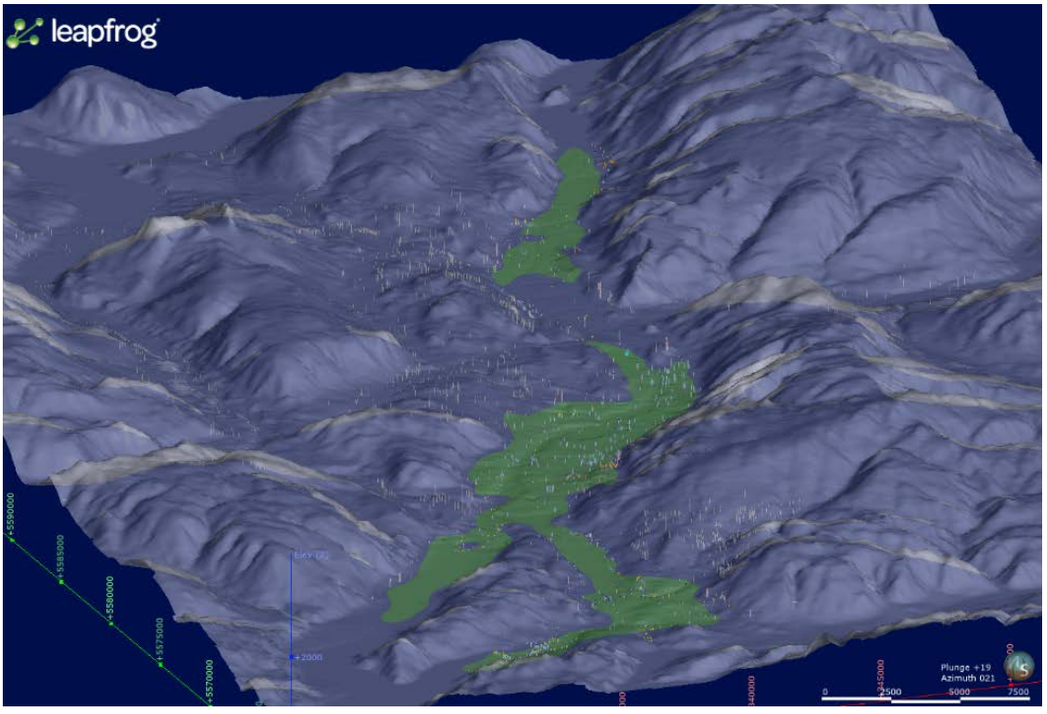
WATER SCIENCE SERIES

North Okanagan Aquifer Mapping & Geologic Modelling
Phase III: Okanagan Valley Aquifer Update

Sadeed Hassan, Martin Stewart and Remi Allard



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Author's Affiliation:
Sadeed Hassan, M.A.Sc., P.Geo., Hydrogeologist*
Martin, J. Stewart, M.Sc., P.Geo., Senior Hydrogeologist*
Remi J.P. Allard, M.Eng., P.Eng, Principal Hydrogeologist*

*Piteau Associates Engineering Ltd.
304-1912 Enterprise Way, Kelowna, BC, V1Y9S9

Cover Photographs:
Digital rendering of the extent of the Upper Confined Aquifer in the Okanagan Valley, looking north; Vernon is at the south end of the image and Mara Lake at the north end;

Acknowledgements

The authors would like to acknowledge the B.C. Ministry of Environment and Climate Change Strategy and the Ministry of Forest, Lands, Natural Resources, and Rural Development, specifically C. Bieber, and D. Thomson, for their assistance in helping formulate this project and conducting ongoing review through to completion.

EXECUTIVE SUMMARY

The updated 3D geologic aquifer Leapfrog™ model results provided herein are a significant refinement to the local aquifer geometry and reflect an improved representation of the conceptual hydrostratigraphy within the North Okanagan Valley Basin. This work builds on the earlier North Okanagan Basin Study report in the B.C. Water Science Series document WSS2017-03. The current update is focused on improving the resolution of aquifers in the Okanagan Valley (Vernon to Mara Lake).

A more precise interpretation of the extent and thickness of the upper confined aquifers, and new subdivisions of Aquifer 1153 and 1155 are presented in this report. The extent of the deep confined aquifer (Aquifer 1155) has been refined and is now mapped in the Okanagan Landing (West Vernon) area. Three subdivisions have been assigned to the deep confined aquifer (Aquifers 1155, 1226 and 1227) and two subdivisions have been assigned to the shallow confined aquifer (Aquifers 1153 and 1225) based on an updated bedrock surface and re-characterizing of the borehole stratigraphy.

Active Provincial Groundwater Observation Wells in the study area have been reassigned to Aquifer 1155 based on the depth of their respective screened intervals. The updated Leapfrog geological model presented in this report includes available groundwater well data, geophysical interpretations and water level information. This provides a robust framework for assessing aquifer utilization, water resource planning and forms a foundation for future updates and groundwater exploration in the area.

CONTENTS

1. BACKGROUND

At the request of the Ministry of Environment and Climate Change Strategy (ENV), Piteau Associates Engineering Ltd. (Piteau) has prepared this technical update to discuss the results of the additional work on the North Okanagan Mapping Project (NOMP). This work builds on the earlier North Okanagan Basin Study report in the BC Water Science Series document WSS2017-03. The current update is focused on improving the resolution of aquifers in the Okanagan Valley, as outlined in Figure 1.

Detailed hydrostratigraphic mapping of the northern Okanagan Basin, extending from Vernon, northwest to Salmon Arm and north to Mara Lake was undertaken by Stewart and Allard (2017). A 3-dimensional (3D) Leapfrog Geo™ (Leapfrog) geological model was developed to study aquifer-aquitard assemblages and aquifer utilization in wells recorded in the BC GWELLS database in the North Okanagan. Several new aquifer subdivisions were defined and regional stratigraphic relationships were explored as part of the geological modelling. A review of previous studies, conceptual hydrogeology, and detailed aquifer descriptions are provided in Stewart and Allard (2017).

1.1 Objectives

The objective of this study was to refine and update the existing Leapfrog model by incorporating new boreholes from the B.C. Groundwater wells database (GWELLS) (B.C. Ministry of Environment, 2019), and a more thorough analysis of water level data to inform the conceptual model. Geophysical interpretations incorporated during the original study were revisited to refine portions of the updated model.

The deliverables for this study include: an updated Leapfrog model (Version 4.4.2), corresponding Leapfrog Viewer files, updated aquifer extent maps and updated aquifer mapping reports for each aquifer.

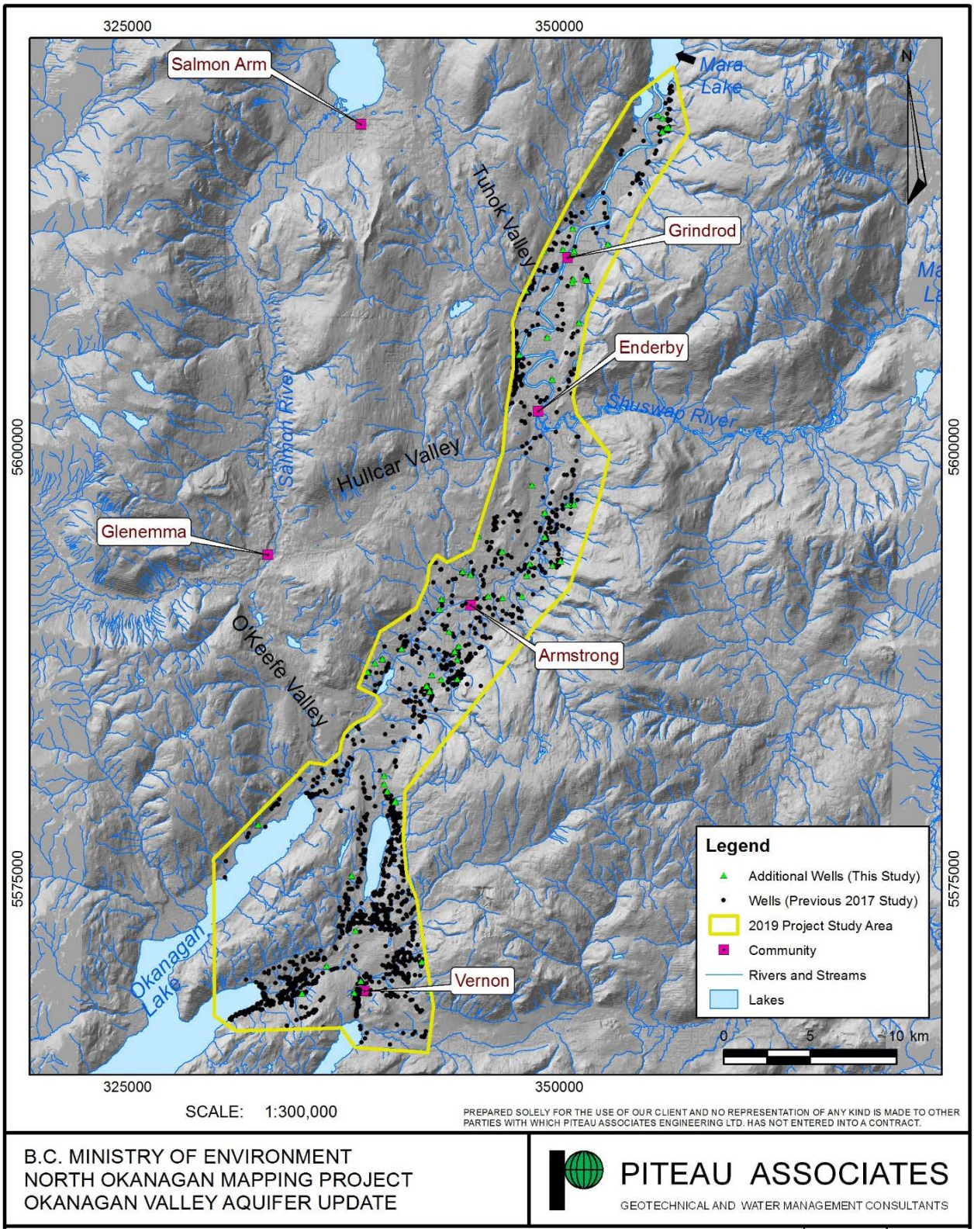

Figure 1: Study area and borehole locations.

2. METHODS

The updated borehole lithological data was categorized based on the aquifer/aquitard naming scheme defined in the initial model (Stewart and Allard, 2017; summarized in Table 2). The bedrock surface was updated using the new borehole information, after which, the model surfaces and volumes were re-evaluated. The lithological divisions and unit contacts were manually refined to fit the geophysical data and maintain consistency with the conceptual geological model of the valley overburden.

Where borehole mapping or geophysical data were not present, control points were inserted into the model to develop the geometry desired. Best efforts were made to incorporate all the data compiled for this assessment. However, due to the variable quality and resolution of well locations and borehole lithology descriptions, the model geology presented here may deviate from some of the well records in the GWELLS database.

2.1 Borehole and Geophysical Data

The previous modelling work (Stewart and Allard, 2017) included all groundwater well records available in the GWELLS database until September 2016. The current study incorporates new water well records available from September 31, 2016 to January 31, 2019. A total of 71 new borehole records were included in the model update, of which three had no lithological information (Appendix A). This new borehole data includes both new groundwater wells completed in the study area and older wells which were not present in the database prior to the original study.

Seismic survey data and interpretations incorporated in the model are summarized in Table 1. Earlier seismic studies have been excluded from the updated model as the quality of the data was insufficient to adequately resolve contacts in the overburden.

Table 1: Summary of Geophysical Seismic Sections in the North Okanagan Valley.

Study	Line Reference or Name	# of Survey Lines	Included in Current Update
MacAulay & Hobson (1972)	Unknown	5	No
Lundberg (1971)	Line 1, Line 2, Line 3	3	No
Pullan et al. (1992)	GSC Line: 100, 200, 300, 400, 500, 700	6	Yes
Vanderburgh (1993)	SFU Line: 100, 110b, 200, 300, 400, 500, 700, 800, 900, 1000, 1200, 1300	12	Yes
Nichol et al. (2015)	Line 1 (Lansdowne Road and Powerhouse Road)	1	Yes

3. UPDATED AQUIFER MODEL

The aquifers of interest included in this model are summarized in Table 2. In most areas, the extents of the revised aquifers are generally consistent with the original model, except for the following new proposed aquifer modifications:

- Deep Okanagan Valley Aquifer (1155) separated into three aquifers (Table 2 and Appendix B), and
- Lower Shuswap River Valley confined aquifer (Aquifer 1153) separated into two new aquifers (Table 2 and Appendix B).

The seismic data is consistent with the horizontal nature and lateral continuity of the aquifer contacts. The distribution of the lowermost confined units are generally constrained by the interpreted geometry of the bedrock topography. Updated aquifer classifications and new ENV aquifer numbers are presented in Table 2. The updated aquifer extent maps and the aquifer mapping reports are provided in Appendix B.

3.1 Lower Shuswap River Upper Confined Aquifer 1153 New Aquifer Subdivision

Aquifer 1153 was previously mapped to be continuous along the length of the valley from Okanagan Lake to Mara Lake. This unit is notably absent in wells WTN 85488, WTN 24159 and WTN 55868 and is interpreted to pinch out below Enderby in the current model (Figure 2). The geological model, when taken in context of the water level data and the bedrock surface, is enough to warrant subdivision of Aquifer 1153 into an upper confined aquifer between Enderby and Mara Lake (new Aquifer 1225, Upper Confined Spallumcheen Aquifer), and a second upper confined aquifer extending from south of Enderby to Vernon (existing Aquifer 1153) [summarized in Table 2]. Aquifer 1153 is interpreted to be hydraulically and hydrostratigraphically connected with Aquifer 1151 (Swan Lake Unconfined). It is also in contact with, and is recharged by, Aquifers 1150 (O'Keefe Basal), 356 (Deep Creek), and 353 (Eagle Rock Unconfined). The upper confined aquifer in the Okanagan Valley is pinched out by a thick silt and clay aquitard where the Shuswap River converges with the main Okanagan Valley, separating it into two aquifers north and south of Enderby (Figure 2). The updated aquifer extent maps and the aquifer mapping reports are provided in Appendix B.

The upper confined aquifer units around the Vernon area (Aquifers 347, 348, and 1154) have been adjusted to conform to the revised bedrock profile and to the conceptual model. However, the aquifer extents have remained similar to the original model.

3.2 Deep Okanagan Confined Aquifer 1155 and New Aquifer Subdivisions

The deep (75 m to 340 m depth) confined Okanagan Valley Aquifer (1155) has been previously mapped as one aquifer unit extending from north of Okanagan Lake to Mara Lake. Based on the updated model, a deep confined aquifer is present in the Okanagan Landing area, West of Vernon and Okanagan Lake. This unit has been assigned to a new aquifer number 1227. The depth of this aquifer is comparable to aquifer 1155 to the north. However, stratigraphically, the aquifer resides on the overburden-bedrock contact like aquifer 1156. It is unclear which of these aquifers it is genetically related to, but there may be hydraulic connections with either unit which have not been identified. The model updates also infer that the existing deep confined aquifer (1155) is absent in the area immediately south of Enderby (Figure 2). The borehole geology, relatively higher bedrock surface in the area and water level gradients in the aquifer, all suggest that two separate deep Okanagan confined aquifers are present. The deep confined aquifer extending from north of Swan Lake to Enderby has been assigned to the existing Aquifer 1155. The deep confined aquifer between Enderby and Mara Lake is assigned to new Aquifer

1226 (Table 2). The geometry of the bedrock surface in the model truncates the deep confined aquifers. This does not preclude the possibility that these aquifers may be stratigraphically related and could be partially or fully contiguous. Insufficient data exists in the immediate area of Enderby to fully define these relationships.

3.3 Basal Okanagan Aquifer 1156

The extent of the basal Okanagan aquifer has not changed significantly with the model update. This aquifer is present in the deepest parts of the valley and the footprint is controlled by the bedrock topography below the valley fill. Few boreholes penetrate the basal aquifer unit and therefore the extent and geometry of the unit is inferred based on the conceptual model of valley fill and interpreted bedrock topography.

3.4 Unconfined Aquifers

Unconfined aquifers in the Okanagan Valley comprise complex interbedded glaciofluvial sediments (Fraser age kame-terrace and deltaic deposits) along the valley margin and modern reworked alluvium along the valley floor. The scale of the model is insufficient to fully capture the localized continuity and character of these shallow and often discontinuous aquifers in the Okanagan Valley. Thus, these units have been grouped together into a single hydrostratigraphic unit in the model. This aquifer assemblage is subdivided into 6 spatially unique aquifers for management purposes, which remain unchanged from the original study (Stewart and Allard, 2017).

Table 2: Revised aquifer assemblage based on the current model update.*

LEAPFROG Unit	ENV Aquifer #	Aquifer Name	Location
OR0	111	Okanagan Valley Unconfined	Lower Shuswap River Valley
		Fortune Creek	NE of Armstrong
	1151	Swan Lake Unconfined	Just north of Vernon to north of Swan Lake
	1152	Vernon Unconfined	Northeast of Vernon along BX Creek
	346	South Vernon Unconfined	Kalamalka Lake to Vernon
	353	Eagle Rock Unconfined	SE of Armstrong
	114	Mara Lake Unconfined	South of Mara Lake
OR1	**1153**	**Spallumcheen Confined**	**Between Okanagan Lake and Enderby**
	348	Swan Lake Confined	Just north of Vernon to north of Swan Lake
	1154	Vernon Confined	Northeast of Vernon along BX Creek
	347	South Vernon Confined	Vernon to Okanagan Lake
	1225	Lower Shuswap River Confined	Enderby to Mara Lake
OR2	1226	Lower Shuswap Deep Confined	North of Enderby to Mara Lake
	1155	**Spallumcheen Deep Confined**	**North of Swan Lake to South of Enderby**
	1227	Okanagan Landing Deep Confined	West Vernon and Okanagan Lake
OR3	1156	Basal Okanagan Valley	Lower Shuswap River Valley

*Modified from Stewart and Allard (2017)

Note: Aquifers highlighted in yellow are new aquifer subdivisions presented in this report, those in '**bold'** are inherited from existing aquifer descriptions, but modified in this model update, the remaining aquifers remain unchanged. The 'Leapfrog Unit' designation refers to a vertical (hydrostratigraphic) aquifer subdivision where: Unit 0 is an unconfined aquifer, Unit 1 is an upper confined aquifer, Unit 2 is a deep confined aquifer, and Unit 3 is basal confined aquifer. This unit is also subdivided geographical by a location code (assemblage) where: OR is the Okanagan Valley. Aquifer mapping reports for new and modified aquifers are provided in Appendix B.

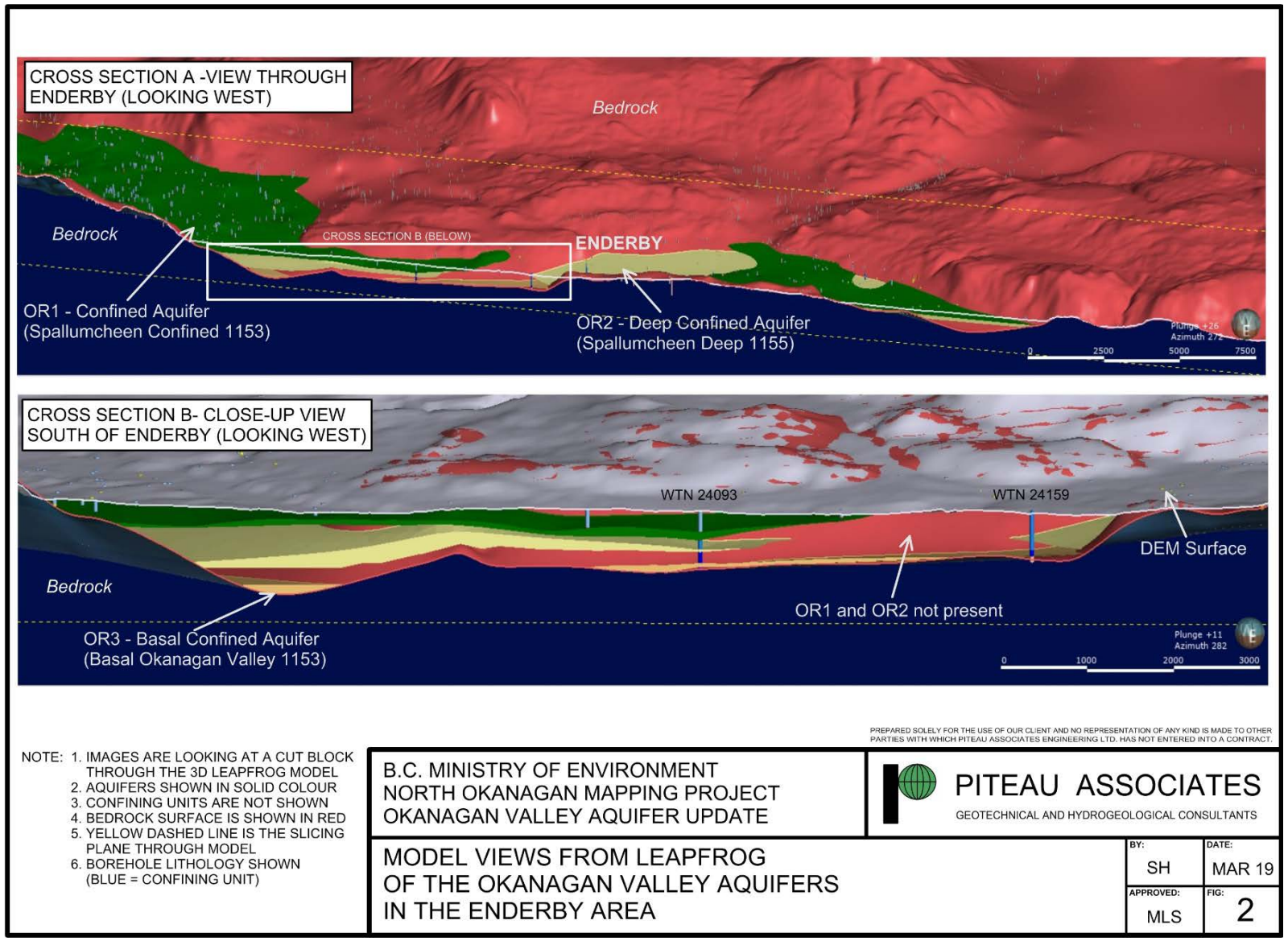

Figure 2: Model views from Leapfrog of the Okanagan Valley aquifers in the Enderby area.

Note: Refer to Table 2 for the revised aquifer assemblage, Leapfrog units and corresponding ENV aquifer numbers

4. PROVINCIAL GROUNDWATER OBSERVATION WELLS

There are currently three active Provincial Groundwater Observation Wells (GW Observation Wells) in the North Okanagan Valley (Figure 3), including:

- -Well 117 (Well ID 24062)
- -Well 118 (Well ID 24080)
- -Well 122 (Well ID 24093)

The original aquifer study assigned these observation wells to Aquifer 1156 (Basal Okanagan Valley) based on the lowest aquifer elevation intercepted in the holes. However, the screened intervals for all of these observation wells are positioned in Aquifer 1155 (Spallumcheen Deep Confined Aquifer 1155). One other GW Observation Well exists in the area studied, which actively monitors the shallow Eagle Rock unconfined aquifer (Well 180- Aquifer 353). Several other abandoned or currently unused GW Observation Wells are known in the area, the status of which should be revaluated in the context of this model update (Figure 3).

The detailed lithology logged at the GW Observation Wells are key control points in the current model, particularly for deeper stratigraphic interpretations. Geophysical logs (Natural Gamma, Spontaneous Potential and Resistivity) for select GW Observation Wells were also reviewed to validate the lithology recorded on the logs with the geophysical signal. This was done in hopes that a clear geophysical signal could be identified for deeper aquifer and/or aquitard units which would be used for correlation purposes across the basin. However, in all cases the lithological logs are also available for all wells that have geophysical logs. Therefore the geophysical well logs do not provide additional stratigraphic correlation value to the model and simply provide another proxy for determining lithological contacts. Due to the interbedded nature of the main aquifer units, whereby the sands are interbedded with finer grained (silts and clays) material, the geophysical logs are not the best stratigraphic correlative tools as they do not provide a very clear identification of aquifer materials. Therefore, the geophysical borehole logs are not included in the model as stratigraphic correlative tools; only the detailed well lithological information is used for correlation.

5. WATER LEVEL DATA

Water level data were compiled from water levels reported on borehole records, which are typically collected soon after drilling or after a pumping test, and do not necessarily represent static water level conditions. Significant variance in shallow water levels may exist due to seasonal fluctuations in aquifer levels, stresses due to pumping or drilling activity, and/or local hydraulic gradients resulting in errors in regional interpolation of a water table. However, the water level data analyzed herein appears sufficient to provide some basin-scale understanding of horizontal hydraulic gradients in the aquifers.

Water levels were used to generate a regional water table in Leapfrog which extends across the area studied (Figure 4). Generally, water levels mimic topography, particularly near the valley margin where aquifer recharge is dominated by seepage from mountainous bedrock catchments. Strong groundwater gradients indicate flow is towards the valley center from the valley walls, and in cases of strong confinement, gradients indicate upward flow from mountain block recharge deep below the valley overburden. Vertical gradients in confined units can generate significant artesian conditions, including, but not limited to:

- locally confined portions of the Swan Lake aquifer (348), Vernon confined (1154) and South Vernon confined (347) and within some unconfined aquifers in south-central Vernon

- within the Spallumcheen confined (Aquifer 1153) western margin of the Eagle Rock aquifer, southeast of Armstrong

The area around Vernon shows higher water levels as it is topographically at a higher elevation than much of the Okanagan valley to the north. The Vernon and the Coldstream area receive a significant amount of recharge from highlands to the east above BX Creek which may contribute to artesian conditions present in the upper confined units. Similarly, southeast of Armstrong, the upper confined aquifer (1153) is noted to have higher water levels and local artesian conditions resulting from recharge to the Eagle Rock unconfined aquifer which sits at a higher elevation above the valley floor along the margin of the valley.

In contrast, the regional groundwater gradient along the length of the valley between Okanagan Lake and Mara Lake is relatively flat. Water levels along the main axis of the valley range from 340 to 360 meters above sea level (m-ASL). Based on these levels, a regional groundwater divide is interpreted to exist in roughly the same area as the surface water divide separating the Okanagan Lake and Shuswap catchments between Armstrong and Enderby. The surface water divide is immediately north of Armstrong where Deep Creek flows north to south and Fortune Creek flows south to north.

Limited data and the inferred large scale of the deep groundwater flow systems limit the ability to fully resolve deep groundwater flow gradients. Based on water levels measured in the provincial GW Observation Wells (Well 122, 118 and 117), groundwater flow is towards the north between Well 118 and Well 122, and towards the south between Well 118 and Well 117. This is broadly consistent with the recognized surface water divide in the area. The main source of groundwater recharge to the deeper confined aquifers is inferred to be from mountain block recharge and local leakage through alluvial fans along the valley margins (e.g. Aquifer 353), or flow along the weathered bedrock and overburden contact. In some cases, unconfined aquifers along the valley margin may be inter-layered and thus hydraulically connected to deeper confined units. This geometry can generate significant local artesian conditions or efficient hydraulic connection for shallow water to reach the deeper aquifers.

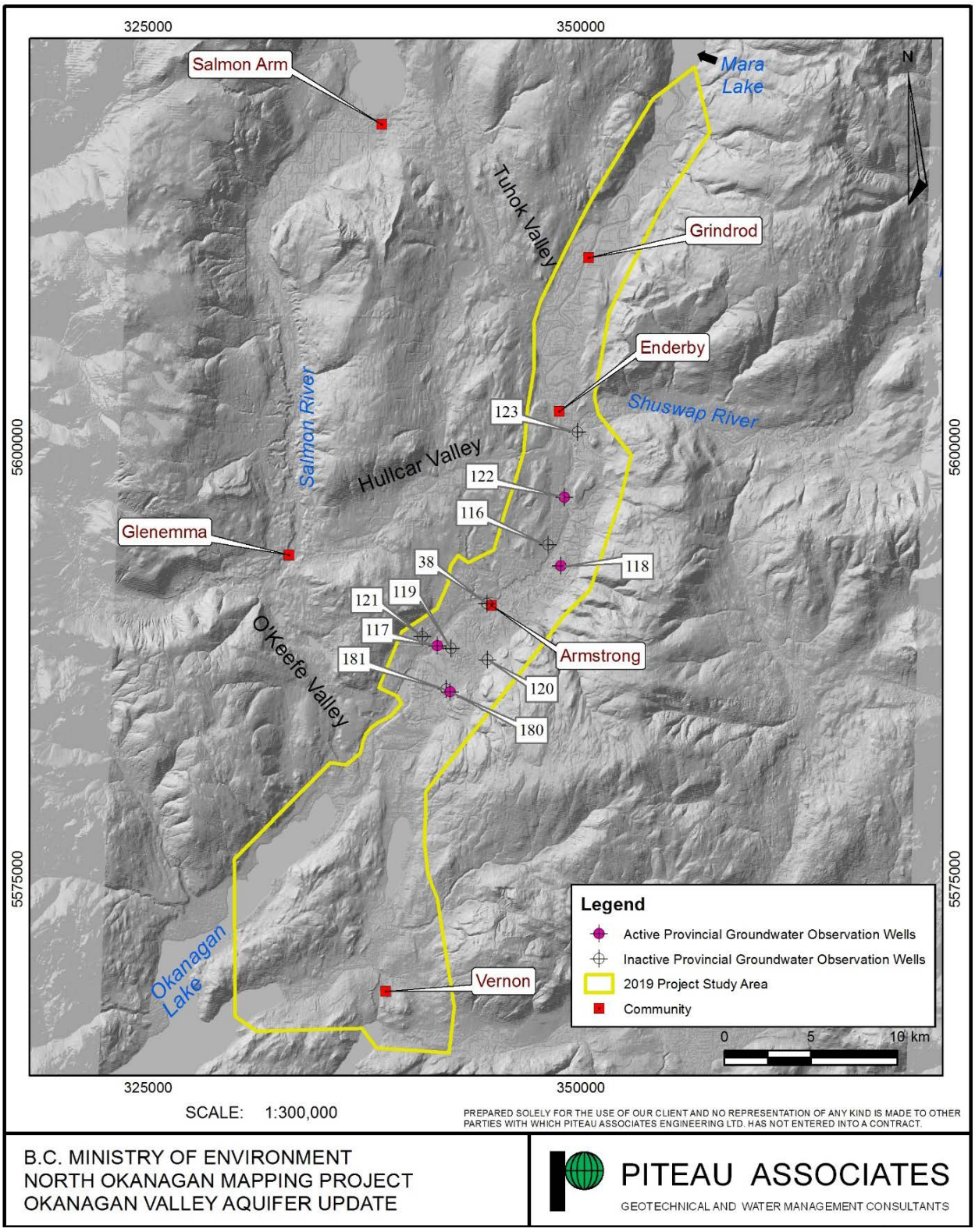

Figure 3: Provincial Groundwater Observation Wells.

Note: Active Well 117, 118 and 122 are completed in aquifer 1155 (Spallumcheen Deep Confined). Active well 180 is completed within aquifer 353 (Eagle Rock Unconfined).

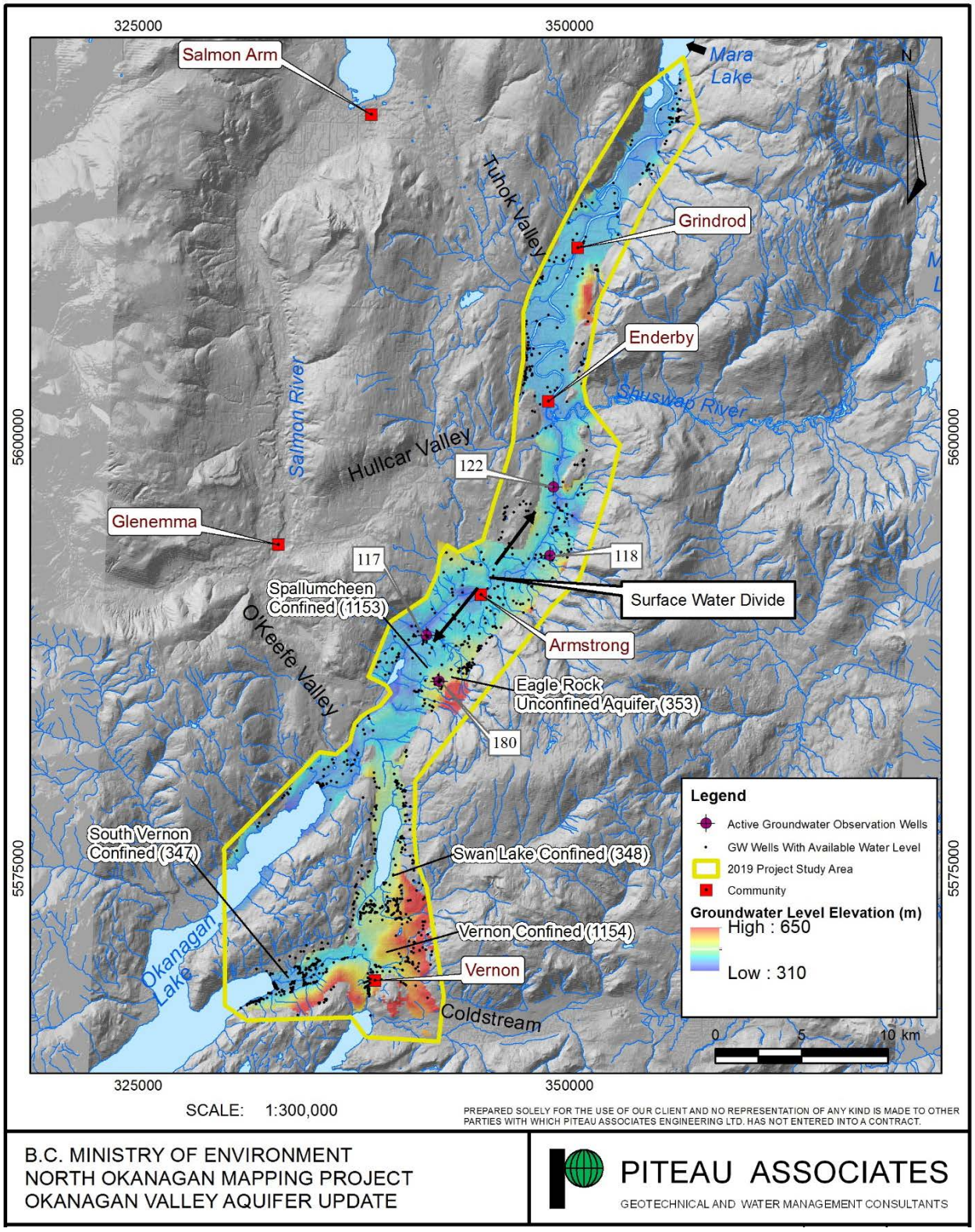

Figure 4: Groundwater level elevation.

6. RECOMMENDATIONS

The current Leapfrog model provides a good understanding of the distribution of hydrostratigraphic units in the area studied at the basin scale. Recommendations for further enhancing the overall understanding of the hydrogeology of the North Okanagan Valley include:

- A study of groundwater geochemistry and isotopic signature of aquifers defined in the mapping program will aid in understanding hydraulic connection between those aquifers, as well as recharge and discharge pathways. An initial assessment of existing groundwater chemistry data from groundwater wells can be used to scope out the general character of the aquifers, and aid in developing a full regional sampling program that would be required to fully understand groundwater flow pathways;
- Once available, LiDAR mapping currently being completed in the Okanagan Valley by the Okanagan Basin Water Board and ENV can be incorporated into the Leapfrog model. This will better depict the detailed topography over the area and may help resolve the geometry and geologic history of the relatively shallow aquifers in the area;
- New provincial groundwater observation wells should be completed in the upper confined aquifers (1153, 348, 1154, 347 and 1225) at key locations in the valley. Despite these aquifers being the most heavily utilized in the region, the monitoring of water levels in these aquifers is sparse or absent. It is also recommended that:
    - Status of inactive or abandoned GW Observation wells should be confirmed to assess the potential to reactivate them as observation wells, a significant cost savings to drilling new wells.
    - Existing industrial users in the valley (e.g. Tolko Mill in Armstrong) could be approached to provide access to monitoring wells for use by the Province.
    - Areas recommended for new deep observation wells to be drilled include: between Enderby and Mara Lake (Aquifer 1226) to fill gaps in understanding deeper stratigraphy and hydrogeology, and near Vernon (Aquifer 1227) to assess deep groundwater conditions in an area of complex hydrogeology and high groundwater demand.
- In conjunction with installation of new monitoring wells, a rigorous survey of aquifer levels should be conducted in as many wells as possible across the region to establish seasonal snapshots of flow direction. All wells included in water level measurements should be surveyed to establish location and elevation. Due to the limitations of hand-held GPS instruments, all surveys should be completed using traditional survey or differential GPS methods;
- An assessment of the regional water balance for the valley, based on the updated conceptual hydrostratigraphic model is critical to determine usage relative to recharge and discharge, and to establish lateral flow contribution between the various aquifers; and,
- A 3D numerical groundwater model is recommended for the Okanagan Valley based on the updated Leapfrog model. Completion of the water level and geochemistry studies mentioned above are critical precursors for the establishment of a numerical model. The objective of such a model would be to validate the water balance and provide a robust tool for groundwater management and risk analysis.

7. SIGNATURES

Piteau Associates Ltd. has exercised reasonable skill, care and diligence in obtaining, reviewing, analyzing and interpreting the information acquired during this study, but makes no guarantees or warranties, expressed or implied, as to the completeness of the information contained in this report. Recommendations provided in this report are based on the information available at the time of this assessment.

In preparing the recommendations contained herein, Piteau Associates Ltd. has relied on information and interpretations provided by others. Piteau Associates Ltd. is not responsible for any errors or omissions in this information. This report is comprised of text, tables, figures, photos and appendices, and all components must be read and interpreted in the context of the whole report. The report has been prepared for the use of B.C. Ministry of Environment and Climate Change Strategy and no representation of any kind is made to any other party.

Respectfully submitted,

PITEAU ASSOCIATES ENGINEERING LTD.

Sadeed Hassan, M.A.Sc., P.Geo.

Hydrogeologist

Martin Stewart, M.Sc., P.Geo.

Senior Hydrogeologist

MARCH 2019.

Remi Allard, M.Eng., P.Eng.

Principal Hydrogeologist

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APPENDIX A: LIST OF NEW WELL RECORDS INCLUDED IN THE MODEL UPDATE

WELL TAG NO.	EASTING	NORTHING	COLLAR ELEVATION	AQUIFER CODE	AQUIFER NO.
169	346182	5591459	366	OR1	1153
987	342197	5589485	353	OR0	111
1419	349323	5595924	353	OR0	111
1421	349211	5592728	406	OR0	111
1679	349018	5594443	363	OR0	111
1700	341350	5570743	507	OR0	1152
2497	343443	5587914	396	OR0	111
2997	340993	5570751	484	OR0	1152
3072	349027	5592854	395	OR0	111
8449	338550	5572910	400	OR1	348
8616	340961	5570754	482	OR0	1152
8627	337822	5573261	395	OR1	348
8661	341535	5571864	500	OR0	1152
9048	340972	5588472	365	OR0	111
9068	339930	5575194	408	OR1	348
9184	337479	5581059	359	OR1	1153
9190	340236	5578735	401	OR1	348
14012	350731	5597245	385	OR0	111
14675	350721	5597037	385	OR0	111
14679	349852	5594358	381	OR0	111
16484	348012	5592985	357	OR0	111
16504	339942	5573240	448	OR0	1152
16521	340145	5570071	451	OR0	1152
16883	340745	5569580	454	OR0	1152
16961	336043	5580906	360	OR1	1153
17350	337835	5570152	380	OR1	1154
17518	345932	5590763	371	OR1	1153
17583	340975	5570128	487	OR0	1152
18058	340446	5578034	405	OR1	348
18089	340248	5579623	409	OR1	348
18182	340725	5570787	477	OR0	1152
18302	337827	5572357	394	OR1	348
18632	340027	5573193	453	OR0	1152
18641	341537	5573224	517	OR0	1152
18725	340197	5573263	469	OR0	1152
18863	337733	5581586	358	OR1	1153
19217	337871	5582051	370	OR1	1153
19218	338037	5581976	365	OR0	111
19345	340141	5577167	396	OR1	348
20225	340076	5576624	399	OR1	348
20315	339215	5573554	398	OR1	348
20581	340245	5569897	448	OR0	1152
20664	345389	5590147	387	OR0	111
20742	339926	5573126	446	OR0	1152
20933	340091	5578701	396	OR1	348
21063	338726	5578580	413	OR1	348
21072	346470	5591153	386	OR1	1153
21211	345214	5590112	376	OR0	111
22199	341169	5588769	369	OR2	1155
23305	338485	5571946	406	OR0	1152
23314	340622	5569868	457	OR0	1152

WELL TAG NO.	EASTING	NORTHING	COLLAR ELEVATION	AQUIFER CODE	AQUIFER NO.
23398	337365	5581009	359	OR1	1153
24060	348122	5594360	382	OR2	1155
24062	341721	5588510	375	OR3	1155
24080	348876	5593141	393	OR3	1155
24093	349072	5597110	371	OR3	1155
24864	336350	5581130	357	OR1	1153
24991	333994	5567992	368	OR2	1227
25214	334308	5568174	358	OR2	1227
25262	334244	5568511	355	OR2	1227
25478	338086	5570557	388	OR0	1152
25671	339586	5586292	352	OR1	1153
25701	338078	5583048	360	OR1	1153
27358	350501	5609315	369	OR1	1225
28781	349955	5612441	361	OR1	1225
28783	349945	5606818	360	OR1	1225
30261	343872	5592352	402	OR1	1153
30775	337138	5581030	366	OR1	1153
30929	349432	5611424	363	OR1	1225
32199	341527	5584418	410	OR1	1153
33228	338507	5572943	400	OR1	348
33323	344039	5592369	395	OR1	1153
33391	339428	5586950	408	OR1	1153
33841	343595	5592194	404	OR1	1153
37158	339249	5572918	402	OR0	1152
37655	337763	5572135	393	OR1	348
38594	338580	5573608	391	OR1	348
38650	344602	5590950	363	OR1	1153
39679	341389	5586282	396	OR2	1155
39792	346288	5590664	379	OR1	1153
39991	332163	5567473	360	OR2	1227
41511	341230	5585243	394	OR1	1153
41994	332511	5567725	354	OR2	1227
42700	337566	5569875	374	OR2	1227
43074	339957	5576208	399	OR1	348
43562	335796	5580738	358	OR1	1153
44509	345679	5591224	365	OR1	1153
44565	341136	5585247	394	OR1	1153
45014	341293	5585328	393	OR1	1153
45104	344831	5592584	382	OR1	1153
45422	344347	5592727	384	OR1	1153
45440	342737	5590334	357	OR1	1153
45535	337083	5581810	382	OR1	1153
45742	339313	5574256	395	OR1	348
47488	341031	5585293	396	OR1	1153
48212	337767	5581708	362	OR1	1153
50243	345041	5592898	397	OR1	1153
50713	341334	5570291	504	OR0	1152
51115	344440	5592655	394	OR1	1153
53228	350204	5607955	373	OR1	1225
53621	345005	5592631	374	OR1	1153
56610	337558	5581293	362	OR1	1153
57780	351340	5610323	374	OR1	1225

WELL TAG NO.	EASTING	NORTHING	COLLAR ELEVATION	AQUIFER CODE	AQUIFER NO.
58139	340145	5572147	437	OR0	1152
58497	339662	5586351	348	OR1	1153
62410	346183	5590291	393	OR1	1153
62415	345872	5590721	370	OR1	1153
62424	339047	5587017	404	OR1	1153
62438	345598	5591966	386	OR1	1153
62502	349892	5607585	360	OR1	1225
62562	339003	5579675	410	OR1	348
63205	338322	5583845	352	OR1	1153
68480	339747	5586936	398	OR1	1153
70115	335637	5579757	349	OR1	1153
70123	335674	5579770	350	OR1	1153
70125	335694	5579786	351	OR1	1153
70127	335634	5579724	349	OR1	1153
70133	335934	5579915	353	OR1	1153
70135	338320	5571142	396	OR0	1152
74440	336528	5580008	363	OR1	1153
76265	350697	5611048	360	OR1	1225
82394	336896	5580493	365	OR1	1153
82439	333008	5578023	343	OR1	1153
82442	345689	5592826	394	OR1	1153
82638	338249	5571100	393	OR0	1152
82929	345614	5592327	392	OR1	1153
82958	350773	5609454	386	OR1	1225
83196	350802	5611058	361	OR1	1225
83738	345488	5592586	388	OR1	1153
84321	335460	5579974	344	OR1	1153
84418	341075	5585257	395	OR1	1153
84959	350262	5607130	392	OR1	1225
84977	350022	5608282	359	OR1	1225
85488	349181	5602704	356	OR2	1226
87403	339922	5572057	430	OR0	1152
99065	349610	5611419	360	OR2	1226
101773	335667	5579838	349	OR1	1153
103993	340696	5572125	448	OR0	1152
104597	335759	5580366	348	OR1	1153
104853	345760	5593073	396	OR1	1153
106770	348763	5595843	380	OR1	1153
106772	350220	5611821	360	OR2	1226
106893	331956	5577438	378	OR1	1153
108681	335713	5579930	349	OR1	1153
109458	339350	5579224	401	OR1	348
111532	342077	5590031	368	OR1	1153
122	344438	5589276	394	OR1	1153
1390	344113	5586529	425	OR00	353
1392	343642	5586561	425	OR00	353
1887	343876	5586660	420	OR00	353
9072	344039	5586696	418	OR00	353
9127	340394	5579083	411	OR0	1151
9171	340381	5579144	410	OR0	1151
9192	340393	5579204	411	OR0	1151

WELL TAG NO.	EASTING	NORTHING	COLLAR ELEVATION	AQUIFER CODE	AQUIFER NO.
13790	351109	5600602	385	OR0	111
14017	344075	5586404	431	OR00	353
14680	347595	5605063	367	OR0	111
15087	344236	5586930	413	OR00	353
15088	344080	5586800	415	OR00	353
15558	342597	5593325	452	OR00	111
17575	351010	5599221	418	OR1	1153
17852	340343	5578972	407	OR0	1151
17909	344101	5586715	418	OR00	353
19997	340375	5579520	418	OR1	348
20168	340342	5579482	415	OR1	348
21426	340532	5578803	433	OR0	1151
21526	341975	5569431	587	OR00	1152
22903	342029	5585859	412	OR00	353
22918	341682	5585256	415	OR00	353
24668	335494	5567233	511	OR00	346
25323	342206	5585670	423	OR00	353
25661	335721	5567300	534	OR00	346
26404	338490	5566489	395	OR0	346
27359	354579	5615767	368	OR00	111
27494	342019	5585115	426	OR00	353
28186	344113	5586494	427	OR00	353
29675	344120	5586754	417	OR00	353
30407	341137	5589077	371	OR1	1153
30575	344088	5586465	428	OR00	353
30864	347480	5603658	363	OR0	111
31264	350212	5596647	369	OR2	1155
32340	342455	5585850	421	OR1	353
32452	336962	5581259	375	OR1	1153
33426	343573	5586425	438	OR00	353
33495	354632	5615523	381	OR00	111
35351	336967	5581180	369	OR1	1153
36469	342714	5593323	449	OR00	111
38622	354513	5615482	371	OR00	111
38865	346299	5593380	392	OR1	1153
40429	347630	5604982	360	OR0	111
40539	350532	5603442	406	OR00	111
41703	351579	5609940	392	OR00	111
41708	351620	5609844	397	OR00	111
42037	349833	5594441	383	OR1	1153
42108	355861	5617711	385	OR00	111
43060	348146	5609044	374	OR0	111
44904	346702	5593202	393	OR1	1153
45408	345974	5590642	384	OR1	1153
51019	340506	5577748	404	OR1	348
51161	354496	5615428	375	OR00	111
53789	342609	5593355	455	OR00	111
57342	344899	5587915	418	OR00	353
59177	344108	5586619	421	OR00	353
62371	342562	5585952	415	OR00	353
62412	350117	5593527	406	OR1	1153

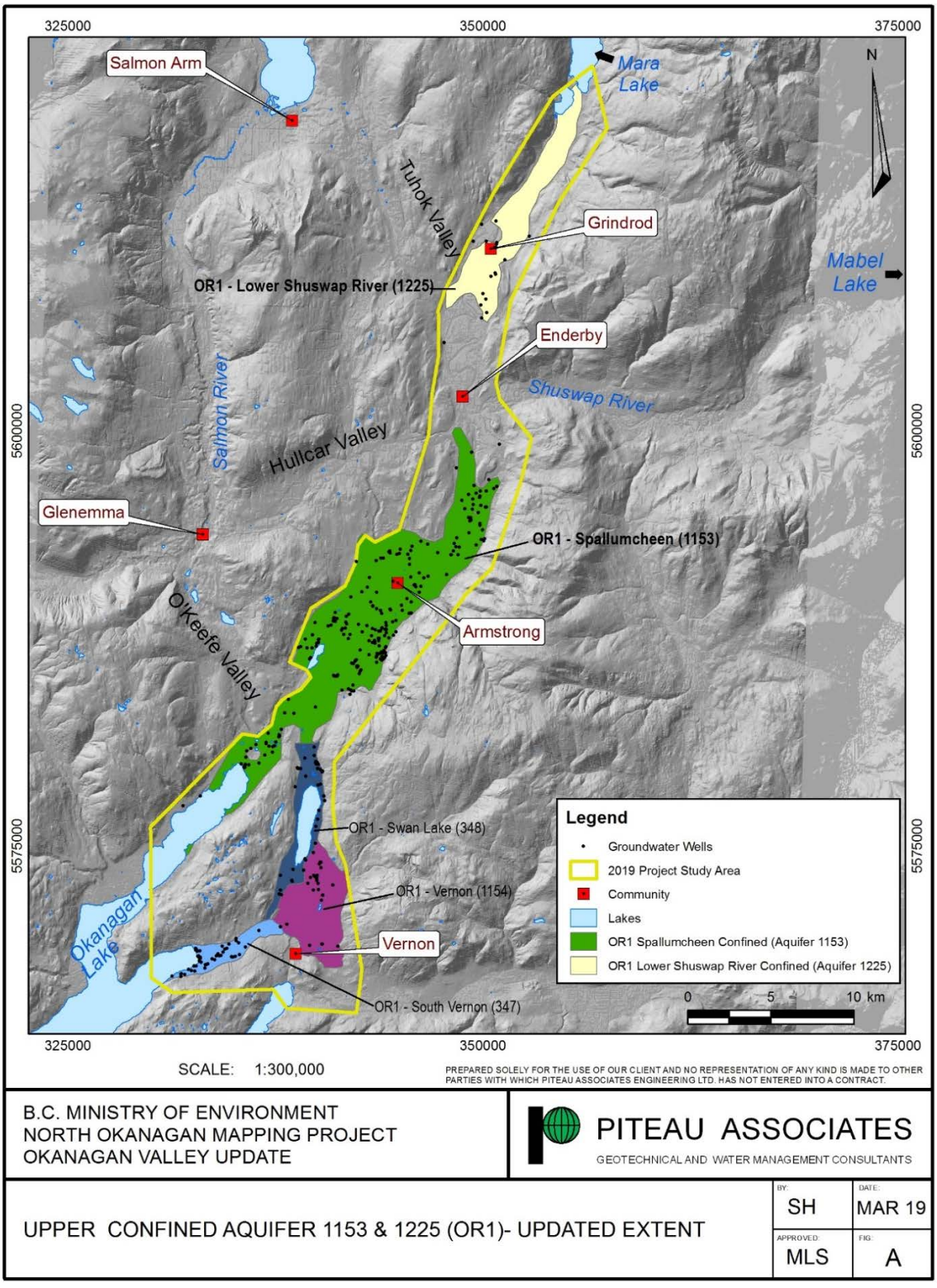
WELL TAG NO.	EASTING	NORTHING	COLLAR ELEVATION	AQUIFER CODE	AQUIFER NO.
62450	350553	5603915	444	OR00	111
62521	350690	5613541	427	OR00	111
62563	339045	5579682	407	OR1	348
62564	338893	5579674	412	OR1	348
62565	338936	5579681	410	OR1	348
62900	349861	5596384	361	OR1	1153
63187	350374	5597074	384	OR1	1153
67968	356333	5618276	418	OR00	111
67970	356290	5618297	416	OR00	111
67977	356204	5618302	406	OR00	111
68089	347877	5600060	419	OR00	111
70124	335674	5579770	350	OR1	1153
71865	348097	5599678	417	OR00	111
76246	355874	5618508	375	OR00	111
82467	342460	5585962	416	OR00	353
82960	354641	5615851	370	OR00	111
84275	342410	5592154	410	OR1	1153
85180	342886	5584797	494	OR00	353
87378	354537	5615667	368	OR00	111
87582	341751	5570342	569	OR00	1152
89445	342029	5587771	392	OR1	1153
90122	355827	5618113	376	OR00	111
97360	342593	5593289	449	OR00	111
103895	350392	5613188	407	OR00	111
104596	344848	5587748	440	OR00	353
104814	339942	5583388	394	OR1	1153
106781	338835	5579722	415	OR1	348
110088	356006	5618455	386	OR00	111
110391	351076	5606710	476	OR00	111
111803	350073	5593393	411	OR1	1153
111811	344180	5588472	398	OR1	1153
111850	350796	5612656	360	OR1	1225
111851	348283	5593236	365	OR1	1153
111868	350216	5611431	362	OR1	1225
111876	339757	5587744	391	OR1	1153
111880	340871	5588321	364	OR1	1153
111890	342619	5586809	399	OR1	1153
111897	348118	5592551	365	OR1	1153
111908	348412	5597792	392	OR1	1153
111972	350835	5611242	361	OR1	1225
111973	351627	5609647	402	OR00	111
111982	349159	5594793	373	OR1	1153
111986	350860	5596681	385	OR1	1153
111995	345874	5591356	364	OR0	111
111996	339337	5587484	400	OR1	1153
111997	339754	5587739	391	OR1	1153
111998	338932	5586966	407	OR1	1153
112005	350496	5596650	374	OR3	1156
112018	356002	5619011	355	OR00	111
112019	344878	5592602	384	OR0	111
112020	340035	5580070	402	OR1	348

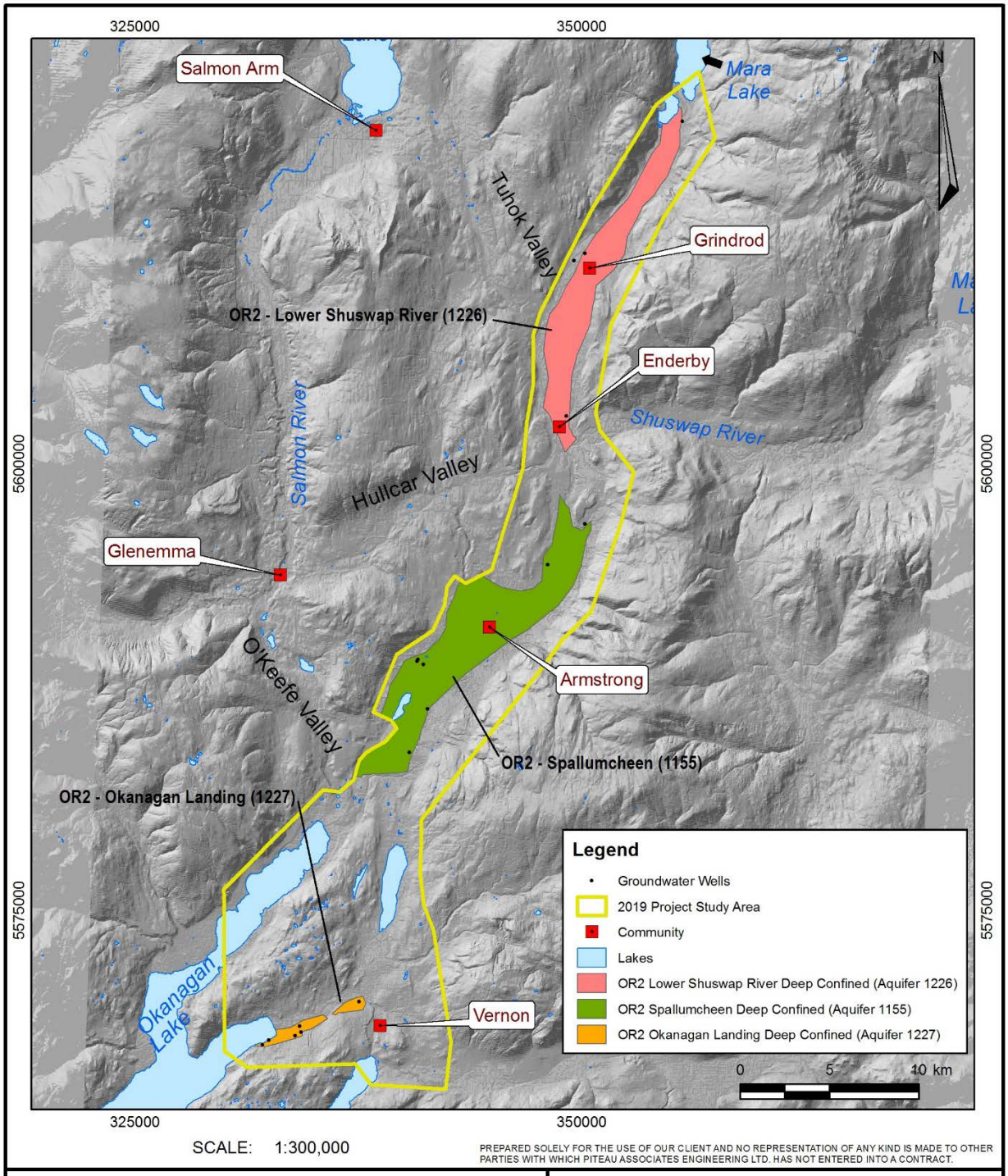
WELL TAG NO.	EASTING	NORTHING	COLLAR ELEVATION	AQUIFER CODE	AQUIFER NO.
112024	347690	5605322	355	OR1	1225
112029	355683	5619208	353	OR2	1226
112038	344404	5592786	384	OR1	1153
112039	343069	5590603	360	OR1	1153
112212	349622	5593135	402	OR1	1153
112479	351133	5607179	473	OR00	111
112504	338128	5568395	401	OR0	346
112651	342344	5586173	408	OR0	353
112897	343200	5591195	391	OR1	1153
112964	336536	5569944	368	OR1	347
112971	338519	5569086	390	OR0	346
112979	335108	5568375	368	OR1	347
113411	356246	5618443	406	OR00	111
113412	356217	5618495	413	OR00	111
113413	356318	5618450	412	OR00	111
113656	339851	5580483	402	OR1	348
113657	339854	5580983	401	OR1	348
113660	343625	5589316	388	OR1	1153
113701	343923	5588104	400	OR1	1153
113887	347829	5591360	377	OR1	1153
113889	355964	5618266	376	OR00	111
113971	344095	5587676	400	OR1	353
114420	349311	5606335	357	OR0	111
114894	346722	5591262	377	OR1	1153
114905	342505	5585843	422	OR1	353
115018	348104	5609035	377	OR0	111
115033	350758	5609520	373	OR1	1225
115161	344095	5586553	424	OR00	353
115463	350862	5611357	361	OR1	1225
115474	352823	5611724	375	OR1	1225
115537	349150	5596186	373	OR1	1153
115686	343158	5586532	406	OR1	353
116159	342335	5586170	408	OR1	353
116160	342322	5586160	409	OR1	353

Note:

'Bold' New groundwater well added to this model update

APPENDIX B: UPDATED AQUIFER EXTENT MAPS AND AQUIFER SUMMARY SHEETS





SCALE: 1:300,000

B.C. MINISTRY OF ENVIRONMENT
NORTH OKANAGAN MAPPING PROJECT
OKANAGAN VALLEY AQUIFER UPDATE

PITEAU ASSOCIATES
GEOTECHNICAL AND WATER MANAGEMENT CONSULTANTS

DEEP CONFINED AQUIFER 1226, 1155 and 1227 (OR2)- UPDATED EXTENT

BY:	DATE:
SH	MAR 19
APPROVED:	FIG:
MLS	B

B1: Aquifer Summary Sheet - Spallumcheen Confined (No. 1153)

AQUIFER CLASSIFICATION WORKSHEET
DATE: March 2019

AQUIFER REFERENCE NUMBER: 1153

DESCRIPTIVE LOCATION OF AQUIFER: Spallumcheen Confined

BCGS MAP SHEET:

Aquifer Summary:

CLASSIFICATION: II B RANKING: 12

Aquifer Size: 93 km^2

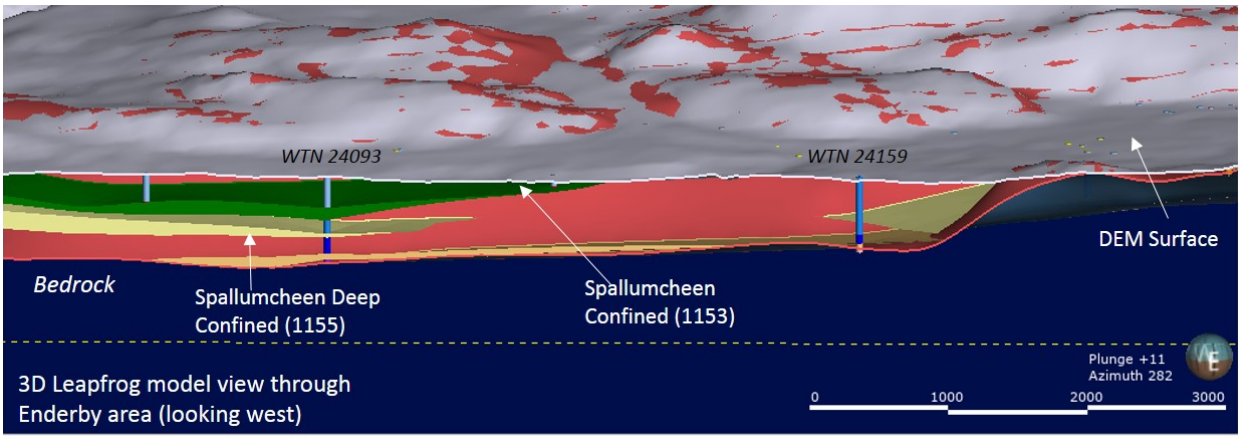
Aquifer Sub-type: 4b [Wei et al. (2009).]

Observation Wells: Observation wells 117 (WTN24062), 118 (WTN24080), 119 (inactive, WTN24104), and 122 (WTN24093); (note: while these wells penetrate this aquifer and provide detailed lithological information about the aquifer-aquitard assemblage, the active wells are screened within the 1155 aquifer)

Mapping Level: Stage II Detailed – For more information consult Water Science Series WSS2017-03 and WSS2019-03 North Okanagan Aquifer Mapping & Geologic Modelling Available at: http://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-science-data/water-science-series)

Aquifer Boundaries:

- Bounded by the approximate limit of overburden along the margins of the valley
- Northern limit is defined by facies change to finer-grained silt and clay south of Enderby based on 3D hydrostratigraphic modelling
- Southern limit is Okanagan Lake and equivalent connected aquifers in Vernon area (Swan Lake Confined Aquifer 348)



3D Leapfrog model view through Enderby area (looking west)

Geologic Formation (overlying materials):

Clay to silty clay dominated confining unit, lesser sandy silt and silty sand; may be compacted; brown, grey, blue; wood (103648) grass (43562)

Geologic Formation (aquifer):

Clean fine to medium-grained sand dominated, minor gravel; grey, black and white

Confined / Partially Confined / Unconfined:

Confined

Vulnerability:

Moderate; This moderately permeable aquifer is extensive and relatively continuous between Enderby and Okanagan Lake and is confined over most of that extent by clay and silt of varying thickness. There is potential hydraulic connection to the overlying unconfined aquifer via alluvial aquifers along the margins of the valley, including the Eagle Rock alluvial fan, which provide important recharge to the aquifer, while increasing its local vulnerability to contamination.

Productivity:

High - Geomean 2.0 L/s; Pumping data indicates that well yield ranges from 0 to 37.8 L/s.

Depth to Water:

Groundwater depths range from at or just below ground surface to as deep as 68 m-bgs, and is generally deeper where the topographic surface rises at the margins of the valley. Artesian groundwater pressures are present in wells scattered across the footprint of the aquifer, but appear more common below the centre of the valley next to significant recharge sources like the Eagle Rock Aquifer (aquifer 353) and Deep Creek Aquifer (aquifer 356).

Direction of Groundwater Flow:

It is assumed that the groundwater flow roughly follows the direction of surface water flow. A groundwater flow divide is present between Armstrong and Enderby. The groundwater south of Armstrong flows south towards Okanagan Lake, whereas groundwater north of Enderby flows north towards Mara Lake.

Recharge:

Recharge to the aquifer is from a variety of sources and likely changes across the footprint of the aquifer. There is likely local leakage across the confining layer from the overlying unconfined aquifer (no. 111, 849, 346, 1151, 1152) where it thins or becomes coarser grained. Hydraulic gradients suggest that a significant amount of recharge originates from infiltration along alluvial and colluvial fans which line the margins of the valley. Alluvial fans at the outlet of the O'Keefe valley (aquifer no's 354 and 1150), Deep Creek valley (aquifer 356), and the Eagle Rock (aquifer 353) aquifers likely provide significant recharge from surface water and direct precipitation. Mountain block recharge from catchments to the east and west of the valley also assumed to provide recharge to the aquifer.

Domestic Well Density: Moderate 3.7 wells/km^2; wells are evenly distributed within the aquifer

Type of Known Water Use: Domestic, and irrigation.

Reliance on Source: Conjunctive

Conflicts between Users: None documented

Quantity Concerns: None documented

Quality Concerns: None documented

Comments:

Stage II Detailed Mapping has been completed. If warranted, future studies could include, but would not be limited to well head surveys to verify the locations of boreholes in key locations, groundwater level and flow characterization, and Stage III Mapping Refinement together with development of a numerical groundwater model in key areas (Stewart and Allard 2017).

Water Budget: None documented

Groundwater Model(s): None documented

References:

Berardinucci J. and K. Ronneseth, 2002. *Guide to Using the BC Aquifer Classification Maps for the Protection and Management of Groundwater*. BC Ministry of Water, Land and Air Protection, Water Air and Climate Change Branch, Water Protection Section.

Hassan, S., Stewart, M. and Allard, R. 2019. North Okanagan Aquifer Mapping and Geologic Modelling Phase III: Okanagan Valley Aquifer Update. Water Science Series, WSS2019-03. Prov. B.C., Victoria B.C. http://www2.gov.bc.ca/gov/content/ECCSironment/air-land-water/water/water-science-data/water-science-series.

Stewart, M. and Allard, R. 2017. North Okanagan Digital Mapping Project: Summary of Results and 3D Geological Modeling. Water Science Series, WSS2017-02. Prov. B.C., Victoria B.C. http://www2.gov.bc.ca/gov/content/ECCSironment/air-land-water/water/water-science-data/water-science-series.

Wei, M., D. M. Allen, A. P. Kohut, S. Grasby, K. Ronneseth, and B. Turner. 2009. Understanding the Types of Aquifers in the Canadian Cordillera Hydrogeologic Region to Better Manage and Protect Groundwater. Streamline Watershed Management Bulletin, FORREX Forum for Research and Extension in Natural Resources.

AQUIFER CLASSIFICATION AND RANKING

Ranking Component:	***Ranking Value***
Productivity:	3
Vulnerability:	2
Size:	3
Demand:	1
Type of Use:	3
Quality Concerns:	0
Quantity Concerns:	0
Total:	**12**

*** Demand may be based of water budget/demand models where available or if unavailable a higher level assessment based on domestic well density, irrigation and commercial/industrial wells, large diameter wells that have been drilled (i.e., greater than 20 cm) as well as general knowledge of well use and land use in the area. If demand assumes that the reported well capacity is the amount of water used, a note should be included to explain that the reported well capacity is often higher than actual use.**

B2: Aquifer Summary Sheet - Lower Shuswap River Confined (No. 1225)

AQUIFER CLASSIFICATION WORKSHEET

DATE: March 2019

AQUIFER REFERENCE NUMBER: 1225

DESCRIPTIVE LOCATION OF AQUIFER: Lower Shuswap River Confined

BCGS MAP SHEET:

Aquifer Summary:

CLASSIFICATION: III B RANKING: 11

Aquifer Size: 24.7 km^2

Aquifer Sub-type: 4b [Wei et al. (2009).]

Observation Wells: None.

Mapping Level: Stage II Detailed – For more information consult Water Science Series WSS2017-03 and WSS2019-03 North Okanagan Aquifer Mapping & Geologic Modelling Available at: http://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-science-data/water-science-series)

Aquifer Boundaries:

- Bounded by the approximate limit of overburden along the margins of the valley
- Bounded to the north by Mara Lake
- Southern limit is defined by facies change to finer-grained silt and clay below Enderby based on 3D hydrostratigraphic modelling

Geologic Formation (overlying materials):

Clay to silty clay dominated confining unit, lesser sandy silt and silty sand; may be compacted; brown, grey, blue.

Geologic Formation (aquifer):

Clean fine to medium-grained sand dominated, minor gravel; grey, black and white

Confined / Partially Confined / Unconfined:

Confined

Vulnerability:

Moderate; This moderately permeable aquifer is extensive and relatively continuous between Enderby and Mara Lake, and is confined over most of that extent by clay and silt of varying thickness. There is potential hydraulic connection to the overlying unconfined aquifer via alluvial aquifers along the margins of the valley, which provide important recharge to the aquifer, while increasing its local vulnerability to contamination. The general hydraulic gradient in the aquifer is north to South, towards Mara Lake, inferred to be consistent with surface water gradients.

Productivity:
Moderate; Geomean 1.6 L/s, with maximum recorded yields of 6.3 L/s.

Depth to Water:
Groundwater depths range from at or just below ground surface, and are generally noted to be higher towards the margins of the valley.

Direction of Groundwater Flow:
It is assumed that groundwater flow roughly follows the direction of surface water flow, and thus, flows to the north towards Mara Lake.

Recharge:
Recharge to the aquifer is from a variety of sources and likely changes across the footprint of the aquifer. There is likely local leakage across the confining layer from the overlying unconfined aquifer (no. 111) where it thins or becomes coarser grained. Hydraulic gradients suggest that a significant amount of recharge originates from infiltration along alluvial and colluvial fans which line the margins of the valley. Alluvial fans at the outlet of the Mara Lake (aquifer 114) aquifer likely provide some recharge from surface water and direct precipitation. Mountain block recharge from catchments mainly to the east of the valley also provide recharge to the aquifer.

Domestic Well Density: Light 0.70 wells/km^2; wells in this aquifer are mostly concentrated towards the south, mainly Grindrod and south of Grindrod.

Type of Known Water Use: Domestic, and irrigation.

Reliance on Source: Conjunctive

Conflicts between Users: None documented

Quantity Concerns: None documented

Quality Concerns: None documented

Comments:
Stage II Detailed Mapping has been completed. If warranted, future studies could include, but would not be limited to well head surveys to verify the locations of boreholes in key locations, groundwater level and flow characterization, and Stage III Mapping Refinement together with development of a numerical groundwater model in key areas (Stewart and Allard 2017).

Water Budget: None documented

Groundwater Model(s): None documented

References:
Berardinucci J. and K. Ronneseth, 2002. *Guide to Using the BC Aquifer Classification Maps for the Protection and Management of Groundwater*. BC Ministry of Water, Land and Air Protection, Water Air and Climate Change Branch, Water Protection Section.

Hassan, S., Stewart, M. and Allard, R. 2019. North Okanagan Aquifer Mapping and Geologic Modelling Phase III: Okanagan Valley Aquifer Update. Water Science Series, WSS2019-03. Prov. B.C., Victoria B.C.

http://www2.gov.bc.ca/gov/content/ECCSironment/air-land-water/water/water-science-data/water-science-series.

Stewart, M. and Allard, R. 2017. North Okanagan Digital Mapping Project: Summary of Results and 3D Geological Modeling. Water Science Series, WSS2017-03. Prov. B.C., Victoria B.C. http://www2.gov.bc.ca/gov/content/ECCSironment/air-land-water/water/water-science-data/water-science-series.

Wei, M., D. M. Allen, A. P. Kohut, S. Grasby, K. Ronneseth, and B. Turner. 2009. Understanding the Types of Aquifers in the Canadian Cordillera Hydrogeologic Region to Better Manage and Protect Groundwater. Streamline Watershed Management Bulletin, FORREX Forum for Research and Extension in Natural Resources.

AQUIFER CLASSIFICATION AND RANKING

Ranking Component:	***Ranking Value***
Productivity:	3
Vulnerability:	2
Size:	2
Demand:	1
Type of Use:	3
Quality Concerns:	0
Quantity Concerns:	0
Total:	**11**

*** Demand may be based of water budget/demand models where available or if unavailable a higher level assessment based on domestic well density, irrigation and commercial/industrial wells, large diameter wells that have been drilled (i.e., greater than 20 cm) as well as general knowledge of well use and land use in the area. If demand assumes that the reported well capacity is the amount of water used, a note should be included to explain that the reported well capacity is often higher than actual use.**

B3: Aquifer Summary Sheet - Lower Shuswap Deep Confined (No. 1226)

AQUIFER CLASSIFICATION WORKSHEET

DATE: March 2019

AQUIFER REFERENCE NUMBER: 1226

DESCRIPTIVE LOCATION OF AQUIFER: Lower Shuswap Deep Confined

BCGS MAP SHEET:

Aquifer Summary:

CLASSIFICATION: III C RANKING: 11

Aquifer Size: 30 km^2

Aquifer Sub-type: 4b [Wei et al. (2009).]

Observation Wells: None

Mapping Level: Stage II Detailed – For more information consult Water Science Series WSS2017-03 and WSS2019-03 North Okanagan Aquifer Mapping & Geologic Modelling Available at: http://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-science-data/water-science-series)

Aquifer Boundaries:

- Bounded by the approximate limit of overburden deep below the Okanagan valley overburden cover
- Bounded to the north by Mara Lake
- Southern limit extends to Enderby

Geologic Formation (overlying materials):

Silt and clay confining unit; clay is described as sticky (85488) and/or solid (106772)

Geologic Formation (aquifer):

Sand dominated, but can be silty; sand is cemented in places

Confined / Partially Confined / Unconfined:

Confined

Vulnerability:

Low; This aquifer is confined below 100 to 166 m of overburden and comprises fine grained aquifer sediments ranging from sand to silty sand. Hydraulic gradients are interpreted to be low, and thus groundwater flow through the aquifer is also interpreted to be low.

Productivity:

High; Only three wells are documented to have been completed in this aquifer, two of which have reported yields of 12.6 L/s.

Depth to Water:
Only one groundwater level measurement is recorded in this aquifer at 5.5 m below surface (Well 85488).

Direction of Groundwater Flow:
Unknown, but likely towards the north.

Recharge:
Given the extent and thickness of low permeability deposits (aquitards) overlying the aquifer, most recharge to this aquifer is expected to derive from mountain block recharge via seepage from fractures and faults below the valley.

Domestic Well Density: Very light 0.1 wells/km^2

Type of Known Water Use: Three water well records are present in this aquifer, one is an active domestic well (106772), one is an active irrigation well (112029) and one is abandoned (85488).

Reliance on Source: Conjunctive

Conflicts between Users: None documented

Quantity Concerns: None documented

Quality Concerns: None documented

Comments:
Stage II Detailed Mapping has been completed. If warranted, future studies could include, but would not be limited to well head surveys to verify the locations of boreholes in key locations, groundwater level and flow characterization, and Stage III Mapping Refinement together with development of a numerical groundwater model in key areas (Stewart and Allard 2017).

Water Budget: None documented

Groundwater Model(s): None documented

References:
Berardinucci J. and K. Ronneseth, 2002. *Guide to Using the BC Aquifer Classification Maps for the Protection and Management of Groundwater*. BC Ministry of Water, Land and Air Protection, Water Air and Climate Change Branch, Water Protection Section.

Hassan, S., Stewart, M. and Allard, R. 2019. North Okanagan Aquifer Mapping and Geologic Modelling Phase III: Okanagan Valley Aquifer Update. Water Science Series, WSS2019-03. Prov. B.C., Victoria B.C. http://www2.gov.bc.ca/gov/content/ECCSironment/air-land-water/water/water-science-data/water-science-series.

Stewart, M. and Allard, R. 2017. North Okanagan Digital Mapping Project: Summary of Results and 3D Geological Modeling. Water Science Series, WSS2017-03. Prov. B.C., Victoria B.C. http://www2.gov.bc.ca/gov/content/ECCSironment/air-land-water/water/water-science-data/water-science-series.

Wei, M., D. M. Allen, A. P. Kohut, S. Grasby, K. Ronneseth, and B. Turner. 2009. Understanding the Types of Aquifers in the Canadian Cordillera Hydrogeologic Region to Better Manage and Protect Groundwater. Streamline Watershed Management Bulletin, FORREX Forum for Research and Extension in Natural Resources.

AQUIFER CLASSIFICATION AND RANKING

Ranking Component:	***Ranking Value***
Productivity:	3
Vulnerability:	1
Size:	3
Demand:	1
Type of Use:	3
Quality Concerns:	0
Quantity Concerns:	0
Total:	**11**

*** Demand may be based of water budget/demand models where available or if unavailable a higher level assessment based on domestic well density, irrigation and commercial/industrial wells, large diameter wells that have been drilled (i.e., greater than 20 cm) as well as general knowledge of well use and land use in the area. If demand assumes that the reported well capacity is the amount of water used, a note should be included to explain that the reported well capacity is often higher than actual use**

B4: Aquifer Summary Sheet - Spallumcheen River Confined (No. 1155)

AQUIFER CLASSIFICATION WORKSHEET

DATE: March 2019

AQUIFER REFERENCE NUMBER: 1155

DESCRIPTIVE LOCATION OF AQUIFER: Spallumcheen Deep Confined

BCGS MAP SHEET:

Aquifer Summary:

CLASSIFICATION: III C RANKING: 11

Aquifer Size: 47 km^2

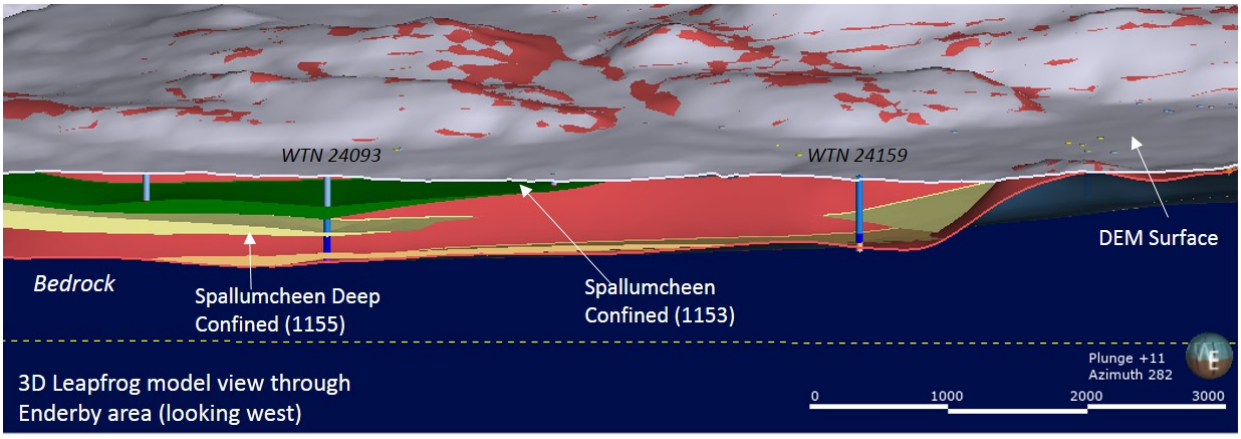
Aquifer Sub-type: 4b [Wei et al. (2009).]

Observation Wells: Observation wells 117 (WTN24062), 118 (WTN24080), and 122 (WTN24093) are screened within this aquifer even though the maximum depths of the wells are recorded to be deeper

Mapping Level: Stage II Detailed – For more information consult Water Science Series WSS2017-03 and WSS2019-03 North Okanagan Aquifer Mapping & Geologic Modelling Available at: http://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-science-data/water-science-series)

Aquifer Boundaries:

- Bounded by the approximate limit of overburden deep below the Okanagan valley overburden cover
- Northern limit is defined by facies change to finer-grained silt and clay south of Enderby based on 3D hydrostratigraphic modelling
- Southern limit extends to the northwestern arm of Okanagan Lake



Vulnerability:
Low; This aquifer is confined below more than 200 m of overburden and comprises sand and gravel interbedded with finer grained aquifer sediments ranging from sand to silty sand. It is confined by thick silt to clay sediments.

Productivity:
High; Only seven wells are documented to have been completed in this aquifer and yields range from 0.07 to 30.3 L/s. Due to the limited number of deep wells in this aquifer and limited testing, it is unclear if this range is typical, although the assumed high hydrostatic head and inferred unit thickness suggests that yields are likely on the higher end of the range for this aquifer.

Depth to Water:
Depth to water, based on the provincial observation wells, ranges from 0.2 m-BGS to 17.50 m-BGS in recent years.

Direction of Groundwater Flow:
The groundwater flow based on the hydraulic gradient, as measured in the observation wells, is towards the north between Well 118 and Well 122, and towards the south between Well 118 and Well 117. There appears to be a groundwater divide in the deep confined aquifer between Enderby and Armstrong.

Recharge:
Given the extent and thickness of low permeability soil overlying the aquifer, most recharge to this aquifer is expected to derive from mountain block recharge via seepage from fractures and faults below the valley

Domestic Well Density: Very light 0.17 wells/km^2; no domestic wells are present in this aquifer

Type of Known Water Use: A total of eight wells are completed in this aquifer: five are Ministry test wells or observation wells (24093, 20269, 22223, 24080, 24062), and the remaining are for the town of Enderby (979, 9233, 9288)

Reliance on Source: Conjunctive

Conflicts between Users: None documented

Quantity Concerns: None documented

Quality Concerns: None documented

Comments:
Stage II Detailed Mapping has been completed. If warranted, future studies could include, but would not be limited to well head surveys to verify the locations of boreholes in key locations, groundwater level and flow characterization, and Stage III Mapping Refinement together with development of a numerical groundwater model in key areas (Stewart and Allard 2017).

Water Budget: None documented

Groundwater Model(s): None documented

References:

Berardinucci J. and K. Ronneseth, 2002. *Guide to Using the BC Aquifer Classification Maps for the Protection and Management of Groundwater*. BC Ministry of Water, Land and Air Protection, Water Air and Climate Change Branch, Water Protection Section.

Hassan, S., Stewart, M. and Allard, R. 2019. North Okanagan Aquifer Mapping and Geologic Modelling Phase III: Okanagan Valley Aquifer Update. Water Science Series, WSS2019-03. Prov. B.C., Victoria B.C. http://www2.gov.bc.ca/gov/content/ECCSironment/air-land-water/water/water-science-data/water-science-series.

Stewart, M. and Allard, R. 2017. North Okanagan Digital Mapping Project: Summary of Results and 3D Geological Modeling. Water Science Series, WSS2017-03. Prov. B.C., Victoria B.C. http://www2.gov.bc.ca/gov/content/ECCSironment/air-land-water/water/water-science-data/water-science-series.

Wei, M., D. M. Allen, A. P. Kohut, S. Grasby, K. Ronneseth, and B. Turner. 2009. Understanding the Types of Aquifers in the Canadian Cordillera Hydrogeologic Region to Better Manage and Protect Groundwater. Streamline Watershed Management Bulletin, FORREX Forum for Research and Extension in Natural Resources.

AQUIFER CLASSIFICATION AND RANKING

Ranking Component:	***Ranking Value***
Productivity:	3
Vulnerability:	1
Size:	3
Demand:	1
Type of Use:	3
Quality Concerns:	0
Quantity Concerns:	0
Total:	**11**

*** Demand may be based of water budget/demand models where available or if unavailable a higher level assessment based on domestic well density, irrigation and commercial/industrial wells, large diameter wells that have been drilled (i.e., greater than 20 cm) as well as general knowledge of well use and land use in the area. If demand assumes that the reported well capacity is the amount of water used, a note should be included to explain that the reported well capacity is often higher than actual use**

B5: Aquifer Summary Sheet - Okanagan Landing Deep Confined (No. 1227)

AQUIFER CLASSIFICATION WORKSHEET

DATE: March 2019

AQUIFER REFERENCE NUMBER: 1227

DESCRIPTIVE LOCATION OF AQUIFER: Okanagan Landing Deep Confined

BCGS MAP SHEET:

Aquifer Summary:

CLASSIFICATION: II C RANKING: 8

Aquifer Size: 3.75 km^2

Aquifer Sub-type: 4b [Wei et al. (2009).]

Observation Wells: None

Mapping Level: Stage II Detailed – For more information consult Water Science Series WSS2017-03 and WSS2019-03 North Okanagan Aquifer Mapping & Geologic Modelling Available at: http://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-science-data/water-science-series)

Aquifer Boundaries:

- Bounded by the approximate bedrock topography/limit of overburden deep below Vernon
- Eastern limit is Vernon
- Southern/western limit extends to Okanagan Lake

Geologic Formation (overlying materials):

Silt and clay confining unit; clay is described as black mud (41994) and stony clay (24991).

Geologic Formation (aquifer):

Sand and gravel dominated, but can be silty

Confined / Partially Confined / Unconfined:

Confined

Vulnerability:

Low; This aquifer is confined below 80 to 100 m of overburden and comprises coarse grained aquifer sediments ranging from silty sand to gravel. It is confined by thick silt to clay sediments.

Productivity:

High; Six wells are documented to have been completed in this aquifer. Reported yields range from 0.6 L/s to 12.6 L/s. It is assumed that due to high hydrostatic head and inferred unit thickness the yields are likely in the higher end of the range for this aquifer.

Depth to Water:
Depth to groundwater ranges from 2.4 to 3.8 m below surface.

Direction of Groundwater Flow:
From east to west, discharge towards Okanagan Lake.

Recharge:
Given the extent and thickness of low permeability deposits overlying the aquifer, most recharge to this aquifer is expected to derive from mountain block recharge via seepage from fractures and faults below the valley.

Domestic Well Density: Light 1.6 wells/km^2

Type of Known Water Use: Domestic and irrigation water supply.

Reliance on Source: Conjunctive

Conflicts between Users: None documented

Quantity Concerns: None documented

Quality Concerns: None documented

Comments:
Stage II Detailed Mapping has been completed. If warranted, future studies could include, but would not be limited to well head surveys to verify the locations of boreholes in key locations, groundwater level and flow characterization, and Stage III Mapping Refinement together with development of a numerical groundwater model in key areas (Stewart and Allard 2017).

Water Budget: None documented

Groundwater Model(s): None documented

References:
Berardinucci J. and K. Ronneseth, 2002. *Guide to Using the BC Aquifer Classification Maps for the Protection and Management of Groundwater*. BC Ministry of Water, Land and Air Protection, Water Air and Climate Change Branch, Water Protection Section.

Hassan, S., Stewart, M. and Allard, R. 2019. North Okanagan Aquifer Mapping and Geologic Modelling Phase III: Okanagan Valley Aquifer Update. Water Science Series, WSS2019-03. Prov. B.C., Victoria B.C. http://www2.gov.bc.ca/gov/content/ECCSironment/air-land-water/water/water-science-data/water-science-series.

Stewart, M. and Allard, R. 2017. North Okanagan Digital Mapping Project: Summary of Results and 3D Geological Modeling. Water Science Series, WSS2017-03. Prov. B.C., Victoria B.C. http://www2.gov.bc.ca/gov/content/ECCSironment/air-land-water/water/water-science-data/water-science-series.

Wei, M., D. M. Allen, A. P. Kohut, S. Grasby, K. Ronneseth, and B. Turner. 2009. Understanding the Types of Aquifers in the Canadian Cordillera Hydrogeologic Region to Better Manage and Protect

Groundwater. Streamline Watershed Management Bulletin, FORREX Forum for Research and Extension in Natural Resources.

AQUIFER CLASSIFICATION AND RANKING

Ranking Component:	***Ranking Value***
Productivity:	3
Vulnerability:	1
Size:	1
Demand:	1
Type of Use:	2
Quality Concerns:	0
Quantity Concerns:	0
Total:	**8**

*** Demand may be based of water budget/demand models where available or if unavailable a higher level assessment based on domestic well density, irrigation and commercial/industrial wells, large diameter wells that have been drilled (i.e., greater than 20 cm) as well as general knowledge of well use and land use in the area. If demand assumes that the reported well capacity is the amount of water used, a note should be included to explain that the reported well capacity is often higher than actual use.**

APPENDIX C: LIST OF DIGITAL PRODUCTS

Leapfrog Files:

[44.6 Mb] NOMP Updated Model_04032018.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

Digital well locations and associated aquifer in shapefile format:

[30 Kb] Groundwater_Wells_with_Aquifers.shp (plus associated .dbf, .xml, .sbn, .prj, .shx, .sbx, .cpg files)

LEAPFROG Unit	ENV Aquifer #	Aquifer Name/ Description	3D Digital Rendered Volumes/Surfaces in DXF Format	Digital Aquifer Boundaries File in Shapefile Format*
OR0/OR00	111	Okanagan Valley Unconfined	[32.9 Mb] Spallumcheen - OR00.dxf [2.6 Mb] Spallumcheen - OR0.dxf [14.2 Kb] Spallumcheen - ORa - OR0 contacts.dxf [5.3 Kb] Spallumcheen - OR0 - ORz contacts.dxf [4.1 Kb] Spallumcheen - ORz - OR00 contacts.dxf	
		Fortune Creek		
	1151	Swan Lake Unconfined		
	1152	Vernon Unconfined		
	346	South Vernon Unconfined		
	353	Eagle Rock Unconfined		
	114	Mara Lake Unconfined		
OR1	1153	Spallumcheen Confined	[27.7 Mb] Spallumcheen - OR1.dxf [4.6 Kb] Spallumcheen - ORb - OR1 contacts.dxf [12.1 Kb] Spallumcheen - OR1 - ORa contacts.dxf	[3 Kb] OR1_Spallumcheen_Confined_(1153).shp
	348	Swan Lake Confined		
	1154	Vernon Confined		
	347	South Vernon Confined		
	1225	Lower Shuswap River Confined		[2 Kb] OR1_Lower_Shuswap_River_Confined_(1225).shp
OR2	1226	Lower Shuswap Deep Confined	[12.3 Mb] Spallumcheen - OR2.dxf [2.4 Kb] Spallumcheen - ORc - OR2 contacts.dxf [3.0 Kb] Spallumcheen - OR2 - ORb contacts.dxf	[1 Kb] OR2_Lower_Shuswap_River_Deep_Confined_(1226).shp
	1155	Spallumcheen Deep Confined		[1 Kb] OR2_Spallumcheen_Deep_Confined_(1155).shp
	1227	Okanagan Landing Deep Confined		[1 Kb] OR2_Okanagan_Landing_Confined_(1227).shp
OR3	1156	Basal Okanagan Valley	[2.8 Mb] Spallumcheen - OR3.dxf [575 Kb] Spallumcheen - ORd - OR3 contacts.dxf [712 Kb] Spallumcheen - OR3 - ORc contacts.dxf	
ORz, ORa, ORb, ORc, ORd	N/A	Aquitards, not formally defined.	[2.6 Mb] Spallumcheen - Ord.dxf [19.7 Mb] Spallumcheen - Orc.dxf [22.0 Mb] Spallumcheen - Orb.dxf [39.5 Mb] Spallumcheen – Ora.dxf [18.4 Mb] Spallumcheen – Orz.dxf [3.2 Kb] Spallumcheen - BR – Ord contacts.dxf	
Water Level	N/A	Water level surface	[18.6 Kb] Spallumcheen - Water Level.dxf	

Note:
N/A- not applicable
The Leapfrog model units are defined based on 'aquifer' or 'aquitard' properties. These are as follows from surface to bedrock: OR0/OR00 are the upper/surficial unconfined aquifer units; ORz is the sparse surficial aquitard material; ORa is the first aquitard material encountered at surface or below the unconfined aquifer (OR0/OR00); OR1 is the first confined aquifer unit; ORb is the second major aquitard unit commonly present between OR1 and OR2; OR2 is the deeper confined aquifer unit; ORc is the deeper aquitard unit, occurring between OR2 and OR3; OR3 is the basal aquifer unit; ORd is the lower most aquitard unit, typically present between the bedrock and OR3; BR is the bedrock.
**plus associated .dbf, .xml, .sbn, .prj, .shx, .sbx, .cpg files*