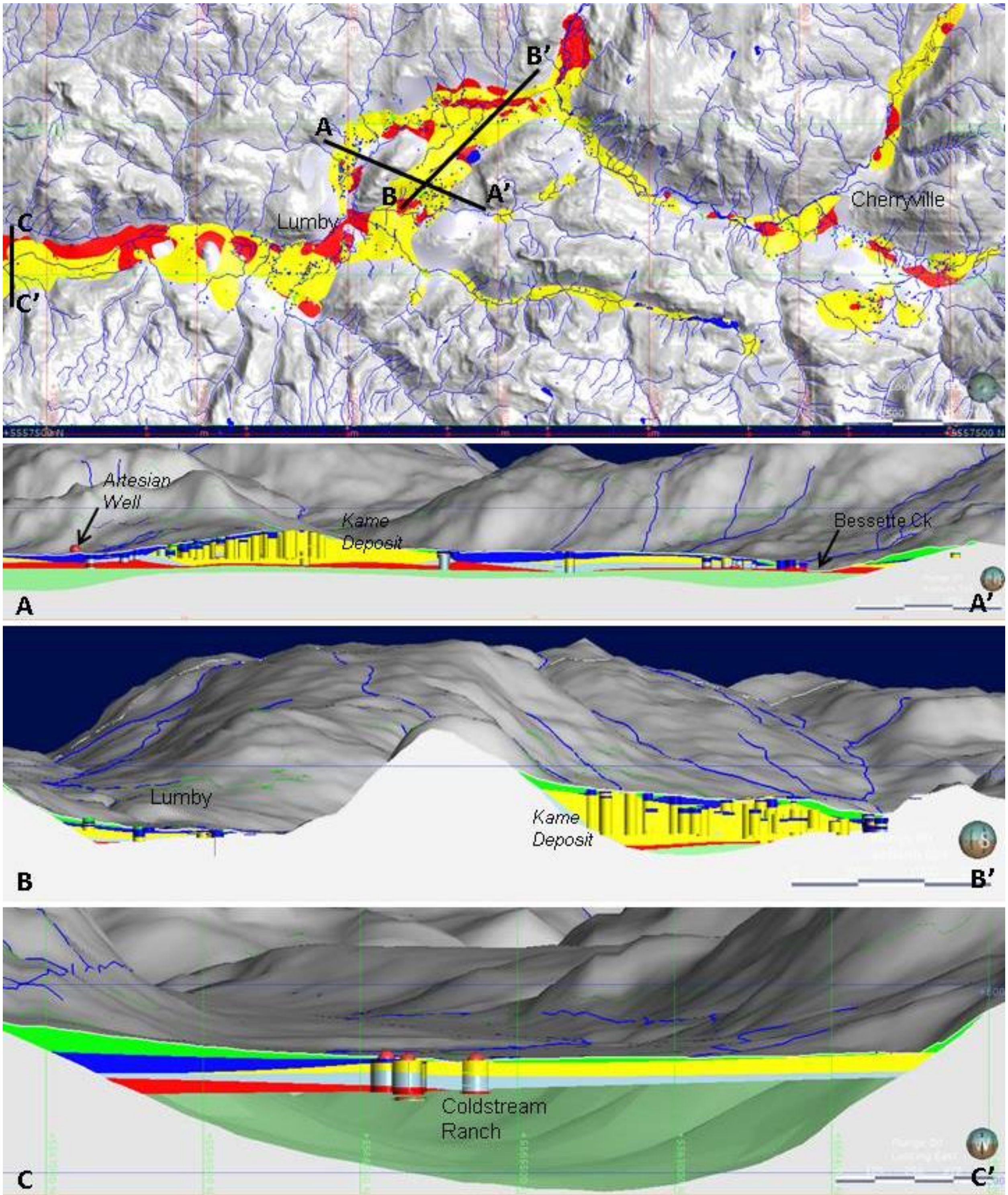

Figure 5: Plan view of the Coldstream Valley aquifers, including the upper aquifers (yellow), and lower aquifer (red and green). Section A-A' is a north-south oriented section (looking west) through Aquifer 1002, north to Aquifer 0318 below Bessette Creek. Section B-B' is an east-west section through Bessette Creek north of Lumby showing Aquifer 1002. Section C-C' is a north-south section through the Coldstream Ranch area showing the flowing artesian well. Unsaturated sand and gravel cover is shown in green.

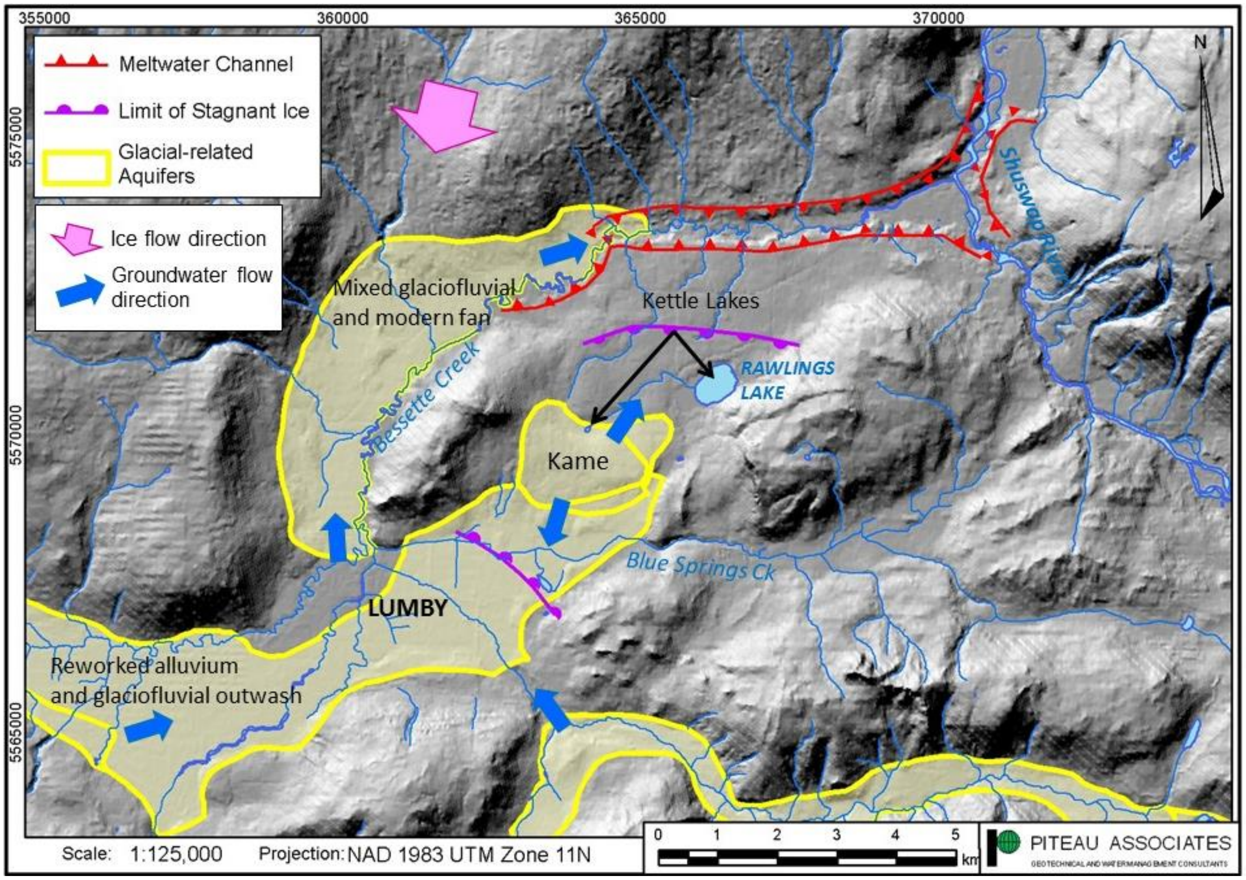

Figure 6: Plan view of glacial-related aquifers and major glacial features originating from the last (Fraser) glaciation in the Lumby area. Note the current opposing groundwater (and surface water) flow direction in relation to the regional ice flow direction during the last glaciation.

The Lower Cherryville Aquifer (1159) is a significant aquifer which has been mapped underneath the Shuswap River between Shuswap Falls and Cherryville. This aquifer is a complex mix of sand and gravel of varying origins (colluvium and alluvium). There is likely a strong hydraulic connection between this aquifer and the river as groundwater levels are close to ground surface. The aquifer appears to be a composite of shallow unconfined recent deposits and deeper portions confined by till, kame and mixed colluvium along the valley margins. Scouring during the Fraser glaciation likely created significant local hydraulic connections between the river and both shallow unconfined and deeper confined portions of the aquifer.

The Sugar Lake Aquifer (1158) has been mapped along the Shuswap River between Cherryville and Sugar Lake. This aquifer is fully connected with Aquifer 1159, and is similar in composition and geometry (a semi-continuous mix of alluvium and fan material). Despite the similarities, it resides in a significant tributary valley, and so was provided a unique aquifer number for management purposes. The aquifer may be confined by kame terraces and till along the valley margins. The aquifer is deeper adjacent to Sugar Lake, although this may be a local aquifer that is distinct from the shallower material, which is drained. Insufficient information is currently available to distinguish between the two.

The Bear Valley Aquifer (1160) has been delineated along Highway 6 in the highlands east of Lumby. This aquifer is a thin accumulation of sand and gravel below clay, silt and till. This aquifer has limited recharge and limited usage, primarily for domestic and irrigation purposes.

4.3 Tappen

Three aquifers are currently defined in the Tappen area including

- Gleneden Aquifer (0100),
- Sunnybrae Aquifer (0231), and
- Tappen Aquifer (0232).

Outlines of aquifers and modifications made to existing aquifer boundaries are illustrated in Figure 7. A summary of the age and hydraulic connectivity relationships between neighbouring or overlapping aquifers in this area is presented in Table II.

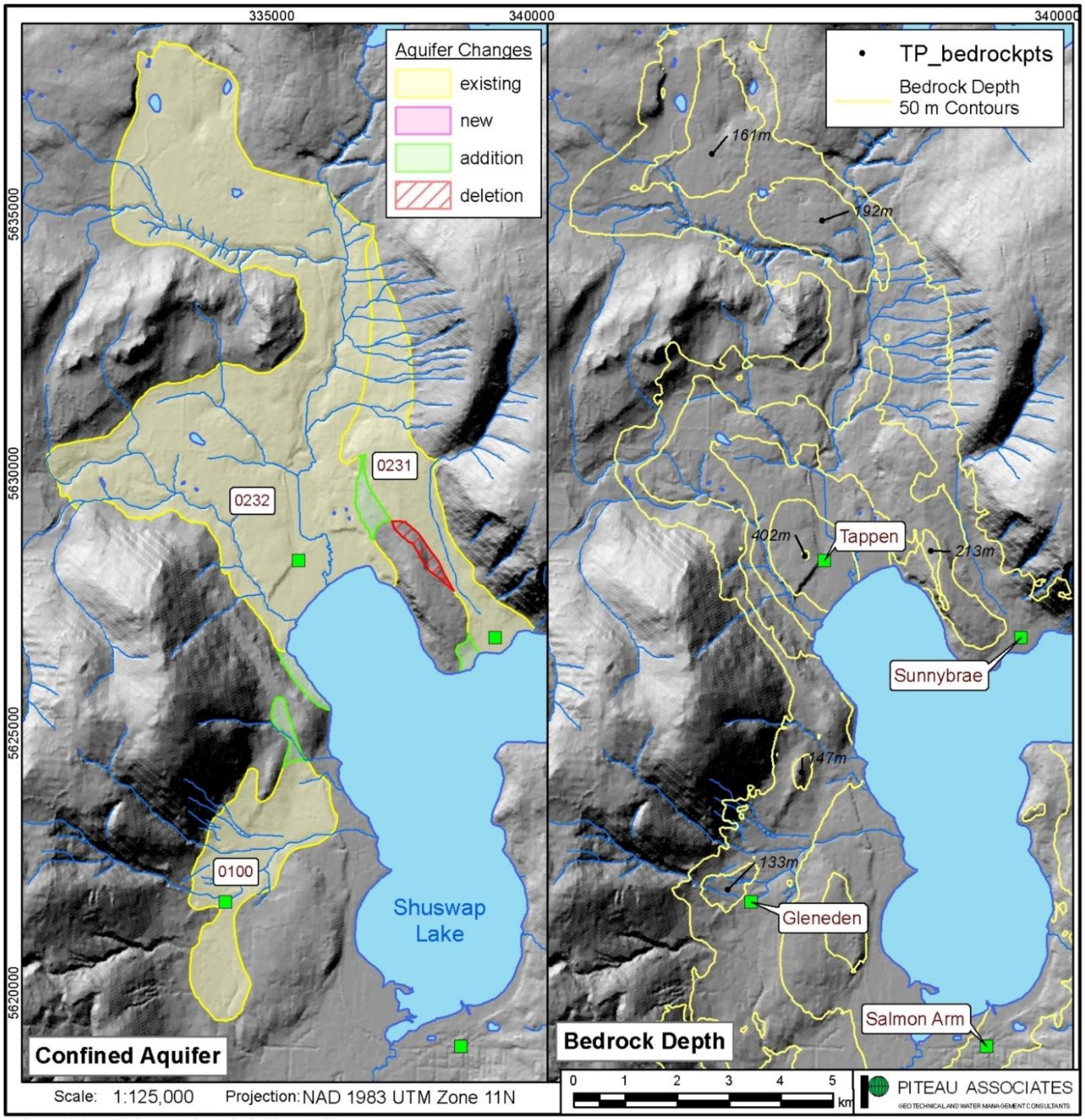

Figure 7: Limits of Tappen (0232), Sunnybrae (0231) and Gleneden (0100) aquifers and contours of depth to bedrock from surface in the Shuswap Lake region.

The Gleneden Aquifer (0100) was extended north to include several additional shallow wells completed within the aquifer. The geology of the aquifer is comprised of a gravel unit interpreted to be colluvium deposited at the bedrock contact. The aquifer is confined by a mix of clay, silty clay to sand and diamicton (clay and gravel) that appears to be a mix of glacial till and glacial-lacustrine sediments. This unit is overlain by a small alluvial fan along Syphon Creek below the steeper bedrock slopes.

The Tappen Aquifer (0232) was extended south along the west shoreline of Shuswap Lake to include additional wells. The contact of this aquifer with the Sunnybrae aquifer was expanded east of Tappen to reflect the revised shape of the bedrock surface. The Sunnybrae Aquifer was trimmed in the same area for the same reason. The Tappen and Sunnybrae Aquifers may be hydraulically connected in the north, however they remain separated in part due to subtle differences in geometry and geology (Figure 8).

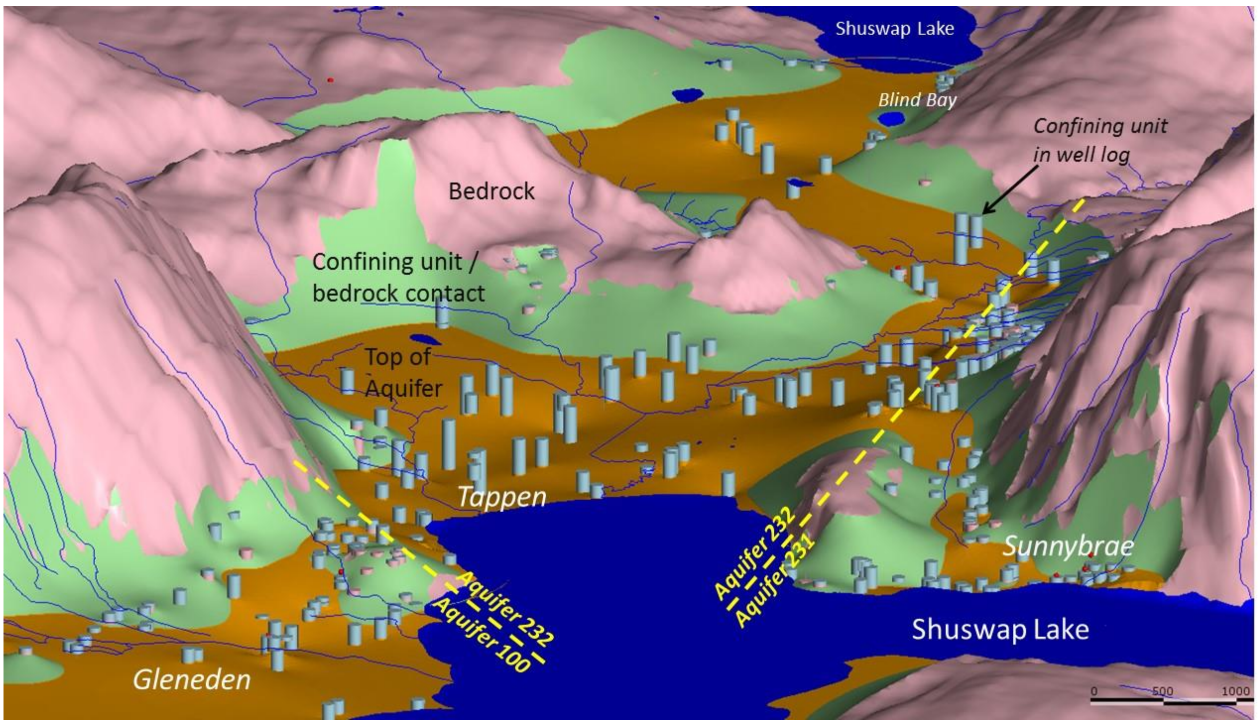

Figure 8: Oblique 3D view of the Tappen, Gleneden and Sunnybrae aquifers, looking north-northeast towards the northwest arm of Shuswap Lake, from Salmon Arm.

5. DATA GAPS AND UNCERTAINTY

There is a significant amount of data available for the Study Area. However, numerous assumptions were incorporated in the completion of this body of work. There is a level of uncertainty in the resulting conceptual hydrogeological model which cannot be quantified as a result of inconsistent quality in the reporting of geology in borehole data, spatial data gaps and the limitations of the software used for 3D interpretation. The scale of the models also limits the resolution of local interpretations and compliance of the model contacts with lithology interpretations from well logs. Many of the geological relationships used are consistent with similar work undertaken by the authors in the north Okanagan (Stewart and Allard, 2017). As more information becomes available, this work should be updated.

The distribution of wells defining the upper and lower limits of aquifers is plotted in Figure 9 (Upper Salmon River), Figure 10 (Coldstream) and Figure 11 (Tappen). The greatest uncertainty evident from these figures resides in the lower aquifer units where only scattered deep wells penetrate the subsurface. The deep wells tend to only penetrate the top of the lower aquifer and the underlying stratigraphy extending down to bedrock is rarely determined. Upper aquifers are generally well defined on a regional scale. Local scale hydraulic relationships and sources of recharge or hydraulic connection to the surface are poorly defined in more complex aquifers such as the Lower Cherryville Aquifer (1159), and portions of the Salmon River Aquifer (0097).

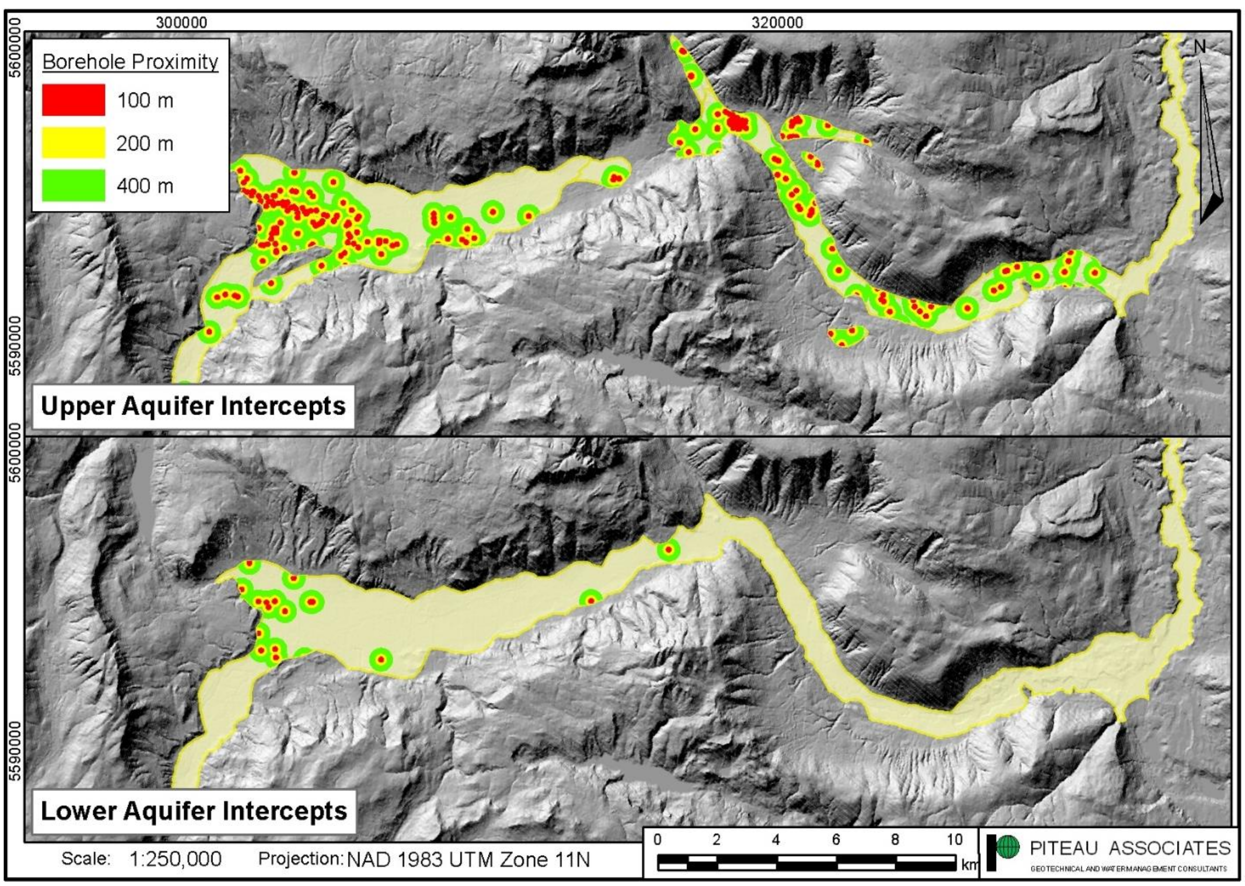

Figure 9: Proximity to lithology information documented in the wells database that was used to model the upper and lower aquifers in the Upper Salmon River basin. Colouration is meant to illustrate where confidence in the model is highest (red) and where nearby data is absent (outside green area).

There is insufficient well coverage to delineate hydraulic connections between the upper and lower aquifers in the Upper Salmon River Basin and the Coldstream-Cherryville area. It is likely that windows through confining layers exist in places, as the intervening unit is thin in some wells, and may be absent in others. In some areas, aquifers appear anomalously thick (east of Westwold), which could indicate intercepts of both upper and lower aquifers, and an absence of a confining layer which is typically present. Aquifer units are not distinguishable by lithology description alone in the absence of some stratigraphic marker, such as an intervening confining layer.

In the absence of age dates, stratigraphic relationships in the area remain uncertain and generally rely on superposition to determine age. The origin of Aquifer 0098 in the Westwold area is not known. This aquifer may comprise lower Bessette age sediments (below pre-Fraser lacustrine deposits), or may be Westwold sediments of pre-Okanagan Center glaciation age (Fulton, 1975) or both. North of Westwold, the deeper confined aquifer is at greater than 100m depth, which is very close to the top of bedrock. Further to the south the deeper confined aquifer is less than 50 m deep, which is significantly higher in the stratigraphic column. Both occurrences appear to underlie only one till sequence which implies Bessette age. In contrast, the presence of Westwold Sediments at or above the valley floor in hillslopes southwest of Westwold infers much older aquifer sediments that could be in contact laterally with younger aquifer sediments. The plateau above Westwold has not been drilled to test the potential for aquifers to be present in the older sediments, and Aquifer 0098 has not been age dated to confirm its relationship to the stratigraphy.

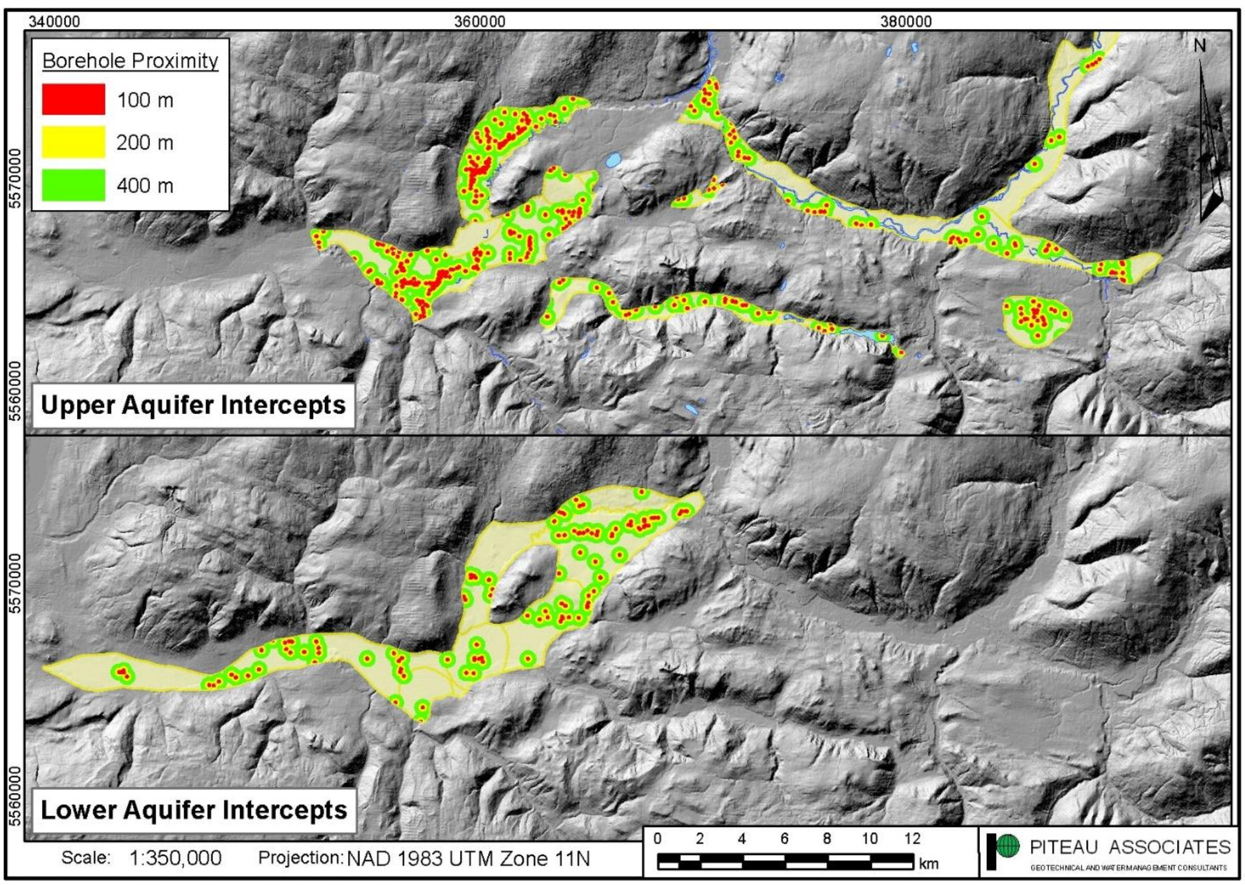

Figure 10: Proximity to lithology information documented in the wells database that was used to model the upper and lower aquifers in the Coldstream-Cherryville region.

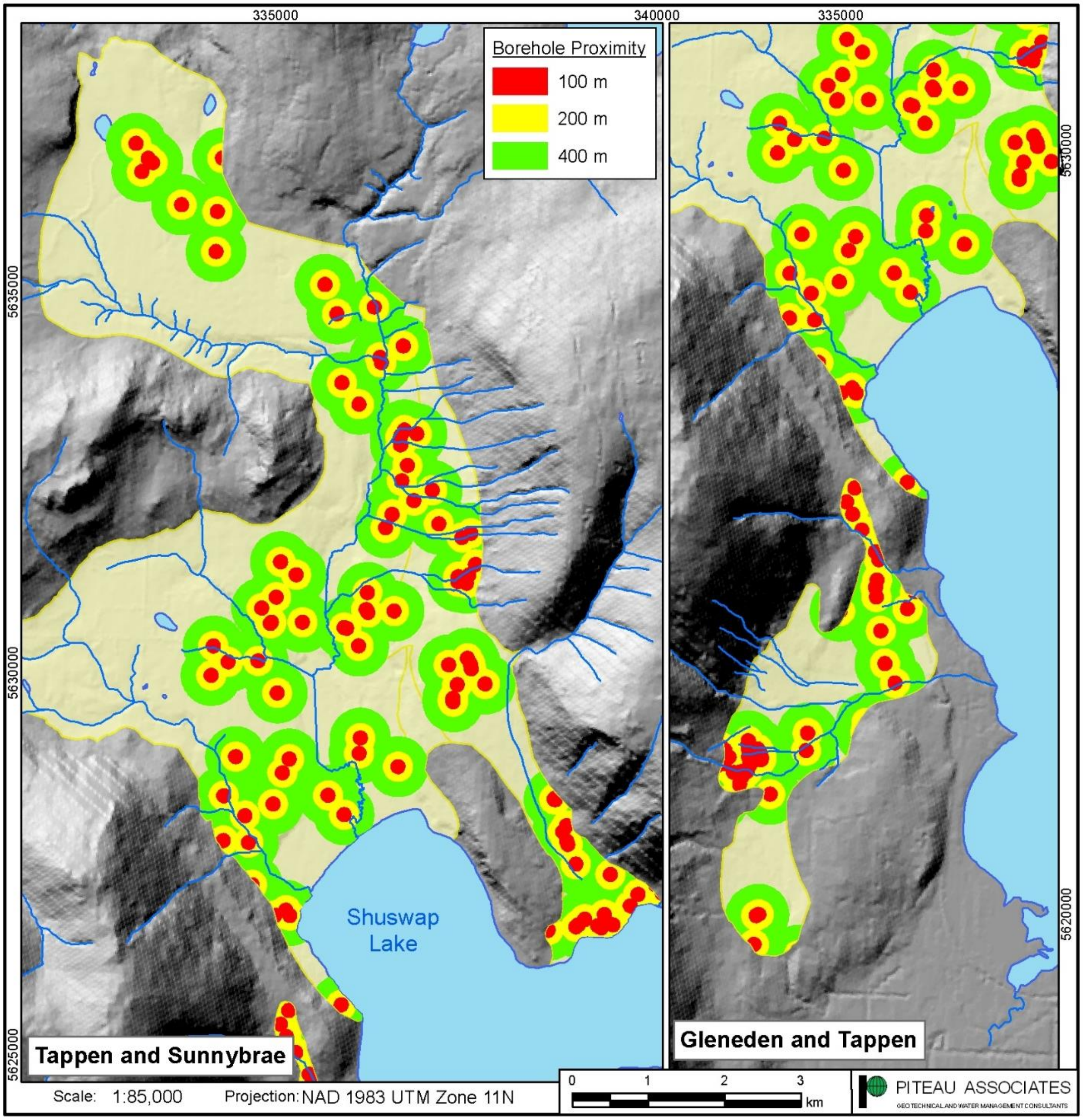

Figure 11: Proximity to lithology information documented in the wells database that was used to model the aquifers in the Tappen area.

6. CONCLUSIONS

Modelling in the Upper Salmon River, Coldstream and Tappen areas has allowed refinement of boundaries and clarification of hydraulic relationships between important local aquifers. Aquifer sheets have been refined based on these results to assist in sustainable management and effective use of groundwater resources in the aquifers.

New aquifers have been defined including:

- Two minor perched aquifers in the Falkland area (1161 and 1162)
- Two extensive, complex aquifers in the Shuswap Falls-Cherryville area (1158 and 1159), and
- One additional minor aquifer in Bear Valley (1160), near Blue Springs Creek, east of Lumby

Old aquifers have been removed including:

- Aquifer 0315 has been combined with Aquifer 0314
- Aquifer 0317 has been combined with Aquifer 0316

Shallow aquifers are the primary source of groundwater utilized by domestic and irrigation wells. These aquifers are well understood due to the density of well data and the resolution of geomorphologic features at surface. Deeper aquifers are utilized by community water suppliers and industrial operations, primarily for their higher yield and reduced risk of contamination from surface. Significant uncertainty exists with respect to the extent and thickness of the deeper aquifers. Furthermore, deeper aquifers may have higher potential for artesian conditions.

Aquifers which are known to host artesian conditions include:

- 0289, 097, 098 and 1161 in the Westwold area,
- 0310, 0314, 0316, 0318, 0319, 0352 and 1159 in the Coldstream area, and
- 0100, 0231 and 0232 in the Tappen area

Artesian conditions have not been identified in the remaining aquifers (0311, 1002, 1158, 1160 and 1162). However, due to their location in steep mountainous terrain, the potential for localized artesian conditions is still present.

The models presented in this report provide a means of estimating potential for new areas of development of deeper groundwater resources, while highlighting the potential risk associated with artesian conditions which are common in aquifers in mountainous terrain.

7. RECOMMENDATIONS

The scale of this study was sufficient to refine aquifer boundaries and improve the understanding of aquifer hydraulics on a regional scale. The results have highlighted the widespread risk of flowing artesian conditions. However, the scale of the study was too regional to provide a clear understanding of why some wells are flowing artesian and some are not, and hence, how to assess the risk for new well construction. The complexity of stratigraphy in the flowing wells at Coldstream Ranch and Westwold could not be captured in a regional groundwater scale geologic model. Additional local scale geologic studies and numerical modelling are recommended to better understand the interaction between stratigraphy and geology in generating local artesian conditions.

Significant uncertainty exists concerning the geometry, stratigraphic relationships and hydraulics of the deepest stratigraphy in the larger valleys near Westwold and Lumby. Age dating of organic matter, microfossils or pollen in the fine-grained material comprising the lower aquifers near Westwold and Lumby would be valuable if samples could be extracted from existing wells, or taken from newly drilled wells.

Exploratory drilling and deep geophysics (seismic) of the deepest portions of valleys are the most effective means of unravelling the structure and composition of overburden in deeper portions of these basins. Leapfrog interpolation of well data suggests that there may be a significant thinning of the confining layer east of Westwold, such that portions of the lower aquifer are interpreted to be unconfined. The existing well database is inconclusive in determining if this geometry is real. If there are significant concerns regarding the risk of the lower aquifer being locally unconfined, it is recommended that a test well be completed in the lower formation. This well would provide information regarding the presence and thickness of the confining layer which is interpreted to be absent in the model, and would provide monitoring of water levels in the lower aquifer. Currently the only observation well in the area is ENV observation well 45; this well appears to be completed in the upper aquifer and does not provide information on the lower aquifer.

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APPENDIX A: AQUIFER WELL COMPLETIONS AND WELL SUMMARY SHEETS

Information on the well-aquifer completions is provided in a separate Excel file. The data included in this appendix has been used to update the BC ENV GWELLS Database. Well Summary sheet information corresponding to the identified well tag numbers (WTN) is accessible through GWELLS database (https://apps.nrs.gov.bc.ca/gwells/) and EcoCat (https://www2.gov.bc.ca/gov/content/environment/research-monitoring-reporting/libraries-publication-catalogues/ecocat).

APPENDIX B: AQUIFER SUMMARY SHEETS AND SHAPEFILES

Aquifer worksheets and outlines associated with this project are available online from the BC ENV and can be accessed through the GWELLS Database (https://apps.nrs.gov.bc.ca/gwells/aquifers) and iMapBC (https://arcmaps.gov.bc.ca/ess/sv/imapbc/).

APPENDIX C: LIST OF DIGITAL PRODUCTS

Leapfrog Viewer Files:

- Coldstream.lfview
- Tappen.lfview
- Westwold.lfview

The Leapfrog Viewer files are provided as separate files to the report. A free Leapfrog viewer can be downloaded from ARANZ Geo Limited:
http://www.leapfrog3d.com/products/leapfrog-viewer/downloads